INTEGRATING BUILDING INFORMATION MODELING FOR IMPROVING FACILITY MANAGEMENT OPERATIONS: A FUZZY SYNTHETIC EVALUATION OF THE CRITICAL SUCCESS FACTORS

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ABSTRACT

Purpose: Building information modelling (BIM) is a novel technological advancement in the built environment. Despite the potentials of BIM, its adoption and implementation are undermined in facility management operations. This might be because of limited information on the critical success factors that can enhance its adoption. The study seeks to assess the critical success factors (CSFs) required to influence the successful adoption and implementation of BIM for facility management (FM) operations.

Design/methodology and approach: Data for the study were sourced from practicing and registered facility managers within Lagos metropolis, Nigeria. The data collected were analysed using a combination of methods which include mean item score, factor analysis, and Fuzzy Synthetic Evaluation (FSE).

Findings: The factor analysis results showed that six underlying groups of CSFs would enhance the effective adoption of BIM in facility operations. The FSE results showed that out of the six groups, the three topmost important CSFgrouping (CSFG) in the decision rule would enhance the effectiveness of BIM adoption for FM operations.

Practical implication: The result of this study provides a credible road map for facility managers, policymakers, and other stakeholders in facility management operations on the CSFs and CSFG required for the adoption of BIM

Originality and value: Previous studies that aimed at integrating BIM into facility management are limited. Hence, this study provides a broad perspective on the CSF required for BIM adoption and implementation in FM operations using the FSE approach.

Keywords: Building Information Modelling, Implementation, Success Factors, Facility Management, Operations, Nigeria.

Paper type: research paper

INTRODUCTION

Facility management has been considered the last phase of construction projects; nevertheless, it is the most stretched stage (Nordstrand, 2000; Misron *et al.,* 2018). Due to its process complexity, Olawumi and Chan (2018) expressed that it is essential to adopt technological approaches in effectively managing the facilities. Technology integration is imperative in any industry, including construction and facility management (Yaakob *et al*., 2016). Successful and total facilities management will be achieved if a building is fundamentally controlled by technologies (Nordstrand, 2000; Mustapa *et al.,* 2008). This is one of the core responsibilities of Building Information Modelling (BIM). This is because it enables the modernisation of the facility management (FM) industry and increases production and value (Hoang et al., 2020).

The nature of BIM falls into collaborative technology used in FM for data interoperability and life cycle management (Yaakob *et al.,* 2016). This is why Hoang *et al*. (2020) avow that a way to trigger FM development in this present era is by adopting a modern technology that refines practices and productivity. Noor *et al*. (2018) pointed out that BIM can be applied to a facility's lifecycle. Yaakob *et al*. (2016) described BIM as a method of developing and maintaining a building facility using a cohesive and up-to-date computer model system. Therefore, BIM could transform the facility management industry if well implemented (Yaakob *et al*., 2016).

Aziz *et al*. (2016) noted that BIM offers some benefits wherever it is deployed. This includes site planning and maintenance operations, design visualisation, utilisation, site scheduling, layout, and framework coordination. Terreno *et al.* (2016) also revealed that the advantages BIM could offer to FM practice include maintenance operation, space planning, and renovation. Moreover, Hoang *et al*. (2020) claimed that BIM is very significant during the operation stage of facilities for modeling records, scheduling maintenance, asset and space management, and disaster planning. However, despite the benefits of BIM, its implementation during FM activities is lacking in developing nations, especially in building operation and maintenance phases. Morlhon *et al.* (2014) argued that due to the numerous standards and procedures involved, the implementation of BIM had been hampered. For instance, the adoption of BIM in the facility management industry has been slow and not comprehensive on a global scale. Kassem *et al.* (2013) suggested that this might be attributable to insufficient information on the critical success factors (CSFs) needed for productivity. Although most professionals know BIM's concept, its awareness alone is not sufficient to justify the critical success factors' understanding, adoption, and implementation (Gao & Bozogi, 2019) in FM operations. In this study, CSFs are the drivers that require attention to integrate and implement BIM in FM operation successfully.

An important issue affecting the success of FM operations is inadequate knowledge on how to handle digital information. Yaakob *et al.* (2016) regarded BIM as the game-changer for information handling within FM operations. FM teams must identify and understand the effective and efficient CSFs needed to successfully implement BIM in FM operations. Unfortunately, a dearth of coherent information on the CSFs and drivers to enhance BIM implementation in the facilities' lifecycle is lacking. Therefore, it is important to gain a deeper understanding of the success factors necessary for FM operation. Rockart (1982) and Oluleye *et al.* (2020) averred that CSFs are essential for attaining a set objective, which requires attention for a positive result in the long run. Therefore, without evaluating these CSFs, it may be challenging to implement BIM for FM operations.

As used in this study, FM involves multiple disciplines that aid the built environment functionality by integrating people, place, processes, and technology (IFMA, n.d). This means making informed, data-driven decisions, promoting change, and improving results by combining technology with FM. This study investigates the CSFs that would facilitate BIM adoption in facility management operations. These are imperative for innovative and new systems in the workplace (Morlhon et al., 2014). The CSFs can be regarded as drivers and enablers that would ensure the efficiency of a particular process (Chileshe & Kikwasi, 2014). This study adopts a fuzzy synthetic approach to examine the critical success factors that can enhance BIM adoption and implementation in FM operations. The results of this study would provide insights for facility managers, practitioners, and policymakers on how best to execute FM operations in the contemporary age. It would also provide information on how best to incorporate BIM for successful facility management operations.

CRITICAL SUCCESS FACTORS FOR BIM IMPLEMENTATION

The effective implementation of BIM in a project requires vision and support from management, training on a new set of skills, and stakeholders' interest alignment (Liao & Teo, 2017). Misron *et al.* (2018) identified the necessary CSFs to enhance BIM adoption for facility management. The study established that top management support and commitment, staff training and education, preparing the personnel for change, product information sharing, motivation for BIM adoption, effective teamwork, participants collaboration, guidelines, and framework are essential. Olawumi and Chan (2018) observed that the implementation of BIM and sustainability practices in construction projects need an increasing contractors' experience, comprehensive awareness, and expertise

Chan (2014) emphasised that BIM implementation in industries would bring about effective leadership and awareness creation regarding the use of BIM and the availability of relevant codes, standards, rules, and regulations. According to Abdirad (2016), BIM enhancement would come into the limelight when its research is promoted within the industry and academia. Standard integrated platforms, staff training, and education, a clear understanding of clients' and users' requirements, development cost attention, and standardising products and processes are indicators for successful BIM implementation (Yusuf, 2018). The author further suggests that organisation support, synergy among professionals in the built environment, and capacity for technology adoption are essential for BIM implementation. Therefore, BIM adoption is achievable when enabling databases are made available (Abolghasemzadeh, 2013; Antón & Díaz, 2014).

According to Azhar (2011), comprehensive knowledge management, BIM awareness level, availability of information and technology, clear understanding of the perceived benefits of BIM, availability of appropriate software and hardware, and proper coordination among project parties are required for effective BIM implementation in any industry. Redmond *et al.* (2012) posited that the availability of BIM software vendors and appropriate BIM legislation and enforcement by the government is crucial to BIM success in any industry. Training specialists on BIM is a panacea for its implementation in the construction industry (Ah *et al.,* 2014; Chan, 2014). In Nigeria, the establishment of start-up funding for firms to kickstart BIM initiatives is a veritable gateway to BIM adoption (Abubakar et al., 2014). In India, Nanajkar and Gao (2014) revealed that adequate financing of BIM software, licensing, and regular upgrading is a factor that would enhance its implementation and adoption. In Australia, developing a strategy and framework to support BIM and the protection of intellectual property rights is important for the successful adoption of BIM in the construction sector (Albinu & Vankatesh, 2014). Proper cost allocation for the adoption of BIM is also vital for its adoption in the industry. Aksamija (2012) observed that standardisation and simplicity of BIM are integral to ensuring its adoption in any industry.

In Egypt, Darwish et al. (2020) identified factors to enhance the implementation of BIM. They include proper project coordination, education and training, awareness, adequate knowledge of BIM functions, collaboration of project stakeholder's, availability of experienced, competent, and qualified staff, a framework for BIM adoption, appropriate software and hardware tools, information and sharing of ideas, and development of good model practice. Similarly, Antwi-Afari et al. (2018) affirmed that knowledge sharing and management, availability of information and technology, coordination and activity planning, and collaboration among stakeholders are needed for implementing BIM. Ganiyu *et al.* (2018) identified proper cultural orientation, good synergy among professionals, building capacity for modern technology adoption, support from the organisation, stakeholders' knowledge, and commitment to BIM as essential CSFs for BIM implementation. Ugwu and Kumaraswamy (2007) claimed that appropriate hardware technology, employee training, improved productivity, stakeholder and end-user participation, detailed user requirements, availability of appropriate software, top management support, and re-engineering of a business process are needed for successful implementation of BIM.

Ozorhon and Karahan (2016) found that BIM implementation is a function of collaboration among project parties, availability of finance, technology, and information, organisational experience and culture, comprehensive and practicable legislation. Re-engineering business processes, availability of competent employees, and appropriate technology availability are the CSFs for implementing BIM in the construction industry (Arayici *et al.,* 2012). According to Won and Lee (2010), adequate investment in BIM cost, BIM quality, and performance metrics are the CSFs for BIM implementation in the construction industry. Marthon et al. (2014) pointed out that awareness of the cost of developing BIM, reliable platform for its incorporation, knowledge, and simplicity in design, the experience of the in-house team in BIM, and communication of aim of BIM are CSFs required for the adoption of BIM in any industry. Won et al. (2013) revealed that the holistic achievement of BIM implementation is tied to the level of experience within an organisation, adequate investment in BIM, development of a good practice model for BIM, availability of competent staff, government support and incentive, development of BIM adoption framework and adequate financing arrangement. Table 1 presents the summary of CSFs for BIM adoption extracted from the literature.

INSERT TABLE 1

RESEARCH METHODOLOGY

Research approach

A survey approach was adopted for this study. The survey method is deemed suitable for this research as it enables eliciting data from representative population samples. Additionally, they are well-suited for obtaining data that describes the sample's composition (McIntyre, 1999), versatile in terms of the types and numbers of variables that may be investigated, and make generalisations reasonably easy (Bell, 1996)

In this research, the identified constructs were used to design a closed-ended 7-point Likert scale with 7 = extremely high importance, 6 = very high importance, 5 = high importance, 4 = moderate importance, 3 = low importance, 2 = very low importance and 1 = extremely low importance. A closed-ended survey questionnaire was adopted for the data collection. This is based on the premise that it offers respondents a limited number of options to select their response. The questionnaire administration was adopted because it has low administration costs and can yield meaningful responses from a large survey (Gilham, 2015). A closed-ended question is intended to be read exactly as prepared to the respondent by a survey interviewer, complete with the entire range of response possibilities.

Identification of the critical success factors

Twenty-three critical success factors were selected from peer-reviewed articles for investigation. A pilot survey of the research instrument among experts in facility management was done within academia to strengthen the instrument. For the pilot studies, a total of twenty questionnaires were distributed among lecturers who are experienced in facilities management. The retrieved questionnaires were then harmonized and deployed to amend the main instrument used for the data collection. Afterward, the revised instrument devoid of ambiguity and ensured clarity was administered to one hundred and ninety-seven (197) registered and practising facility managers in Lagos metropolis. Out of the questionnaire distributed, only one hundred and fifty-three (153) were retrieved. Out of this, only one hundred and forty-six (146) were completed and considered valid for the data analysis. This represents 95.42% of the retrieved questionnaires.

Reliability analysis.

A data reliability test was performed to measure the consistency of the CSFs' and the construct of the survey instrument. It is impossible to understand how consistent the CSFs utilized in this study are without such an examination.

The alpha statistics of the instrument reliability means whether or not the questionnaire scale is appropriately created. It is believed that alpha statistics ≥ 0.70 means the questionnaire scale is well designed and has good data quality (Olawumi and Chan 2018).

Mean score analysis

This is a quantitative analysis method used to rank the importance of variables used in a survey. This approach has been popularly used in various built environment research (see Shi *et al.,* 2013; Chan *et al*., 2018, Adabre & Chan, 2019; Olawumi & Chan, 2019). The mean score analysis was adopted in this study to establish the relative priorities attributed to the CSFs required for BIM adoption in facility management operations. The mean values of the CSFs from the opinion of the experts were deployed to know which BIM variables could be adopted for facility management operations. The mean values obtained range between 5.03 and 6.10. This connotes the relative importance and contribution of each CSFs. The mean values of all the CSFs labels are higher than a 5.0 minimum benchmark for a 7.0 Likert scale; hence they were all retained for the process of factor analysis.

Exploratory factor analysis (EFA.)

This is a data reduction tool. It identifies the number of factors/groups connected with a collection of variables by grouping them to represent a connection (Liao & Teo, 2017). The method identifies the factors that have been shown to influence respondents based on their individual factor scores. Also, it reduces the number of redundant variables by identifying usable variables and their underlying factors (Chan *et al*., 2018). Factor extraction and rotation are part of the EFA process. The factor groupings for the variables are first established, making factor rotation easier and more interpretable (Hair *et al*., 2009; Adabre & Chan, 2019). Therefore, in this work, we utilised EFA to reveal the underlying grouping among the investigated CSFs.

The suitability of factor analysis is often based on a sample ratio of 1:5 (Osei-Kyei *et al.,* 2016). This could be determined via preliminary statistical analyses such as anti-imagery correlation, Kaiser-Meyer-Olkin (KMO), and Bartlett's test of sphericity (Osei-Kyei *et al.,* 2016). For this study, the anti-imagery correlation matrix for the data was computed. The variables have Measure of Sampling Adequacy (MSA) ranging from 0.523 to 0.858, which is above the benchmark of 0.50, thus indicating the appropriateness of the sample size for factor analysis. The Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were conducted to ascertain the degree of intercorrelation among the CSFs. The EFA analysis for the KMO value is 0.731, which is above the minimum threshold, hence the suitability of the data set of EFA. Also, the Barlett's sphericity $\chi 2$ value is 740.486 with a p-value of 0.00, suggesting a strong relationship among the CSFs (Norusis, 2008).

Fuzzy synthetic evaluation (FSE)

This type of fuzzy mathematics is applied to complex decision-making scenarios. The method aids reliable decisions by identifying and clarifying unclear facts using linguistic terms. The approximation and manipulation are utilised for approximate reasoning, and then the uncertainties are spread throughout the decision-making process. FSE, as employed in this research, was developed from that used by Yeung *et al.* (2010) and Liu *et al.* (2013). The steps to the FSE technique used is given as:

a. identify the set of fundamental factors, that is, the CSFs. These are the 23 identified variables used in the study
b. establish the scale of measurement. For this investigation, this is the 7-point Likert scale.
c. from equation (i), determine the weightings for CSFs and CSFGs

$$W_i = \frac{Mi}{\sum Mii} \ldots\ldots\ldots\ldots Equation(i)$$

Where:
W_i = weightings of a CSF/CSFG.
Mi = mean score value of a CSF/CSFG
ΣM_{ii} = summation of mean score values of all the CSFs/CSFGs.

d. from equation (ii), determine the membership function of each of the CSFG (first level) and CSFs (second level).

$$D = W_{i.} R \ldots\ldots\ldots\ldots Equation\ (ii)$$

where:
W_i = weightings for all the CSFs under each CSFG
R = function matrix for each CSFG

e. Following the results obtained in d, use equation (iii) to determine the significance level for each CSFG

$$\sum_{i=1}^{7} D \times E \ \ldots\ldots\ldots\ldots Equation(iii)$$

The research processes

Figure 1 shows the schematic diagram of the process for the research which was employed in achieving the goal of the research.

INSERT FIGURE 1

RESULTS AND DISCUSSION

INSERT TABLE 2

Factor extraction was carried out using the principal component analysis. As shown in Table 2, the varimax rotation of the 23 CSFs resulted in six underlying components and explains 69.002% of the total variance. To know the variables for inclusion in factor analysis, Akintoye (2000) argued that a variable with factor loading close to or above 0.50 should be retained. Therefore, since all the variables have a factor loading above 0.50, they were all retained for the analysis. The factors were grouped into six classes and given a suitable nomenclature. These CSFs are classified into:

- *Adequate knowledge management of BIM in the FM industry*
- *FM leaders and staff commitment to BIM*
- *Availability of metric, model, and affordable technology for BIM*
- *BIM investment and organisation readiness for change*
- *Accessible BIM hard and soft packages*

- *Stakeholders' awareness and commitment to BIM*

These six factors form the underlying grouping of the twenty-three CSFs for BIM adoption for facility management operations. With the attention to the six underlying groups, it is necessary to ascertain factor grouping as an integral component for BIM adoption in facility operation. This is achieved using the Fuzzy Synthetic Evaluation predictive tool.

As stated earlier, the FSE approach was adopted to determine the relative contribution of the twenty-three CSFs understudy. There exist two categories of membership functions in the FSE. The first level is the CSF Groups (CSFGs), while the second level is the CSFs. A Fuzzy evaluation model was demonstrated to ascertain the weighting of each level of membership function.

Ascertaining the weightings for CSFs and CSFGs:

The twenty-three CSFs for BIM adoption for facility operations and the six-cluster grouping weighting are defined based on the mean scores from the survey conducted on the facility managers. The weightings are estimated from equation (i), and the results presented in Table 4

Ascertaining the membership function of each CSFG (first level) and CSFs (second level).

To determine the membership function of the respective CSFG, each membership function of the CSFs is first defined. This makes the foundation for estimating CSFG membership function to become more apparent. The membership function of the CSFs is derived from the experts' evaluation using the grades for selection (i.e., *1 – extremely low important…7- extremely high important)*. Findings are that the facility managers rated CSF01 as very low important, low important, moderate, important, very high important, and extremely high important with values of 1.6%, 9.5%, 17.5%, 17.5%, 25.4%, and 28.6%, respectively. With regards to this, the membership function and other CSF is given as:

$$MF\ of\ CSF01 = \frac{0.00}{ELI(1)} + \frac{0.016}{VLI(2)} + \frac{0.095}{LI(3)} + \frac{0.175}{M(4)} + \frac{0.175}{I(5)} + \frac{0.254}{VI(6)} + \frac{0.286}{EI(7)}$$

This gives (0.00, 0.02, 0.10, 0.18, 0.18, 0.25, 0.29).

A similar approach was used to determine the membership function of the other 22 CSFs. Having established their CSFs membership functions, the CSFG membership function was then ascertained from equation ii:

INSERT TABLE 3 & 4

CSF Grouping 1: Adequate BIM knowledge management in the FM industry

This CSFG has a percentage (%) variance of 30.795, the highest among the six underlying groups. This group has the highest index of 5.73 and a coefficient of 0.170 (**see table 4**). This group is regarded as the most important CSFG for BIM adoption for facility management operations. The 6 CSFs (sub-factors) under this grouping include staff education and training, BIM research promotion, adequate knowledge sharing on BIM, motivation for BIM adoption in FM Industry, building capacity for modern technology adoption, and government support and incentive for BIM in the FM industry. BIM research promotion, one of the sub-factors under this CSFG, has a mean score of 5.73 (**see table 3**) and a factor loading of 0.770 (**see table 2**) which is the highest factor loading in the group. More findings and research is required to promote the adoption of BIM in the facility management industry. This is not far from Abdirad (2016) submission that BIM enhancement would come to the limelight when its research is promoted in industry and academia.

Government support and incentive for BIM is another important sub-factor under this group with a factor loading of 0.640 and a mean value of 5.78. Government establishment of start-up funding to kickstart BIM initiatives is crucial for its adoption in the FM facility management industry (Wong & Lee, 2010; Olawumi & Chan, 2018). Another factor in this group is staff education and training on BIM, which has a factor loading of 0.593 and a mean value of 5.29. There is a need to educate various practitioners and staff of the FM industry on how BIM works; this is important because training and education are some of the best approaches to knowledge gain for modern technology adoption (Ganiyu, 2018). Facilities managers' top-level and junior staff must be trained on BIM, arranging training and seminars programs on new skillsets that could help them adopt BIM and change the present workplace culture (Ugwu & Kumaraswamy 2007; Olawumi & Chan, 2018; Yusuf et al., 2018). The next CSFs under this group with high factor loading (0.589) is building capacity for modern technology adoption with a mean value of 5.76. It implies that adequate capacity must be developed to adopt modern technology in the FM industry to support the implementation and promotion of BIM effectively. According to Ganiyu et al. (2018) and Yusuf et al. (2018), adequate BIM implementation capacity to handle BIM tools and packages are crucial for a smooth adoption. Adequate knowledge sharing on BIM is another important CSF in this group, with a factor loading of 0.538 and a mean value of 5.56. With proper knowledge management, sharing, and transfer of BIM in the facility management industry, BIM implementation for facility operations would be achieved (Azhar, 2011; Olawumi & Chan, 2018). Knowledge sharing is an organized and systematic approach to utilize the knowledge within an organization to improve its performance; hence it is imperative for a successful BIM implementation. Motivation for BIM adoption for facility management is another important sub-factor in this group, with a factor loading of 0.522 and a mean value of 5.87. Personal motivation for the use of new technologies is very important for BIM adoption. All concerned authorities such as staff, professionals, and other stakeholders need to be spurred on the need for BIM adoption in FM operations (Misron *et al.,* 2018).

CSF Grouping 2: FM leaders and staff commitment to BIM

This CSFG has a percentage variance of 10.866 of the total variance in the factor analysis. Although based on FSE, this group ranked 4th with an index of 5.57 and a coefficient of 0.166 (**see table 4**). This group is relatively important for BIM adoption for facility operations. These CSFs in this group are five (5): executive leadership support for BIM, personnel preparation for change, end-user participation, early involvement of in-house FM project teams, and availability of competent staff. Among the CSFs, executive leadership support for BIM adoption has the highest factor loading of 0.775 (**see table 2**) and ranked first with a mean score of 6.10 (**see table 3**). This is considered the most important in this group due to leaders' commitment to organization decisions. Therefore, with credible commitment from the executive leaders in the FM firm for BIM adoption, implementation would be smooth and efficient. This is not far from the conclusion that with BIM vision and commitment among leaders and executives in an organisation, its adoption would be enhanced (Abdirad 2016; Liao &Tea, 2017; Ganiyu *et al*., 2018; Misron *et al*., 2018; Darwish *et al*., 2020).

End-user participation is another second important subfactor in this group, with a factor loading of 0.660 and a mean value of 5.11. The involvement of users in the process is paramount to BIM adoption for facility management operations. This confirms the position of Ugwu and Kumaraswamy (2007) that implementation of BIM is a function of end users' active involvement. Proper knowledge of harnessing the appropriate software to meet the BIM model's users' requirements is fundamental to its adoption for FM practice (Ganiyu, 2018). The next subfactor in this group is personnel preparation for change which has a factor loading of 0.653 and a mean value of 5.59. This depicts that FM staff should be prepared formally for a change in management program to accommodate BIM implementation. Adopting BIM requires a substantial change in the work process that needs the preparedness of all personnel with the organisations (Misron *et al*., 2018). Availability of competent staff is another CSF in this group, with a factor loading of 0.646 and a mean value of 5.51. Staff with experience in IT and other cloud-based technology availability is very important for promoting BIM in the FM industry. Accordingly, since BIM entails a change in responsibility, it becomes necessary for individual competency in advanced technology for effective BIM adoption (Ozorhon & Karahan, 2016; Olawumi & Chan, 2018; Darwish et al., 2020). Early involvement of in-house FM project teams has the lowest factor loading. The involvement and participation of the FM project team early enough could expedite the implementation process of BIM in the industry. - This was the position of Ahn et al. (2014) that the participation of the project team early enough in the adoption of BIM for FM is a significant factor that must not be overlooked.

CSF Grouping 3: Availability of Metric and Model for BIM

This CSFG has a percentage variance of 9.216 of the total variance explained. It ranked 6th based on FSE with an index of 5.42 and coefficient of 0.162 (**see table 4**). The group has four subfactors which out of which development of the BIM framework has the highest factor loading of 0.838 (**see table 2**) and a mean value of 5.78 (**see table 3**). According to Howard and Bjork (2008), a coherent framework is needed where numerous BIM standards can fit and enhance its integration into FM operations. Establishing a credible legal framework for using and deploying BIM in FM projects is crucial for BIM adoption (Olawumi & Chan, 2018).

Another important CSF is developing a good practice model with a factor loading of 0.820 and a mean value of 5.25. An accurate and good BIM model for FM is very important. It will promote the integration and allow the downstream firms to document the precise information from the integrated 3D models. Developing a better practice model before BIM implementation in the FM industry is a very important CSF (Olawumi & Chan, 2018). The availability and affordability of cloud-based technology are other significant CSFs in this group, with a factor loading of 0.812 and a mean score of 5.25. A cloud-based technology must be economically affordable for the industry; otherwise, the adoption process would be stunted (Olawumi & Chan, 2018). The least subfactor in this group is adequate BIM regulations and guidelines. The development of BIM adoption rules, standards, and regulations for FM are very important for successful implementation (Olawumi & Chan, 2018).

CSF Grouping 4: BIM investment and organisation readiness for change

This CSFG has a percentage variance of 8.060 and ranked 5th with an index 5.47 of and a coefficient of 0.163 (**see table 4**). This indicates that an organisation's adequate readiness and investment in BIM are relatively important for its adoption in the FM industry. The CSFG contains three different subfactors: organisational re-engineering for BIM, organisation of general commitment to BIM adoption for FM, and adequate investment in BIM. Among these, organisational re-engineering for BIM has the highest factor loading of 0.804 (**see table 2**), with a mean value of 5.10 (**see table 3**). This connotes that better attention must be given to re-engineering the overall organisation process of doing things in the FM industry to accommodate and pave the way for BIM adoption (Ugwu & Kumaraswamy, 2007). Adequate investment in BIM is another important subfactor with a factor loading of 0.738 and a mean value of 5.38. Organisations should be ready to invest time, money, and resources to fuel BIM adoption for FM management operations (Won & Lee, 2010; Won et al., 2013; Nanajkar & Gao, 2014). Therefore, investment in BIM for FM by organisations is a very important CSF. The organisation of general commitment to BIM adoption for FM is the least ranked subfactor based on the factor loading. However, overall organisation commitment and collaboration are pivotal for BIM adoption for FM operations (Ah et al., 2014; Chan, 2014).

CSF Grouping 5: Accessible BIM hard and soft packages

This CSFG has a percentage variance of 5.401 and ranked 3rd based on the FSE with an index of 5.65 and a coefficient of 0.168 (**see table 4**). It means that BIM adoption for facility operation would see the light of the day when the necessary hard and soft packages are accessible and available. Accordingly, the CSFG has three CSFs: BIM hardware and software availability, accessible BIM software vendors for FM, and availability of BIM databases. Among these three, BIM hardware and software availability has the highest factor loading of 0.803 (**see table 2**) and a mean value of 5.30 (**see table 3**). This indicates that BIM would not function in isolation, hence the need for the required software and hardware availability for effective adoption in the facility management industry (Azhar, 2011; Ganiyu *et al.,* 2018; Darwish *et al.*, 2020).

Furthermore, accessible BIM software vendors for FM are another subfactor under the CSFG, with a factor loading of 0.738 and a mean value of 5.68. Therefore, the accessibility of facility managers to BIM software vendors is an excellent motivation for adopting BIM in facility management operations. This was the submission of Azhar (2011), Redmond et al. (2012), and Abubakar et al. (2014) that when vendors of BIM software for FM are available, facility managers would be motivated to adopt it in their practice.

Another CSF under this group is the availability of BIM databases with a factor loading of 0.683 and a mean value of 5.67. The importance of these CSFs is not far-fetched. Without a database for BIM for facility management, its adoption would be crippled, hence the need for a comprehensive database for BIM adoption for facility management operations (Abolghasemzadeh, 2013; Anton & Diaz, 2014).

CSF Grouping 6: Stakeholder's collaboration and commitment to BIM

This CSFG has a percentage variance of 4.665 out of the total variance explained. Despite having the least percentage of variance explained, it ranked 2nd in the FSE analysis with an index of 5.71 and a coefficient of 0.170 (**see table 4**). This indicates that stakeholders' collaboration and commitment to BIM are very important (Ganiyu et al., 2018) for promoting BIM adoption for facility management operations. This CSFG has two subfactors which are promoting BIM benefits among stakeholders and cooperation among and project stakeholders. Among these two, collaboration and project stakeholders have the higher factor loading of 0.606 (**see table 2**), with a mean value of 5.65 (**see table 3**). It, therefore, implies that if the FM stakeholders are not committed to the adoption of BIM in industry, the process would be stunted (Liao & Teo, 2017; Antwi-Afari et al., 2018; Olawumi & Chan, 2018). Promoting BIM benefits among stakeholders is the second sub-factor in this group, with a factor loading of 0.556 and a mean value of 5.78. This connotes that adequate awareness and information on the inherent benefits and significance of BIM in facility management operations among FM stakeholders would trigger their commitment and collaboration to embrace it (Azhar, 2011; Darwish *et al.*, 2020).

In table 4, The CSFG decision rule matrix showed that adequate BIM knowledge management in FM industry ranks first with a coefficient of 0.171. The second ranked is stakeholders collaboration and commitment (0.170), third is the FM leaders and staff commitment to BIM (0.166), followed by accessible BIM hard and soft packages (0.168), BIM investment and organisation readiness for change (0.163) and the availability of metric and model for BIM (0.162). The coefficient was deployed to develop an evaluation model denoted in equation (iv).

$$\mathbf{Y} = 0.171\mathbf{(a)} + 0.170\mathbf{(b)} + 0.166\mathbf{(c)} + 0.168\mathbf{(d)} + 0.163\mathbf{(e)} + 0.162\mathbf{(f)} \ldots\ldots \text{equation (iv)}$$

where:

Y = CSF for BIM adoption for FM operations

a = Adequate BIM knowledge management in FM industry

b = Stakeholders collaboration and commitment

c = FM leaders and staff commitment to BIM

d = Accessible BIM hard and soft packages
e = BIM investment and organisation readiness for change
f = Availability of metric, model and affordable technology for BIM

The practical implication of the developed model is that it can assist facility managers, policy makers and practitioners in ascertaining the appropriate mix of factors and the major areas attention should be given to in order to promote the BIM adoption for facility management operations.

Conclusion

This study has identified the CSFs needed for the feasibility of implementing BIM in facility management operations. Comprehensive literature research that gave them an initial framework for creating the 23 CSFs was used to develop a distributed questionnaire to facility managers. BIM knowledge management within the FM industry, FM leaders and staff commitment to BIM, BIM metric and model availability, BIM investment and organisation readiness for change, accessible BIM hard and soft packages, and stakeholder's awareness and commitment to BIM were found by using the factor analysis approach with the principal component analysis. Additional Fuzzy Synthetic Evaluation was undertaken to break down the subset of the six groups. Findings revealed that FM leaders and staff hold the most important BIM knowledge management skills. This is followed by the FM organisation's commitment to BIM, FM leaders and staff having a strong commitment to BIM, accessible BIM packages, FM leaders and staff commitment to BIM, investment in BIM, and organisation readiness for change. This study will help increase the usage of BIM for facility operations. This research offers practical consequences to facility managers, policymakers, and stakeholders in the FM industry. The managers will be acquainted with critical success information that will enhance BIM adoption for facility management operations. Additionally, it provides a roadmap and practical strategy for FM practitioners. Finally, the facility management operations would be strengthened if these success factors are closely followed.

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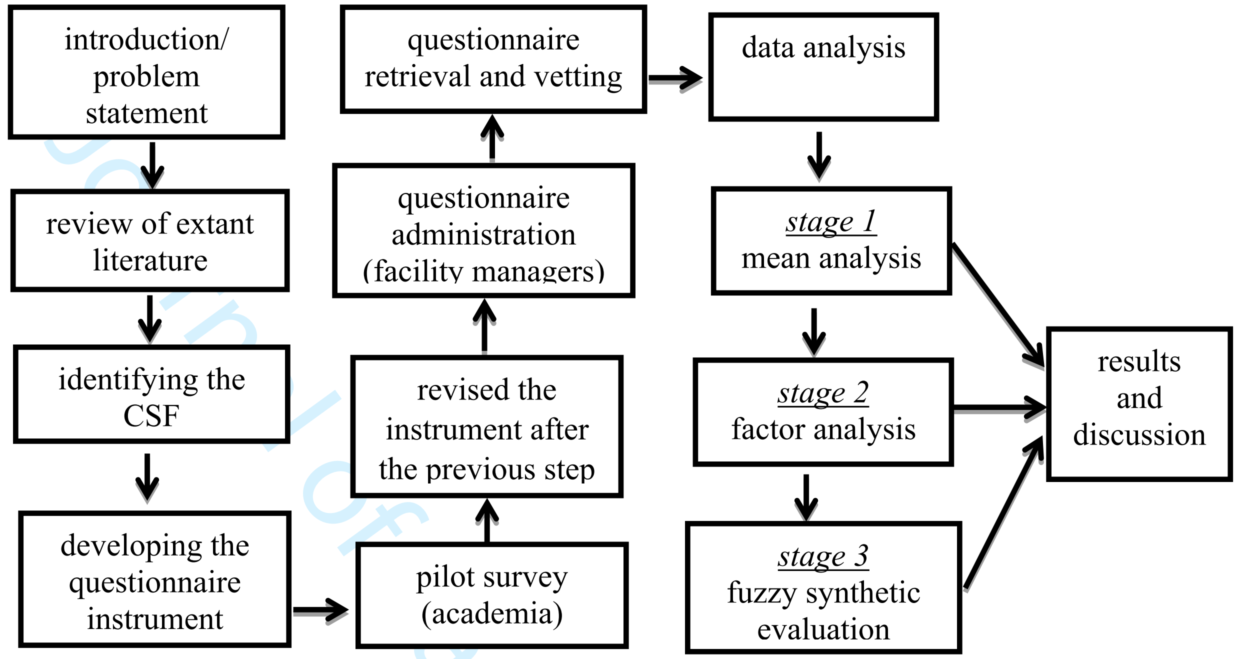

Fig 1: Flowchart of the research process

Table 1: Review of Critical Success Factors for BIM adoption in FM Operations

CSF Codes	CSFs Label	References
01	Organisation of general commitment to BIM adoption for FM	[5],[6],[15],[27]
02	Development of BIM adoption framework	[10],[11]
03	Motivation for BIM adoption on FM	[2],[28]
04	Personnel preparation for change	[21],[19]
05	End-users participation	[4],[19]
06	Availability and affordability of cloud-based technology	[7],[18]
07	Adequate knowledge sharing on BIM	[2]
08	Involvement of in-house FM project teams	[4],[14]
09	Development of good practice model for BIM	[5],[3]
10	Promoting BIM benefits among stakeholders	[1],[2],[3],[4],[5]
11	Support and incentive from government for BIM in FM industry	[16],[19]
12	Availability of BIM databases	[12],[13],[14],[7]
13	Organisation re-engineering for BIM	[14],[4],[5]
14	BIM research promotion	[15],[19],[9]
15	Adequate BIM regulations and guidelines	[2],[8],[9]
16	Availability of BIM hardware and software	[15],[16],[17]
17	capacity building for the adoption of modern technology	[7],[22],[23]
18	Staff education and training on BIM	[5],[25],[26]
19	Investment in BIM	[2],[6],[7],[4]
20	Availability of competent staff	[15],[14];[28]
21	Accessible BIM software vendor for FM	[18],[4],[2],[19]
22	Leadership backing for BIM	[14],[19]
23	Collaboration of project stakeholders	[1],[19],[7],[4],[20]

[1] Liao and Teo (2017); [2] Misron et al., (2018); [3] Abdirad (2016); [4] Darwish et al.,(2020); [5] Ganiyu et al., (2018); [6] Yusuf et al., (2018); [7] Ugwu and Kumaraswamy (2007); [8] Chan (2004); [9] Albinu and Vankatesh (2014); [10] Anton and Diaz (2014); [11] Abolghasemzadeh (2013); [12] Redmond et al., (2012); [13] Abubakar et al., (2014); [14] Azhar (2011); [15] Won et al., (2013); [16] Won and Lee (2010); [17] Nanajkar and Gao (2014); [18] Ozorhon and Karahan (2016); [19] Olawumi and Chan (2018); [20] Antwi-Afari et al., (2018); [21] Marthon et al., (2014); [22] Bui et al.,(2016); [23] Kassem et al.,(2012);[24] Chua and Yeoh(2015); [25] Ross et al.,(2006);[26] Chan (2014);[27]Ah et al.,(2014);[28] Gu and London (2010)

Table 2: Factor analysis based on expert opinion

CSFS Code	Groups	Label	Factor loadings	Eigen value	variance explained %	Cumulative %
18	1. Adequate BIM knowledge management in FM industry	Staff education and training on BIM	.593	7.083	30.795	30.795
14		BIM research promotion	.770			
07		Adequate knowledge sharing on BIM	.538			
03		Motivation for BIM adoption on FM	.522			
17		capacity building for the adoption of modern technology	.589			
11		Support and incentive from government for BIM in FM industry	.640			
22	2. FM leaders and staff commitment to BIM	Leadership backing for BIM	.775	2.499	10.866	41.661
04		Personnel preparation for change	.653			
05		End-users' participation	.660			
08		Involvement of in-house FM project teams	.517			
20		Availability of competent staff	.646			
02	3. Availability of Metric, Model and affordable technology for BIM	Development of BIM adoption framework	.838	2.120	9.216	50.877
06		Availability and affordability of cloud-based technology	.812			
09		Development of good practice model for BIM	.820			
15		Adequate BIM regulations and guidelines	.809			
13	4. BIM investment and organisation readiness for change	Organisation re-engineering for BIM	.804	1.854	8.060	58.937
01		Organisation of general commitment to BIM adoption for FM	.770			
19		Investment in BIM	.738			
16	5. Accessible BIM hard and soft packages	Availability of BIM hardware and software	.803	1.242	5.401	64.337
21		Accessible BIM software vendor for FM	.738			
12		Availability of BIM databases	.683			
10	6. Stakeholders' collaboration and commitment to BIM	Promoting BIM benefits among stakeholders	.556	1.073	4.665	69.002
23		Collaboration of project stakeholders	.606			

Extraction Method: Principal Component Analysis. *Rotation Method: Varimax with Kaiser Normalization*

Table 3: CSFs weightings and membership functions for BIM adoption in facility operations

CSF					Weighting		Membership functions	
Codes	Factor grouping	Label	Mean Score	CSFG Total Mean Score	CSF	CSFG	Level 2	Leve1 1
18	1. Adequate BIM knowledge management in FM industry	Staff education and training on BIM	5.29	33.99	0.156	0.268314	(0.00, 0.02, 0.13, 0.21, 0.19, 0.13, 0.33)	(0.00, 0.01, 0.06, 0.13, 0.25, 0.23,0.34)
14		BIM research promotion	5.73		0.169		(0.00, 0.02, 0.08, 0.03, 0.27, 0.24, 0.37)	
07		Adequate knowledge sharing on BIM	5.56		0.164		(0.00, 0.02, 0.05, 0.13, 0.27, 0.33, 0.22)	
03		Motivation for BIM adoption on FM	5.87		0.173		(0.00, 0.00, 0.03, 0.16, 0.21, 0.11, 0.49)	
17		Capacity building for the adoption of modern technology	5.76		0.169		(0.00, 0.00, 0.03, 0.13, 0.21, 0.32, 0.32)	
11		Support and incentive from government for BIM in FM industry	5.78		0.170		(0.00, 0.00, 0.02, 0.10, 0.32, 0.24, 0.33)	
22	2. FM leaders and staff commitment to BIM	Leadership backing for BIM	6.10	27.41	0.223	0.216372	(0.00, 0.00, 0.02, 0.05, 0.24, 0.22, 0.48)	(0.00, 0.02, 0.06, 0.12, 0.24, 0.25, 0.31)
04		Personnel preparation for change	5.59		0.204		(0.00, 0.02, 0.10, 0.18, 0.18, 0.25, 0.29)	
05		End-users participation	5.11		0.186		(0.00, 0.00, 0.02, 0.14, 0.30, 0.32, 0.22)	
08		Involvement of in-house FM project teams	5.10		0.186		(0.00, 0.06, 0.13, 0.14, 0.24, 0.18, 0.25)	
20		Availability of competent staff	5.51		0.201		(0.00, 0.03, 0.06, 0.11, 0.24, 0.27, 0.29)	
02	3. Availability of metric and model for BIM	Development of BIM adoption framework	5.78	21.31	0.271	0.168219	(0.00, 0.02, 0.02, 0.18, 0.18, 0.21, 0.41)	(0.00, 0.03, 0.06, 0.25, 0.17, 0.17, 0.33)
06		Availability and affordability of cloud-based technology	5.25		0.246		(0.00, 0.02, 0.10, 0.18, 0.18, 0.25, 0.29)	
09		Development of good practice model for BIM	5.25		0.246		(0.00, 0.00, 0.06, 0.38, 0.13, 0.10, 0.33)	
15		Adequate BIM regulations and guidelines	5.03		0.236		(0.00, 0.10, 0.06, 0.25, 0.18, 0.13, 0.29)	
13	4. BIM investment and organisation readiness for change	Organisation re-engineering for BIM	5.10	15.89	0.321	0.125434	(0.00, 0.00, 0,18, 0.06, 0.13, 0.19, 0.44)	(0.00, 0.01, 0.11, 0.21, 0.15, 0.18, 0.35)
01		Organisation of general commitment to BIM adoption for FM	5.41		0.340		(0.00, 0.02, 0.10, 0.18, 0.18, 0.25, 0.29)	
19		Investment in BIM	5.38		0.339		(0.00, 0.00, 0.06, 0.38, 0.13, 0.10, 0.33)	
16	5. Accessible BIM hard and soft packages	Availability of BIM hardware and software	5.30	16.65	0.318	0.131434	(0.02, 0.05, 0.33, 0.19, 0.19, 0.29, 0.24)	(0.01, 0.02, 0.17, 0.16, 0.24, 0.25, 0.25)
21		Accessible BIM software vendor for FM	5.68		0.341		(0.00, 0.00, 0.06, 0.13, 0.22, 0.24, 0.35)	
12		Availability of BIM databases	5.67		0.341		(0.00, 0.00, 0.14, 0.16, 0.32, 0.22, 0.16)	
10	6. Stakeholders' collaboration and commitment to BIM	Promoting BIM benefits among stakeholders	5.78	11.43	0.506	0.090227	(0.00, 0.03, 0.05, 0.13, 0.11, 0.27, 0.41)	(0.00, 0.02, 0.05, 0.13, 0.17, 0.26, 0.37)
23		Collaboration of project stakeholders	5.65		0.494		(0.00, 0.00, 0.06, 0.13, 0.24, 0.24, 0.33)	
Total Mean Score for CSFG				126.68				

Table 4: CSF grouping decision rule for BIM adoption in FM operations

CSF grouping	Factors	Index	Coefficient	Decision rule	Rank
1	Adequate BIM knowledge management in the FM industry	5.73	0.171	Very Important	1
6	Stakeholders' awareness and commitment to BIM	5.71	0.170	Very Important	2
5	Accessible BIM hard and soft packages	5.65	0.168	Very Important	3
2	FM leaders and staff commitment to BIM	5.57	0.166	Very Important	4
4	Investment in BIM and organisation readiness for change	5.47	0.163	Important	5
3	Availability of metric and model for BIM	5.42	0.162	Important	6

[a]*coefficient= (criterion index/sum of indices of all criteria)*

QUESTIONNAIRE

Dear participants,

You are cordially invited to participate in this research, which aims to provide a better understanding of the **Critical Success Factor for the adoption of Building Information Modelling towards improving the operations of facility management**. This questionnaire will take about 5 minutes to complete. Your participation is voluntary and anonymous. All information provided would be kept confidential and used solely for academic purposes. Upon request, we will provide you with a summary of our findings.

Regards,

Note: Please tick accordingly

Questions

1. Please indicate your year of industrial experience in facility management
   a. 1-5yrs { } b. 6-10yrs { } (c) 11-15yrs { } (d) 16-20yrs { } (e) Above 20yrs { }

2. Position in the organisation --

3. The following factors are elements in BIM that have been deemed critical and important to improve facility management operations. Based on your opinion and understanding, rate these factors in order of importance using the key 7 = extremely high importance, 6 = very high importance, 5 = high importance, 4 = moderate importance, 3 = low importance, 2 = very low importance and 1 = extremely low importance.

	CSF	**ELI (7)**	**VLI (6)**	**LI (5)**	**M (4)**	**I (3)**	**VI (2)**	**EI (1)**
CSF01	Staff education and training on BIM							
CSF02	BIM research promotion							
CSF03	Adequate knowledge sharing on BIM							
CSF04	Motivation for BIM adoption on FM							
CSF05	capacity building for the adoption of modern technology							
CSF06	Support and incentive from government for BIM in FM industry							
CSF07	Leadership backing for BIM							
CSF08	Personnel preparation for change							
CSF09	End-users participation							
CSF10	Involvement of in-house FM project teams							
CSF11	Availability of competent staff							
CSF12	Development of BIM adoption framework							
CSF13	Availability and affordability of cloud-based technology							
CSF14	Development of good practice model for BIM							
CSF15	Adequate BIM regulations and guidelines							
CSF16	Organisation re-engineering for BIM							
CSF17	Organisation of general commitment to BIM adoption for FM							
CSF18	Investment in BIM							
CSF19	Availability of BIM hardware and software							
CSF20	Accessible BIM software vendor for FM							
CSF21	Availability of BIM databases							
CSF22	Promoting BIM benefits among stakeholders							
CSF23	Collaboration of project stakeholders							

Some Workings

In CSFG1,

the weightings for all the CSFs is:

W_i= (0.156, 0.169, 0.164, 0.173, 0.168, 0.170) and R=

$$\begin{vmatrix} 0.00 & 0.02 & 0.13 & 0.21 & 0.19 & 0.13 & 0.33 \\ 0.00 & 0.02 & 0.08 & 0.03 & 0.27 & 0.24 & 0.37 \\ 0.00 & 0.02 & 0.05 & 0.13 & 0.27 & 0.33 & 0.22 \\ 0.00 & 0.00 & 0.03 & 0.16 & 0.21 & 0.11 & 0.49 \\ 0.00 & 0.00 & 0.03 & 0.13 & 0.21 & 0.32 & 0.32 \\ 0.00 & 0.00 & 0.02 & 0.10 & 0.32 & 0.24 & 0.33 \end{vmatrix}$$

The membership function of CSFG1 is calculated as:

$$D_1 = (0.156, 0.169, 0.164, 0.173, 0.168, 0.170) \quad \mathbf{X} \quad \begin{vmatrix} 0.00 & 0.02 & 0.13 & 0.21 & 0.19 & 0.13 & 0.33 \\ 0.00 & 0.02 & 0.08 & 0.03 & 0.27 & 0.24 & 0.37 \\ 0.00 & 0.02 & 0.05 & 0.13 & 0.27 & 0.33 & 0.22 \\ 0.00 & 0.00 & 0.03 & 0.16 & 0.21 & 0.11 & 0.49 \\ 0.00 & 0.00 & 0.03 & 0.13 & 0.21 & 0.32 & 0.32 \\ 0.00 & 0.00 & 0.02 & 0.10 & 0.32 & 0.24 & 0.33 \end{vmatrix}$$

CSFG Membership function

D = (0.00, 0.01, 0.06, 0.13, 0.25, 0.23, 0.34)

Equation iii

CSFG1 = (0.00, 0.01, 0.06, 0.13, 0.25, 0.23, 0.34) x (1, 2, 3, 4, 5, 6, 7) = 5.73
CSFG2 = (0.00, 0.02, 0.06, 0.12, 0.24, 0.25, 0.31) x (1, 2, 3, 4, 5, 6, 7) = 5.57
CSFG3 = (0.00, 0.03, 0.06, 0.25, 0.17, 0.17, 0.33) x (1, 2, 3, 4, 5, 6, 7) = 5.42
CSFG4 = (0.00, 0.01, 0.11, 0.21, 0.15, 0.18, 0.35) x (1, 2, 3, 4, 5, 6, 7) = 5.47
CSFG5 = (0.01, 0.02, 0.17, 0.16, 0.24, 0.25, 0.25) x (1, 2, 3, 4, 5, 6, 7) = 5.65

Membership functions

$$CSF01 = \frac{0.00}{ELI(1)} + \frac{0.016}{VLI(2)} + \frac{0.095}{LI(3)} + \frac{0.175}{M(4)} + \frac{0.175}{I(5)} + \frac{0.254}{VI(6)} + \frac{0.286}{EI(7)}$$

$$CSF23 = \frac{0.00}{ELI(1)} + \frac{0.00}{VLI(2)} + \frac{0.063}{LI(3)} + \frac{0.127}{M(4)} + \frac{0.238}{I(5)} + \frac{0.238}{VI(6)} + \frac{0.333}{EI(7)}$$