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Knowledge-based decision support for BIM adoption by small and medium-sized enterprises in developing economies

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Abstract

BIM is often considered to be unsuitable and there are no systematic approaches to guiding suitability decisions in construction SMEs, especially in developing economies. Thus, this paper evaluated key decision-making factors (DMFs) for BIM-based projects in SMEs. Data was collected through interviews, a Delphi survey and analysed with Fuzzy Synthetic Evaluation (FSE). The result revealed that contractual factors, client requirements and project features are the most important DMF categories. Suitability Decision Support Index (SDSI) was computed, and action plans were compiled. These serve as a decision support engine and a knowledge base in developing a Knowledge-Based Decision Support System (KBDSS). The KBDSS validation showed that it is a useful tool for providing reliable decision support for SMEs. The findings provide solid empirical support for the evaluation of BIM in SMEs from a decision-making perspective. It has significant implications for policy and research and provides ground for technology suitability theory.

Keywords: building information modelling; decision-making factors; developing economies; small and medium-sized enterprises; decision support system

1. Introduction

Building Information Modelling (BIM) has gained widespread awareness and adoption in the architecture, engineering, and construction (AEC) industry because of its benefits and push by the stakeholders [1,2]. However, there are variations in BIM adoption levels across the globe with North America and Europe exhibiting higher adoption rates whilst their counterparts in Africa and the Middle East are lagging in the BIM adoption level [3]. The adoption level disparities have translated into BIM divide between the developed and developing economies

[4,5]. There also exists a BIM divide between the small and medium-sized enterprises (SMEs) and the large firms [6], in which the former are situated on the lowest end of the competitive edge due to limited financial capabilities and resources which limits their innovations commitment [7]. This is coupled with the underrepresentation of SMEs' perspectives in extant BIM studies, especially in the context of developing economies [8]. Consequently, SMEs in developing economies are on the disadvantaged side of the BIM divide. Though SMEs represent over 80% of construction firms in developing economies, fewer studies have focused on BIM adoption in these SMEs. The need for SMEs to be BIM compliant cannot be overemphasised because they are the backbone of the industry [9,10] and are important for economic growth [11]. Implementing BIM goes beyond the mere installation of BIM tools to include reinventing workflow and training of staff [12]. However, this is considered a radical process, risky change and problematic [13,12] by SMEs.

Nevertheless, studies have shown that SMEs can adopt and implement innovations on projects successfully under the right contextual conditions [14,15]. However, one question that remains unanswered relates to the right contextual conditions for implementing BIM-based construction projects by SMEs in BIM infant developing economies. This paper investigated decision-making factors (DMFs) for BIM on construction projects from the context of SMEs in sub-Saharan Africa and developed a knowledge-based decision support system for construction projects. It is important to know what projects are suitable for BIM when there is limited resource from the perspective of the SMEs. Also, implementing BIM on all projects across the board is impossible and riskier for SMEs. The implementation process is often a learning process until expertise is achieved, thus this study is of immense importance by providing empirical evidence to support BIM in SMEs’ projects.

The contribution of this study lies in developing a decision support system for addressing the BIM suitability evaluation problem for construction projects by SMEs in developing economies. Previously, there is no systematic approach to solving this problem as SMEs often ignore BIM and assume BIM is unsuitable for their projects. Also, this study evaluates BIM suitability from a decision-making perspective to conceptualize it as a multi-criteria decision-making process. This serves as a point of departure from extant studies which are focused on the adoption/acceptance of BIM in which suitability of the context is an assumed precondition. Theoretically, the study consolidated and established a framework of decision-making factors that would augment efforts to develop a technology suitability theory for digital technologies in construction. Also, to practitioners and policymakers, this study provides better insights into the conditions that must be considered when assessing the suitability of BIM to construction projects for SMEs in developing economies. It identified factors influencing the decision environment and recommended action plans that can be considered and leveraged to support BIM adoption for construction projects by SMEs in developing economies. The paper is organized into six sections: (1) Introduction, (2) Background, (3) Research methodology, (4) Data analysis and results, (5) Discussion of findings, and (6) Conclusions, contributions, and implications.

2. Background of the study

Despite the reported benefits of BIM in extant studies such as improved project design, reduced project cost, shorten project duration, improved collaboration among others, there are still many projects and firms standing on the fence of BIM adoption[16]. Consequently, studies have been exploring critical success factors (CSFs) to identify the key factors necessary for the adoption and implementation of BIM [17,18]. However, these studies are often from the market or organisation level with little focus on projects which are the unit of design and construction activities [19]. Although the explorations of the critical success factors have improved the understanding of BIM, the studies do not address the decision-making factors (DMFs) for BIM suitability on SMEs projects. These are factors that are considered in making choices to reduce and manage uncertainties and are conceptually different from CSFs[20].

Few extant studies on BIM in SMEs are focused on barriers and drivers [21] and are mostly from developed economies where there is government support for BIM adoption in the AEC industry. These studies have highlighted that the SMEs perceive the BIM adoption to be risky, radical, and not suitable to SMEs' projects [12] This perception is bolstered by the focus of BIM studies on large projects and large firms [22,23] and the dearth of studies on DMFs for BIM projects. Albeit empirical evidence have suggested that SMEs can adopt BIM successfully and stands to gain in its implementation on projects [6,14]. Hitherto, there have been no studies that have explicitly addressed the DMFs for BIM in SMEs' projects. Consequently, not much is known about the decision-making process for BIM-based projects in SMEs which this present study aims to explore and advance.

BIM has specificities and is highly contextually sensitive. The applicability and relative importance of DMFs, drivers, risks, barriers, and CSFs are extremely sensitive to context [24,3]. Thus, Nigeria a developing economy is adopted as a case study in sub-Saharan Africa. BIM Africa [25] reported that the current level of adoption in the country and across the continent is still low despite the increase in awareness. Extant studies on BIM in Nigeria have mostly focused on drivers and barriers to BIM adoption and implementation but none of those studies has addressed how the SMEs make BIM suitability decisions on projects. This is not only peculiar to the Nigerian AEC industry but applicable in developed and developing economies. [21]. Consequently, this study aims to contribute to the growing body of knowledge on BIM in SMEs from a decision-making perspective.

2.1 Decision-Making Factors (DMFs) for BIM Suitability

Decision-making factors (DMFs) are pertinent factors that affect the choice (decision-making process) of organisations or individuals and are considered in reducing and managing risks

[26]. On the other hand, per Bullen and Rockart [27], the original conceptualization of CSFs refers to key areas in '*which favourable results are absolutely necessary*' to achieve success on projects or organisations. Thus, there are fundamental and conceptual differences between CSFs and DMFs. For instance, clients' commitment on project is a CSF but not a DMF, whereas client request for a technology is a DMF and not a CSF.

The Decision-making level ranges from strategic, operational to tactical decision-making level and involves different stakeholders and different objectives [28]. In construction organisations, different decisions are made relating to the physical, financial, and technical feasibility of projects. A decision such as BIM suitability is a strategic decision made by the top management level and influenced by different factors. Although decision-making could be clear and straightforward in some situations, it is often complicated and involves considerations of many factors in other situations. The latter is the case for BIM in SMEs of developing economies where there is an enshrined perception that BIM is unsuitable for SMEs' projects despite a lack of empirical justifications [29]. This problem is compounded for these SMEs where there is a lack of enabling environment and BIM is perceived to be risky [21]. Thus, BIM suitability study is a critical area that would assist in making a complex and often difficult decision for SMEs.

Previous BIM studies have majorly addressed BIM from the perspective of large firms and reported the CSFs [30,31]. Hitherto, there are no explicit studies on DMFs for BIM in SMEs in the literature. Extant studies on DMFs in the construction industry stem from themes such as sustainability and modular construction. Murtaza, et al. [32] identified decision-making factors for modularization of projects and proposed a system for evaluation of such projects using weight computation. The study categorized the DMFs into project risks, labour-related, plant-related, environmental &organizational-related and location-related factors. Bansal, et al. [33] evaluated the DMFs for selecting suitable construction methods for green buildings using Fuzzy Synthetic Evaluation (FSE). It categorised the DMFs into economic, social, and environmental criteria. Similarly, Chen, et al. [34] categorised the DMFs for appropriate method selection for concrete projects into project-related, site conditions, market attributes and location regulations. The study proposed a system for ranking alternative methods based on the DMFs using weight computation and multi-attribute theory (MAUT). Wuni and Shen [20] provided a comprehensive review of DMFs for modular construction and reported 51 DMFs which are categorised into labour considerations, organisational factors, project characteristics, location &site attributes.

Furthermore, Mitropoulos and Tatum [35] examined the adoption decision of new technologies in construction organisations and revealed the process varies and could often be a rational and or behavioural approach. The study further identified the factors affecting decision-making in technology selection to be related to the scope of the technological change and the decision's importance. Recently, Nnaji, et al. [36] reported the lack of studies on technology adoption from the perspective of the decision-making process rather than the prevalent adoption/acceptance models to understand technology usage. Thus, the study developed a decision support tool for selecting safety technologies using Fuzzy Synthetic Evaluation (FSE) to develop a construction safety technology adoption index (C-STAI). The developed index was built on DMFs categorised into organisational-related, technology-related, and organisation-related factors.

Similarly, extant studies on BIM adoption on projects are often from the perspective of CSFs and employ technology adoption/acceptance models[37,30]. These studies do not approach it from the perspective of decision-making process to evaluate the suitability of the BIM but focused on the BIM usage. Albeit these studies are important, they are limited in providing support for making a multi-criteria decision like BIM suitability on SMEs' projects. Consequently, major points of departure of this study are its approach from a decision-making process and consideration of BIM suitability which are assumed precondition and overlooked in extant studies.

2.1.1 Decision-Making Factors

As established in the previous sections, there are no studies on DMFs for BIM suitability, however, different factors have been reported in previous studies which are considered important DMF categories for BIM suitability. The following are the categories of DMFs that have been reported in the literature for technology/sustainability adoption decision-making process which are relevant to BIM suitability:

i) The project features: These are project-related factors that would converge to render projects suitable for BIM/technology adoption. Factors such as size, overall cost, complexity, contract details, and project type affect the suitability of BIM [30,38-40].

ii) The organisation attributes: These are factors related to the organisation in charge of the project which would influence the top management decision's to implement BIM on specific projects. These attributes are not fixed and vary depending on the time and condition of the firm. Factors such as current workload, experience on similar projects and available workforce have been highlighted in the literature as determinants of BIM decisions [40,41,8].

iii) External attributes: These are conditions outside the realm of the project and organisations that would influence the suitability of projects for BIM. These include client-related factors and statutory-related factors such as client request for BIM, and government-mandate for compulsory BIM usage [16,42,39]

2.2 Knowledge-based decision support system

A knowledge-based decision support system (KBDSS) is an integration of decision support system (DSS) and expert system (ES) to leverage the strengths of the two systems and complement their weaknesses [43]. DSS is a computer system that supports decision making in a complex and vague-structured problem by employing analytical techniques, models, and access to databases [44]. The basic objective of the DSS is to provide necessary information to decision-makers that would improve their awareness of the decision environment and the options available during the decision-making process [45,46]. On the other hand, the ES is a computer system that aims to mimic the procedures employed by experts in solving problems and provides recommendations [43]. It is focused on simulating the knowledge, logic, and reasoning of experts in tackling problems. Thus, Per Klein and Methlie [47] KBDSS is 'a computer information system that provides information and methodological knowledge using analytical decision models, and providing access to data and knowledge bases to support decision-makers in making decisions effectively in complex and ill-structured problem domains'.

Asides from leveraging the strengths of the DSS and ES, the KBDSS encompasses flexibility which accommodates changes in the environment of the decision-maker and approaches to decision-making [48]. It provides a friendly user interface that is useable for even people that are not proficient in computer usage [49]. Consequently, extant studies have developed KBDSS for various objectives in the AEC industry. Arain and Pheng [48] developed KBDSS for the management of variation on institutional projects in the AEC industry. Similarly, Hwang, et al. [49] developed KBDSS to aid the implementation of prefabricated prefinished volumetric construction. Other studies have developed it for soil improvement [50], prequalification [51], enterprise risk management [45] and building envelopes [52]. Thus, the KBDSS is a good fit to develop a suitability decision support tool for BIM-based projects in SMEs in developing economies.

3. Research methodology

This research employed a mixed approach which involves qualitative and quantitative techniques. This approach is considered appropriate to leverage the strength of the two techniques. Also, this approach has been employed in previous studies on DMFs and KBDSS [49,52,36]. More importantly, the DMFs cannot be modelled or simulated without collecting experts' opinions, action plans cannot be generated without interviews and KBDSS is best validated through case testing. Thus, the research objectives informed this methodology which is in tandem with the findings of Wuni and Shen [20] that mixed-approach is the most employed method in DMFs and decision support system studies.

The research process was completed in four phases: Phase 1 – preliminary study, Phase 2 – Measurement scale development and survey design, Phase 3 – Data analysis, and Phase 4 – Development of KBDSS. Fig.1 is a schematic of the methodological framework of the study. The various phases are described next.

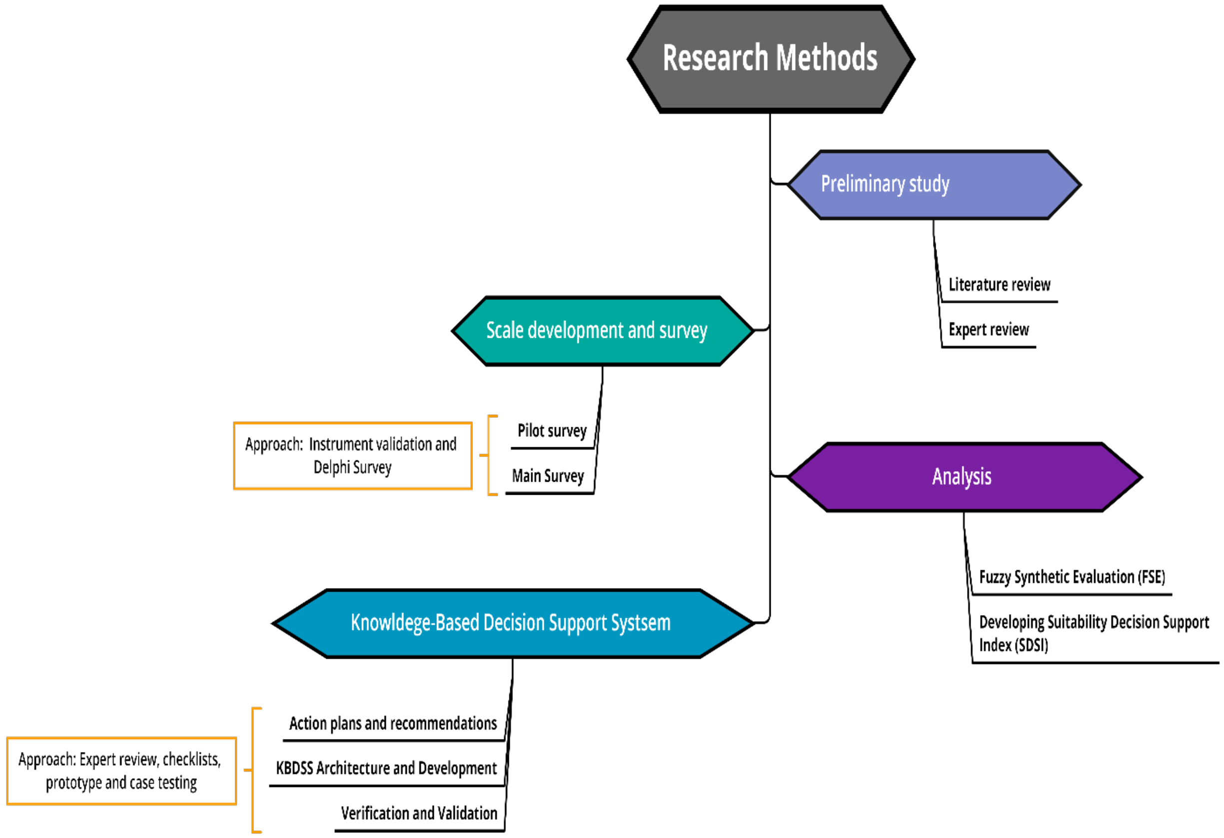

Fig.1. Research Methods for the Study

3.1 Preliminary study

An in-depth literature review was conducted to identify the DMFs of BIM-based projects in SMEs. However, extant studies have not dealt with the subject area explicitly and there are few studies on BIM-based projects in SMEs. Thus, phase I (preliminary study) of the research was complemented with experts' opinions and a review of the list of identified factors from the literature. The factors were reviewed, and other important factors were added and removed as deemed necessary by the experts. Table 1 shows the initial literature review and Table 2 shows the iteration process of the DMFs.

Table 1

Review of DMFs from related literature

Category	DMF	Source

Project-Features	Total project construction cost	[39,30,53]
	Political and social sensitivity	[38,40]
	Economic and cultural sensitivity	[38,30,40]
	Complexity of design (in terms of building shape)	[38,30]
	Availability of project information and data	[30,40]
	Physical size (floor area) of a project	[38]
	Location of the project	[30]
	Clarity of project scope	[40,39]
	Project type	[30,54,53]
	Stage of Usage	[38,54,53]
	Contract type	[30,54,53]
	Project duration	[38]
	Project milestones and deadlines	[38]
Organisation attributes	Experience on previous similar projects	[30,40]
	Project team willingness and capability to use BIM	[30,55,40,56]
	Design team use of BIM	[30]
	Subcontractor's willing and capability to use BIM	[30,40,56]
External attributes	Request from client to use BIM	[30]
	Government mandate	[42]
	Client involvement in the project	[30,39]

The identified DMFs were reviewed by experts and modifications were suggested as captured in the last column of Table 2.

Table 2

Expert review of identified DMFs

Category	DMF	Remarks
Project-Features	Total project construction cost	✓
	Political and social sensitivity	Merged
	Economic and cultural sensitivity	
	Complexity of design (in terms of building shape)	✓
	Availability of project information and data	✓
	Physical size (floor area) of a project	✓
	Location of the project	✓
	Clarity of project scope	✓
	Project type	✓
	Stage of Usage	Divide into project stages
	Contract type	Design-Build & Design-Bid-Build
	Project duration	✓
	Project milestones and deadlines	✓
Organisation attributes	Experience on previous similar projects	✓
	Project team willingness and capability to use BIM	Project manager and project team
	Design team use of BIM	✓
	Subcontractor’s willing and capability to use BIM	Willingness and capability
	Current workload in hand	+: Expert
	Available workforce	+: Expert

External attributes	Request from client to use BIM	✓
	Government mandate	✗: Not applicable in the context
	Client involvement in the project	✓
	Type of client (public, private, mixed, etc)	+: Expert
	Design control responsibility of the client	+: Expert

Notes- ✓: Reviewed; +: DMF suggested by experts; ✗: Removed

Sequel to the expert review, the DMFs were modified as suggested and recategorized to capture the different categories of the DMFs as shown in Fig. 2.

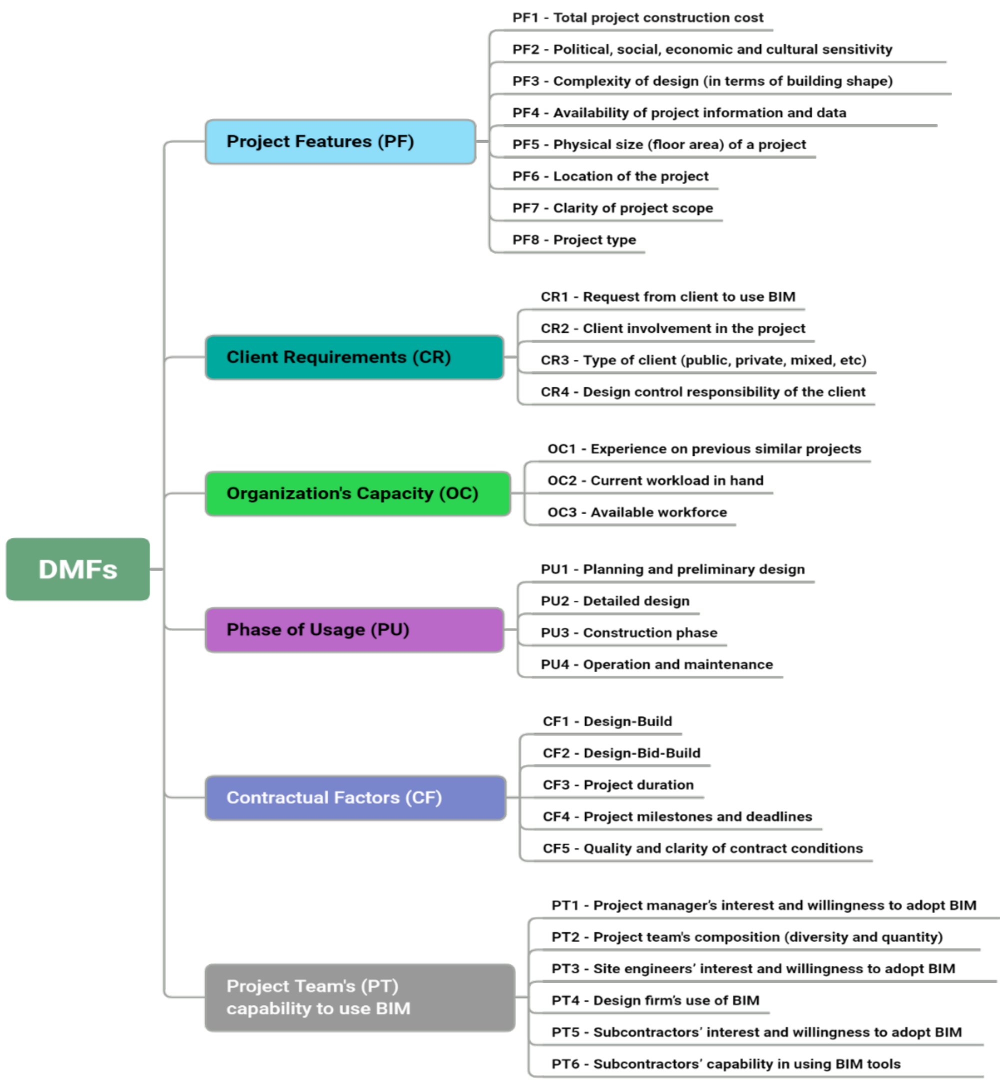

Fig. 2. Decision-making factors for BIM-based projects in SMEs of developing economies.

3.2 Measurement scale development and survey design

Phase II (Measurement scale development and survey design) involves using the DMFs to develop an empirical questionnaire with two sections: the first section gathered the demographic details of the experts, and the second section requested the experts to assess the relative importance of the DMFs using a five-point Likert scale of measurement which ranges from 1 (very low) to 5 (very high). The five-point Likert scale of measurement was employed in this study because of its ability to capture views of the experts with adequate interpretation [57,58]; allows a lower margin of error; provides options without overwhelming the respondents; and lastly, because it has been employed in previous studies for evaluation of DMFs [49,36,52]. The questionnaire was piloted with 5 BIM experts before the administration of the full survey to assess the questionnaire for face validity. All the BIM experts invited for the pilot survey have more than 10 years of working experience in the construction industry and they have been involved in BIM projects in SMEs.

Phase II of the research was concluded with the Delphi survey, which was conducted in two rounds before consensus [59]. Delphi was deemed suitable for this study due to seven corroborating reasons: (i) fewer SMEs have successfully adopted and implemented BIM, consequently, the pool of respondents is small; (ii) quality responses for the questionnaire can only be obtained from experts; (iii) it allow for varying opinions from experts; (iv) it serves as a better substitute for a physical meeting where decisions can be influenced by pressure to agree on the spot; (v) group decision from experts is better compared to an individual decision from professionals; (vi) quality is of utmost importance than the quantity of the experts; (vii) it allows for anonymity of respondents [60]. Experts for Delphi were invited based on a predetermined criterion: experience in the construction industry and the implementation of BIM on SME projects. This was necessary to differentiate BIM users from BIM experts in the

Nigerian AEC industry. Though there is no universally accepted number of experts for the Delphi survey, Mullen (2003) found that extant studies have often employed a minimum of seven panellists from varying backgrounds to improve the quality of the responses. In addition, the issue of consensus in Delphi has been contentious. Defining what connote consensus is very vital as it determines when to stop the rounds of Delphi [61]. Thus, the consensus in the context of this study is defined as when there is stability in the mean of successive rounds [62], the Inter Quartile Deviation IQD) is less or equal to 1 [63], and the computed Chi-square ($\chi 2$) value is higher than critical values from the Table. Lastly, inter-rater agreement (IRA) statistics and significant grading analysis were used to complement the listed measures.

3.3 Data analysis

Phase III (Data analysis) involves data analysis of the data collected via descriptive statistics, and fuzzy synthetic evaluation. The statistical methods adopted in the study are Cronbach's alpha reliability test, Mean Item Score (MIS), standard deviation (SD), Inter Quartile Deviation (IQD), Kendall's coefficient of concordance (W), Chi-square ($\chi 2$), IRA statistics, significant grading analysis and Fuzzy Synthetic Evaluation (FSE). Cronbach's alpha value range from 0 to 1 and measures the reliability of the questionnaire and a value above 0.7 is deemed appropriate for further analysis [64]. However, the value of the alpha does not indicate stability or consistency over time [65]. The IQD measures agreement and consistency and a value of IQD ≤ 1 signifies agreement [66,67]. Kendall's coefficient measures the concordance between the respondents and ranges from 0 to 1 which is perfect disagreement and perfect agreement, respectively. A Chi-square ($\chi 2$) value higher than the critical value also implies consensus and was adopted because the item exceeds seven [68]. The IRA was proposed by Brown and Hauenstein [69] to measure the level of agreement amongst the ratters (panellists) which is agnostic to the sample size and scale type. LeBreton and Senter [70] revised standard for interpreting IRA: '0.00 to 0.30 - Lack of agreement' (L), '0.31 to 0.50 Weak agreement' (W), '0.51 to 0.70 Moderate agreement' (M), '0.71 to 0.90 Strong agreement'(S), and '0.91 to 1.00' Very strong agreement' (V.S) is adopted in this present study and other similar studies [71,72]. Equation 1 shows the IRA equation and equation 2 and 3 shows the equation to determine the lower and upper limit.

$$a_{wg(1)} = 1 - \frac{(2*SD^2)}{\{(A+B)M-(M^2)-(A*B)\}*\frac{n}{n-1}} \quad (1)$$

$$M_{lower} = \frac{B(n-1)+A}{n} \quad (2)$$

$$M_{lower} = \frac{A(n-1)+B}{n} \quad (3)$$

Also, the significance of the responses was further interpreted by adopting interval interpretation by Li, et al. [73]: mean score ≤ 1.5 is 'not important' (N.M); 1.51 ≤ mean score ≤ 2.5 is 'somewhat important'(S.I); 2.51 ≤ mean score ≤ 3.5 is 'important'(I); 3.51 ≤ mean score ≤ 4.5 is 'very important'(V.I), and mean score ≥ 4.51 is 'extremely important (E.I).

The FSE is an analytical technique that applies fuzzy set theory and is capable of evaluating subjective descriptions of multi-attributes and levels of criteria that characterise the decision-making process [74-76]. The FSE is a powerful artificial intelligence technique and was employed in this study because it has the computational framework to deal with human judgement and accounts for fuzziness, thereby objectifying the subjectiveness [76]. FSE is adopted in developing the suitability decision support index (SDSI) in this study, based on the following steps [77].

a) Normalization: $N_m = \frac{M_n - M_{min}}{M_{max} - M_{min}}$ (4)
b) Determining weighting and membership function
c) Defuzzification

3.4 Development of the KBDSS

The last phase of the study is the development of KBDSS which entails the compilation of action plans, system architecture development and validation of the KBDSS. The action plans were compiled by reviewing literature coupled with inputs from the Delphi experts to draft recommendations for improving the project suitability in the SMEs. The KBDSS was developed using an integrated development environment (IDE) of Microsoft visual basic for applications. The developed system was subsequently verified and validated. Per Boehm [78], verification deals with 'building the product/system right' and validation deals with 'building the right product/system'. According to Zhao, et al. [45], verification focuses on sieving errors out of the system and validation deals with the quality of performance of the system. Verification and validation are interwoven but the validation process often outweighs verification procedures [45].

There are different techniques involved in validation and verification (V&V) processes which could be subsumed into qualitative and quantitative techniques. The quantitative technique involves using metrics to access the error and performance of the system e.g. mathematical proofs, simulation and sensitivity analysis. On the other hand, the qualitative technique involves methods such as case testing or prototypes, comparison with other extant models, checklists & interviews, and turning tests [45,78]. The V & V process in this study employs a qualitative technique via checklists, expert interviews, and case testing/case studies (prototypes). This validation approach enables comparison of the system in line with the reality of the case studies (i.e Is the system decision and recommendations consistent with experts' recommendations on the case studies) and it is the most common approach for validation of KBDSS in extant studies [49,45]. Lastly, per Boehm [78] the criteria of consideration in the V & V process are completeness, consistency, feasibility and testability. The interviews and checklist conducted were targeted at completeness and consistency of the system, whilst the developed prototype and case testing assessed feasibility and testability.

4. Results

4.1 Demographic distribution of the Delphi panellists

Twenty (20) experts were identified and invited based on the predetermined criteria. A total of 14 professionals accepted the invitation and participated in all the rounds of the Delphi [60] representing a 70% response rate for both rounds. Table 3 shows the distribution of the 14 experts across a diverse backgrounds in architecture, quantity surveying, engineering, and construction. Also, the respondents are both from contracting and consulting firms representing about 36% and 64% respectively. An important criterion for the inclusion of experts is the participation in the implementation of BIM in SME projects, this limits the respondents' pool as there are few BIM-based SMEs project in developing economies. About 29% have less than 5 years of experience, 42% have between 6 to 10 years of experience and 28% have more than 10 years of experience because BIM implementation in SMEs is still relatively new in sub-Saharan Africa. However, all the respondents are from the upper and middle management levels in the firms which are responsible for making BIM decisions and plans in the firms and have the required experience for the present study.

Table 3

Demographics of the survey respondents

Demographics	Categories	Frequency	Percentage
Profession	Architect	4	28.6
	Quantity Surveyor	4	28.6
	Engineer	4	28.6
	Builder	2	14.3
Organisation	Contracting	5	35.7
	Consulting	9	64.3
Experience in BIM implementation	< 5 years	4	28.6
	6 - 10 years	6	42.9

	> 10 years	4	28.5
Working level of the staff	Upper-level management	7	50.0
	Middle-level management	7	50.0
	Lower-level management	-	-

4.2 Results of Delphi survey

The experts were presented with the validated questionnaire for the ranking of the DMFs in BIM-based projects in SMEs. They were asked to rate the influence of the DMFs on the use of BIM at the project level in the SMEs using a Likert measurement scale of 5. The Cronbach's alpha reliability value was 0.924 for the 30 factors in the first round of the questionnaire. The responses were analysed by computing the mean item score, standard deviation (SD), IQD, Kendall's coefficient and $\chi 2$.

Table 4 shows the ranking of the DMFs in each category (R1) and the general category (R2) for the first round in the first column. The factors were ranked using the mean and standard deviation (SD) when there is a tie between means. Significance grading (S.G) suggested that the experts deem all the factors important, however, some are more important than the others as shown in Table 4. Kendall's coefficient of concordance (W) is 0.112 which is low and the $\chi 2$ value of 45.308 is lesser than the critical values of 55.336 and 49.588 at a p-value of 0.05 and 0.01 respectively.

The administered questionnaire in round one was redesigned to provide feedback for the experts as regards the result of the first round which includes individual responses and group average responses. The filled redesigned questionnaire was evaluated after the second round for reliability using Cronbach's alpha and the value is 0.817 which is greater than the threshold of 0.7 as shown in Table 4. In the second round, there seems to be no difference in the top-ranked DMFs, however, the least ranked DMFs are different compared to the result in round 1 and there was a significant increase in Kendall's coefficient from 0.112 to 0.434 which implies an improvement in the agreement level. The $\chi 2$ value of 176.067 is greater than the critical values of 55.336 and 49.588 at a p-value of 0.05 and 0.01 respectively which implies significant agreement.

Table 4

Ranking results of Delphi survey

Delphi Survey Round 1						**Delphi Survey Round 2**					
Code	**Mean**	**SD**	**Rank 1**	**Rank 2**	**S.G.**	**Mean**	**N_m**	**SD**	**Rank 1**	**Rank 2**	**S.G.**
PF1	4.07	0.829	1	2	V.I	4.43	1.00	0.154	1	1	V.I
PF2	3.36	1.082	7	22	I	3.43	0.53	0.646	5	18	I
PF3	4.00	0.961	2	3	V.I	4.36	0.97	0.497	2	3	V. I
PF4	3.36	1.151	6	21	I	3.43	0.53	0.756	4	19	I
PF5	3.43	1.342	5	16	I	2.86	0.27	0.949	6	26	I
PF6	3.14	1.406	8	27	I	2.50	0.10	0.760	7	29	↓S. I
PF7	3.71	1.139	4	6	V. I	3.71	0.66	0.825	3	12	V.I
PF8	3.79	0.975	3	5	V. I	3.71	0.66	0.825	3	14	V. I
CR1	3.43	1.604	3	17	I	4.36	0.97	0.247	1	2	↑V. I
CR2	3.36	0.929	4	20	I	3.36	0.50	0.633	4	22	I
CR3	3.64	1.008	1	9	V. I	3.36	0.50	1.008	3	21	↓I
CR4	3.57	1.016	2	11	V. I	3.71	0.66	0.825	2	13	V. I
OC1	3.71	0.994	1	8	V. I	4.29	0.93	0.469	1	5	V. I
OC2	2.93	1.328	3	29	I	2.50	0.10	0.650	3	28	↓S. I
OC3	3.50	1.345	2	15	I.	3.57	0.60	0.938	2	16	↑V. I
PU1	3.71	0.994	2	7	V. I	3.79	0.70	0.699	2	9	V. I
PU2	3.86	0.949	1	4	V. I	4.14	0.86	0.770	1	7	V. I
PU3	3.57	1.016	3	13	V. I	3.71	0.66	0.825	3	10	V. I
PU4	3.21	1.578	4	25	I	2.29	0.00	0.469	4	30	↓S. I
CF1	3.21	1.051	4	24	I	3.36	0.50	0.842	2	20	I
CF2	2.71	0.914	5	30	I	2.71	0.20	0.611	5	27	I
CF3	3.36	0.745	1	19	I	3.21	0.43	0.802	3	23	I
CF4	3.29	0.825	3	23	I	3.14	0.40	0.663	4	25	I
CF5	3.36	0.633	2	18	I	3.50	0.57	0.760	1	17	I
PT1	4.21	0.975	1	1	V I	4.29	0.93	0.825	1	4	V. I

PT2	3.64	1.151	2	10	V. I	3.71	0.66	1.069	4	11	V. I
PT3	3.57	1.222	4	14	V. I	4.21	0.90	0.699	2	6	V. I
PT4	3.57	1.158	3	12	V. I	4.00	0.80	0.877	3	8	V. I
PT5	3.00	1.240	5	28	I	3.14	0.40	0.864	6	34	I
PT6	3.14	1.351	6	26	I	3.64	0.63	1.008	5	15	↑V. I
Cronbach's α reliability value					**0.924**						**0.817**
Number of Respondents					**14**						
Kendall's coefficient of concordance (W)					**0.112**						**0.434**
χ2					**45.308**						**176.067**
χ2- Critical value from statistical table											
[a: p = 0.05; b: p = 0.01]											
Degree of freedom (df)											
Significance level (p-value)					**0.027**						**0.000**

Note: SD – Standard Deviation, Rank 1 – Category Ranking, Rank 2 – General Ranking, S.G. – Significance Grading, Nm – Normalized mean, V.I – Very Important, I – Important, S.I- somewhat important, ↑ - Improved, ↓ - Decreased.

The IQD and IRA also reflect no concordance in round 1 per the benckmarks, however, in round 2, all the IQD are ≤ 1, all the awg(1) implies agreement and there is no significant difference in the mean of successive rounds which connote stability as shown in Table 5.

Table 5

Level of agreement for Delphi survey

Code	$a_{wg(1)}$ score		Agreement level		IQD	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
PF1	0.553	0.977	Moderate	↑Very strong	2	1
PF2	0.438	0.797	Weak	↑Strong	2	1
PF3	0.428	0.787	Weak	↑Strong	2	1
PF4	0.364	0.722	Weak	↑Strong	2	1
PF5	0.123	0.580	Lack	↑Moderate	2	1
PF6	0.078	0.714	Lack	↑Strong	2	1
PF7	0.311	0.638	Weak	↑Moderate	2	1
PF8	0.477	0.638	Weak	↑Moderate	2	1
CR1	-0.252	0.947	Lack	↑Very strong	3	1
CR2	0.586	0.808	Moderate	↑Strong	3	1
CR3	0.474	0.512	Weak	↑Moderate	3	1
CR4	0.478	0.638	Weak	↑Moderate	1	1
OC1	0.475	0.825	Weak	↑Strong	1	1

OC2	0.180	0.791	Lack	↑Strong	2	1
OC3	0.104	0.555	Lack	↑Moderate	2	1
PU1	0.475	0.731	Weak	↑Strong	2	1
PU2	0.487	0.592	Weak	↑Moderate	2	1
PU3	0.478	0.638	Weak	↑Moderate	1	1
PU4	-0.169	0.883	Lack	↑Strong	3	1
CF1	0.481	0.660	Weak	↑Moderate	2	1
CF2	0.604	0.823	Moderate	↑Strong	1	1
CF3	0.734	0.698	Very Strong	↓Moderate	1	1
CF4	0.677	0.795	Moderate	↑Strong	1	1
CF5	0.808	0.714	Very Strong	Strong	1	1
PT1	0.304	0.459	Weak	Weak	1	1
PT2	0.315	0.393	Weak	Weak	2	1
PT3	0.245	0.642	Lack	↑Moderate	3	1
PT4	0.322	0.524	Weak	Weak	1	1
PT5	0.286	0.652	Lack	↑Moderate	2	1
PT6	0.148	0.474	Lack	↑Weak	2	1

Note: awg(1) (inter-rater reliability), ↑ - Improved, ↓ - Decreased.

4.3 Fuzzy Synthetic Evaluation (FSE) of the DMFs

The Delphi survey responses were further analysed using the FSE approach to develop a suitability decision support index for SMEs projects in sub-Saharan Africa.

4.3.1 Normalization of mean of DMFs

The mean of the DMFs is normalized using equation 4 as shown in Table 4. DMFs with normalized mean (Nm) values above 0.50 are considered for the next round of evaluation.

4.3.2 Determining weightings of DMFs

The weighting is computed using equation 5 and generated for all the factors as shown in Table 6.

$$W_i = \frac{MS_i}{\sum_{i=1}^{5} MS_i} \quad where\ 0 \leq W_i \leq 1, \qquad and\ \sum W_i = 1 \quad ------- (5)$$

Where W_i = weighting; MS_i = mean score of a selected factor, and $\sum MS_i$ = summation of the mean ratings of the selected factor.

Thus, the weighting of CR1 (Request for BIM use by client) from the CR grouping (total mean is 14.79) is computed as:

$$W_{CR1} = \frac{4.36}{4.36 + 3.36 + 3.36 + 3.71} = \frac{4.36}{14.79} = 0.295$$

Table 6

Weightings of individual DMFs and key groups of DMFs

Code	Factors/Groupings	(Total) Mean	(Total) Weightings
CF	**Contractual factors**	**(6.86)**	**(0.082)**
CF1	Design-Build	3.36	0.490
CF5	Quality and clarity of contract conditions	3.50	0.510
CR	**Client requirements**	**(14.79)**	**(0.176)**
CR1	Request from client to use BIM	4.36	0.295
CR2	Client involvement in the project	3.36	0.227
CR3	Type of client (Public, Private, Mixed, etc)	3.36	0.227
CR4	Design control responsibility of the client	3.71	0.251
OC	**Organization's capacity**	**(7.86)**	**(0.093)**
OC1	Experience on previous similar projects	4.29	0.546
OC3	Available workforce	3.57	0.454
PF	**Project features**	**(23.07)**	**(0.274)**
PF1	Total project construction cost	4.43	0.192
PF2	Political, social, economic and cultural sensitivity	3.43	0.149
PF3	Complexity of design (in terms of building shape)	4.36	0.189
PF4	Availability of information and data	3.43	0.149
PF7	Clarity of project scope	3.71	0.161
PF8	Project type	3.71	0.161
PT	**Project team’s capability to use BIM**	**(19.85)**	**(0.236)**
PT1	Project manager’s interest and willingness to adopt BIM	4.29	0.216
PT2	Project team's composition (diversity and quantity)	3.71	0.187
PT3	Site engineers’ interest and willingness to adopt BIM	4.21	0.212
PT4	Design firm’s use of BIM	4.00	0.202
PT6	Subcontractors’ capability in using BIM tools	3.64	0.183
PU	**Phase of usage**	**(11.64)**	**(0.138)**
PU1	Planning and Preliminary Design	3.79	0.326
PU2	Detailed Design	4.14	0.356

PU3	Construction phase	3.71	0.319

4.3.3 Determining membership functions of DMFs

The membership function (MF) of each of the factors is level 2 and computed before MF of the grouping at Level 2. The MF is deduced from the rating of the experts using the grades (e_1 = Very high, e_3 = Average, and e_5 = Very low).

Thus, MF for CR4 (Design control responsibility of the client) where 25% of the experts agreed that it is a 'very high factor', and 14% (high), 50%, (average), 7% (low) and 0% (very low) is computed as:

$$MF_{CR4} = \frac{0.25}{e1} + \frac{0.14}{e2} + \frac{0.50}{e3} + \frac{0.29}{e4} + \frac{0.00}{e5}$$

This is expressed as (0.25, 0.14, 0.50, 029, 0.00) for CR4 and Table 7 shows the computed MF for the rest of the factors. The MF at level 1 is computed using equation 6.

$$F = W_i \circ R_i \qquad ------------ (6)$$

W_i is the weighting of all the factors within each category and R_i is the fuzzy evaluation matrix.

The MF for the phase of usage (PU) is thus computed as:

$$F_{PU} = \begin{vmatrix} 0.326 \\ 0.356 \\ 0.319 \end{vmatrix} \times \begin{vmatrix} 0.14 & 0.15 & 0.36 & 0.00 & 0.00 \\ 0.36 & 0.43 & 0.21 & 0.00 & 0.00 \\ 0.14 & 0.50 & 0.29 & 0.07 & 0.00 \end{vmatrix} = (0.22 \quad 0.45 \quad 0.28 \quad 0.02 \quad 0.00)$$

The complete membership function for level 1 and 2 are presented in Table 6.

Table 7

Membership function of the decision-making factors

Code	Factor	Weighting	Membership function
Contractual factors		**0.082**	**(0.07, 0.40, 0.43, 0.10, 0.00)**
CF1	Design-Build	0.490	(0.07, 0.36, 0.43, 0.14, 0.00)
CF5	Quality and clarity of contract conditions	0.510	(0.07, 0.43, 0.43, 0.07, 0.00)
Client requirements		**0.176**	**(0.19, 0.43, 0.32, 0.07, 0.00)**
CR1	Request from client to use BIM	0.295	(0.36, 0.64, 0.00, 0.00, 0.00)
CR2	Client involvement in the project	0.227	(0.07, 0.21, 0.71, 0.00, 0.00)

CR3	Type of client (Public, Private, Mixed, etc)	0.227	(0.14, 0.29, 0.36, 0.21, 0.00)
CR4	Design control responsibility of the client	0.251	(0.14, 0.50, 0.29, 0.07, 0.00)
Organization's capacity		**0.093**	**(0.25, 0.48, 0.23, 0.03, 0.00)**
OC1	Experience on previous similar projects	0.546	(0.29, 0.71, 0.00, 0.00, 0.00)
OC3	Available workforce	0.454	(0.21, 0.21, 0.50, 0.07, 0.00)
Project features		**0.274**	**(0.24, 0.42, 0.33, 0.01, 0.00)**
PF1	Total project construction cost	0.192	(0.43, 0.57, 0.00, 0.00, 0.00)
PF2	Political, social, economic, and cultural sensitivity	0.149	(0.07, 0.29, 0.64, 0.00, 0.00)
PF3	Complexity of design (in terms of building shape)	0.189	(0.36, 0.64, 0.00, 0.00, 0.00)
PF4	Availability of information and data	0.149	(0.14, 0.14, 0.72, 0.00, 0.00)
PF7	Clarity of project scope	0.161	(0.21, 0.29, 0.50, 0.00, 0.00)
PF8	Project type	0.161	(0.14, 0.50, 0.29, 0.07, 0.00)
Project team's capability to use BIM		**0.236**	**(0.32, 0.42, 0.21, 0.05, 0.00)**
PT1	Project manager's interest and willingness to adopt BIM	0.216	(0.50, 0.29, 0.21, 0.00, 0.00)
PT2	Project team's composition (diversity and quantity)	0.187	(0.21, 0.43, 0.29, 0.07, 0.00)
PT3	Site engineers' interest and willingness to adopt BIM	0.212	(0.36, 0.50, 0.14, 0.00, 0.00)
PT4	Design firm's use of BIM	0.202	(0.29, 0.50, 0.14, 0.07, 0.00)
PT6	Subcontractors' capability in using BIM tools	0.183	(0.21, 0.36, 0.29, 0.14, 0.00)
Phase of usage		**0.138**	**(0.22, 0.48, 0.28, 0.02, 0.00)**
PU1	Planning and Preliminary Design	0.326	(0.14, 0.50, 0.36, 0.00, 0.00)
PU2	Detailed Design	0.356	(0.36, 0.43, 0.21, 0.00, 0.00)
PU3	Construction phase	0.319	(0.14, 0.50, 0.29, 0.07, 0.00)

4.3.4 Defuzzification of membership functions of DMFs

MFs at level 1 are defuzzified to determine the suitability decision support index (SDSI) using equation 7.

$$SDSI = \sum_{I=1}^{5} F \times g \quad ---------------- (7)$$

where SDSI = suitability decision support index

Thus, SDSI for the CR group (client requirements factors) is computed as:

$$SDSI_{(CR)} = (0.19,\ \ 0.43,\ \ 0.32,\ \ 0.07,\ \ 0.00) \times (1, 2, 3, 4, 5) = 2.25$$

Similarly, other MFs are defuzzified as shown in Table 8 and the coefficient is computed using equation 9.

$$^{y}Coefficient = \left({}^{SDSI\ for\ Each\ group} \Big/ {}_{\sum SDSI\ for\ all\ groups} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Table 8

BIM Implementation Index (BII)

Groups	BII	Coefficient
Contractual Factors	2.57	0.20
Client Requirements	2.25	0.17
Organization's Capacity	2.03	0.16
Project Features	2.11	0.16
Project Team's capability to use BIM	2.00	0.15
Phase of Usage	2.11	0.16
Total	13.07	1.00

Note- BII: BIM Implementation Index for each category of the DMF

The overall index is thus derived using additive and a linear approach for easy usage of the SMEs as shown in equation 9.

$$SDSI = (0.20 \times CF) + (0.17 \times CR) + (0.16 \times OC) + (0.16 \times PT) + (0.15 \times PT) + (0.16 \times PU) \quad ---------(9)$$

4.4 Knowledge-Based Decision Support System (KBDSS)

The main objectives of the KBDSS are: (a) to automate the assessment of the SDSI for construction projects by the SMEs; (b) to provide possible action plans and recommendations for the projects in terms of BIM suitability; and (c) to generate a printable report for the projects. The KBDSS would enable SMEs to evaluate BIM suitability based on the developed SDSI in a simplified and user-friendly manner. The essence of the system is to support suitability decisions and is not designed to take a dominative role in making decisions for the users [48]. It aims to evaluate the construction projects and provides information that would improve the decision-making process of the users [48]. The KBDSS was developed using the Microsoft Visual Basic for Applications which is an integrated development environment (IDE) that enables coding, testing, and implementation of programs. It was employed due to the following reasons: (i) it is a powerful tool and the most widely used in enterprise applications [45]; (ii) the targeted end-users are SMEs in developing economies; thus, the Microsoft Visual Basic (VBA) provides a simplified but comprehensive solution [49]; and (iii) the software is affordable for the SMEs and most of the SMEs are familiar with its usage. Also, it does not require a separate update as it is integrated with the Microsoft Excel program [79].

4.4.1 System Architecture

The system consists of three components which are the knowledge base, a graphical user interface (GUI) and a decision support engine (DSE) as shown in Fig. 3.

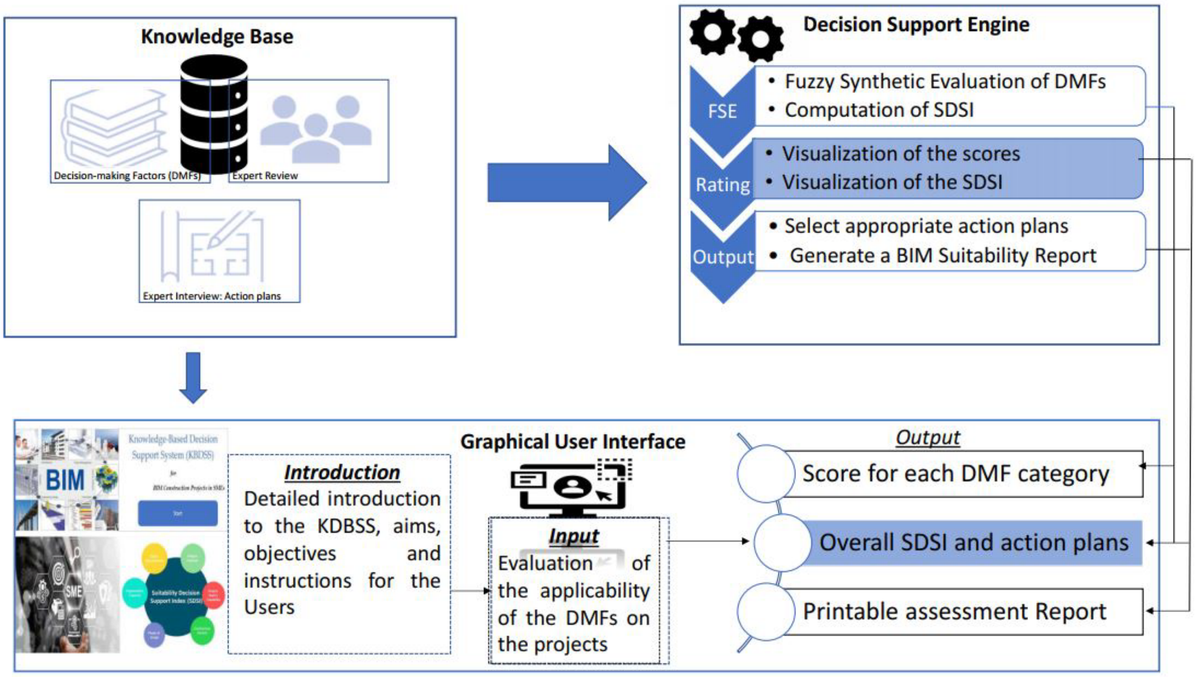

Fig.3. System Architecture of the proposed KBDSS

4.4.1.1 Knowledge Base

This is a database of knowledge derived via literature review and expert interviews. An in-depth literature review and expert review were employed to highlight action plans to improve the suitability of projects for BIM in SMEs. The action plans were categorised into 3 groups: the first group is to improve a decision-making factor from a very low level to a medium level, the second group is to improve a DMF from a low level to a high level and the last group is to improve a DMF from a medium level to a very high level. The compiled action plans are shown in Table 8.

4.4.1.2 Graphical User Interface

This provides interaction between the end-users and the KBDSS. It consists of interfaces for the homepage, introduction, evaluation, SDSI result, and final report generation interface. The Homepage interface is as shown in Fig. 3, while the introduction interface presents the aim of the KBDSS and requires the user acknowledgement as shown in Fig. 4.

Table 8

Action plans to improve the decision-making environment of the SMEs

DMFs	**Action plans for improvement**		
	1 (Very low → Medium)	**2 (Low → High)**	**3 (Medium → Very High)**
Contractual factors (CF) Category			
Design-Build	Highlight the setbacks of employing other procurement routes to the client or client's representative(s).	Brief the client or client's representative(s) on the importance of employing the design and build procurement method and its effect on project delivery	Encourage the client or client's representative(s) to adopt design and build procurement for the project delivery
Quality and clarity of contract conditions	Consider checking through the contract conditions	Highlights ambiguous conditions that are not explicit	Present the consequences and the implications of the contract conditions. Provide alternative statements and clauses where necessary in tandem with standard
Client requirements (CR) Category			
Request from client to use BIM	Prepare a brief on the importance of BIM and the benefits of implementing BIM to the client or client's representative(s)	Present the tangible benefits of implementing BIM to the client or client's representative(s)	Ensure the client or client's representative(s) is aware of the implications of requesting BIM usage on the project.
Client involvement in the project	Brief the client or client's representative(s) on the need for involvement	Ensure there is a clear understanding of client or client's representative(s) involvement on the project	Maximize the benefits of client or client's representative(s) involvement as necessary
Type of client (Public, Private, Mixed, etc)	Understand the client or client's representative(s) perspective on the project	Ensure there is mutual understanding between the client or client's representative(s) and parties involved	

Design control responsibility of the client	Brief the client or client's representative(s) on design control responsibilities	Ensure there is a clear understanding of design control responsibility of the client or client's representative(s)	Presents the implications of client or client's representative design control on the project delivery
Organization's Capacity (OC) Category			
Experience on previous similar projects	Evaluate the projects peculiarities and how the project differs from current and past projects	Examine the similarities of the projects to current and past projects	Identify similar projects and learn from the project executions. Engage employees with experience on such projects
Available workforce	Recruit the staff with knowledge and skills	Employ sufficient qualified staff with knowledge, skills, and expertise	Employ sufficient qualified staff with knowledge, skills, and expertise about BIM implementation
Project Features (PF) Category			
Total project construction cost	Explain the feasibility of adopting BIM on small projects	Explain the feasibility of adopting BIM on small projects and highlight the benefits	
Political, social, economic and cultural sensitivity	Not applicable	Not applicable	Provide a feasibility report for the project. Conduct sensitivity analysis of different political, social, economic and cultural 'what-if' scenarios
Complexity of design (in terms of building shape)	Not applicable	Not applicable	Ensure the project are designed to available standards. Ensure the project execution is feasible
Availability of information and data	Examine the available information and data for the project. Extrapolate data from similar past projects	Make good use of the available information and data towards the successful delivery of the project.	
Clarity of project scope	Review the project goal, deliverables, tasks and deadline		Break the project scope into smaller components and with alternatives. Provide more resources and improve communication link between all parties involved
Project type	Not applicable		Provide feasibility report for the project.

Project Team (PT)'s capability to use BIM Category			
Project manager's interest and willingness to adopt BIM	Provide ad hoc BIM training for the project management team	Provide periodic training for the staff to update their knowledge and skills relating to BIM	Provide regular training for the staff to maintain their high-level knowledge and skills relating to BIM
Project team's composition (diversity and quantity)	Not applicable	Not applicable	Maximize the benefit of diversity in the project team and strategize for effective collaboration
Site engineers' interest and willingness to adopt BIM	Provide ad hoc BIM training for the site engineer's team	Provide periodic training for the staff to update their knowledge and skills relating to BIM	Provide regular training for the staff to maintain their high-level knowledge and skills relating to BIM
Design firm's use of BIM	Set minimum BIM usage on the project	Client or client's representative should request for BIM design	Provide incentive and support for the design firm in BIM usage
Subcontractors' capability in using BIM tools	Set minimum BIM requirements for Subcontractors to be engaged on the project	Provide ad hoc BIM training for the subcontractors	Provide incentive and support for the subcontractors in implementing BIM on project
Phase of Usage (PU) Category			
Planning and Preliminary Design	Not applicable	Present the benefits of adopting BIM at early stage	
Detailed Design	Present the benefits of BIM to detailed design	Present the benefits of BIM to detailed design	Encourage the design team to adopt BIM across board
Construction phase	Encourage usage of BIM during the construction Phase	Provide resources to adopt BIM in the construction phase	Provide incentives for BIM usage in construction phase and request for as-built BIM model

Fig. 3. Homepage of the proposed KBDSS

The evaluation interface presents each DMFs per group per page for ranking using a 5-point Likert scale with a radio point, it informs the user when one of the DMFs is/are unevaluated and provides further information for the DMF via 'Tip Text' that will be shown when the cursor is on the DMF. Fig. 4 shows the introduction and evaluation interfaces with the 'Tip Text' features to improve the user's experience.

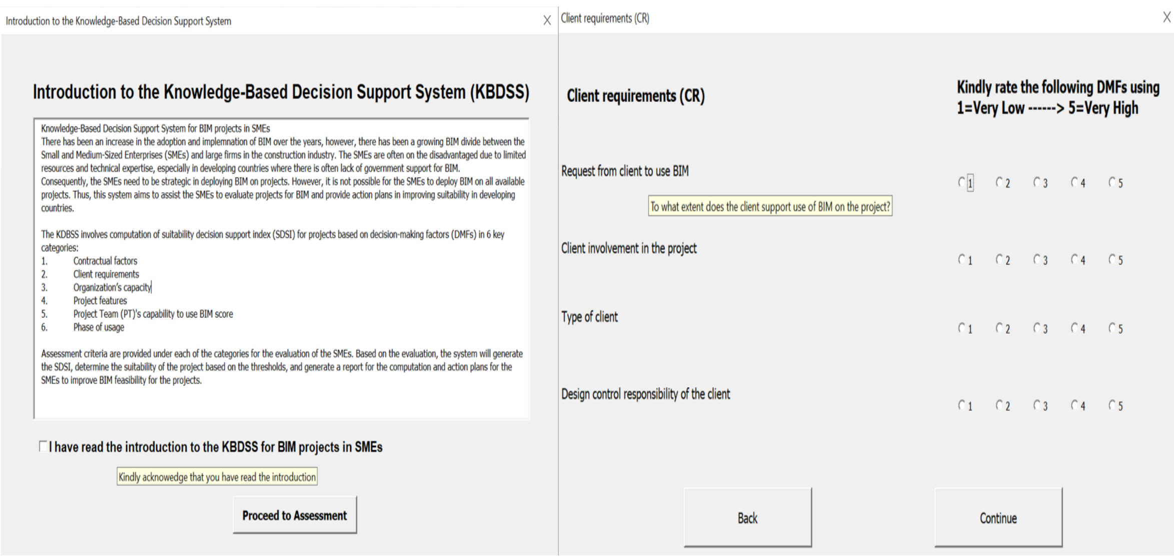

Fig. 4. Introduction and evaluation interface

4.4.1.3 Decision Support Engine (DSE)

The DSE transforms the input for the evaluation of each DMFs and allocates a score for each group based on the developed SDSI and sends a command for visualization of the score based on assigned thresholds. Furthermore, the DSE allocates action plans for the user from the repository in the knowledge base per the input for the DMFs that have been coded via the *if-then* conditional statement. Lastly, after visualization of the SDSI, the system will provide the options of generating the complete project report which will entail the SDSI and the action plans.

4.4.1 Validation of the developed KBDSS

Two construction projects were used as for case testing to validate the developed KBDSS. The projects were handled by SMEs in the study area and have contrasting features.

Case Study A

The project is a residential building project (Duplex) located in the eastern part of Nigeria and belonging to a private client. The project duration was 2.5 years and implemented BIM for planning, preliminary design, detailed design and partially for the construction phase. The project was commissioned and hand-over to the client in 2020.

The project was assessed via the developed KBDSS to determine the suitability of the project for BIM by sending the KDBSS as a Macro-Enabled Workbook to the SME firm that handled the project. The post-adoption evaluation for BIM suitability aims to assess how well the KDBSS can determine suitability. The SDSI computed is as shown in Fig. 5 while the final report generated is shown in Fig. 6.

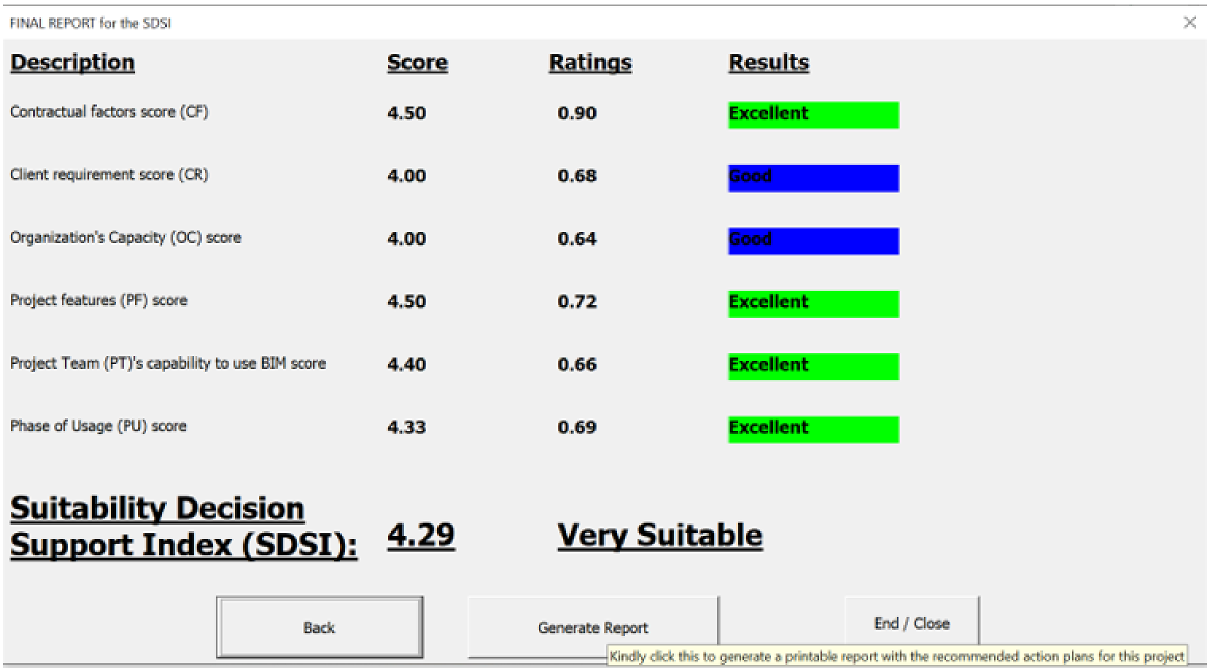

Fig. 5. Computed SDSI for Case Study A during the validation process

BIM Suitability Decision Support Report for SMEs Project

Project Name: **Case Study A**

	Score	VL	L	M	H	VH	Rating	Result
Contractual factors score (CF)	4.50						0.90	Excellent
Client requirement score (CR)	4.00						0.68	Good
Organization's Capacity (OC) score	4.00						0.64	Good
Project features score	4.50						0.72	Excellent
Project Team (PT)'s capability to use BIM score	4.40						0.66	Excellent
Phase of Usage score	4.33						0.69	Excellent

Suitability Decision Support Index (SDSI)

The index ranges from 0 to 5

Disapprove for BIM: SDSI ≤ 2.5
Not suitable: SDSI ≤ 3.00
Neutral: SDSI ≤ 3.5.00
Suitable for BIM: SDSI ≤ 4.00
Very Suitable: SDSI ≤ 5.00

Suitability Decision Support Index (SDSI): 4.29 Very Suitable

Action plans for consideration to improve the suitability of the project

Contractual factors score (CF)	
Design-Build	Encourage the client or client's representative(s) to adopt design and build procurement for the project delivery
Quality and clarity of contract conditions	Present the consequences and the implications of the contract conditions. Provide alternative statements and clauses where necessary in tandem with standard
Client requirement score (CR)	
Request from client to use BIM	Ensure the client or client's represntative(s) is aware of the implications of requesting for BIM usage on the project.
Client involvement in the project	Ensure there is a clear understanding of client or client's representative(s) involvement on the project
Type of client	Excellent
Design control responsibility of the client	Presents the implications of client or client's representative design control on the project delivery
Organization's Capacity (OC) score	
Experience on previous similar projects	Identify similar projects and learn from the project executions. Engage employees with experience on such projects
Available workforce	Employ the sufficient qualified staff with knowledge, skills, and expertise about BIM implementation
Project features score	
Total project construction cost	Excellent
Political, social, economic and cultural sensitivity	Provide feasibility report for the project. Conduct sensitivity analysis of different political, social, economic and cultural 'what-if' scenarios
Complexity of design (in terms of building shape)	Ensure the project are designed to available standard. Ensure the project execution is feasible
Availability of information and data	Excellent
Clarity of project scope	Excellent
Project type	Provide feasibility report for the project.
Project Team (PT)'s capability to use BIM score	
Project manager's interest and willingness to adopt BIM	Provide regular training for the staff to maintain their high-level knowledge and skills relating to BIM
Project team's composition (diversity and quantity)	Maximize the benefit of diversity in the project team and strategize for effective collaboration
Site engineers' interest and willingness to adopt BIM	Provide regular training for the staff to maintain their high-level knowledge and skills relating to BIM
Design firm's use of BIM	Provide incentive and support for the design firm in BIM usage
Subcontractors' capability in using BIM tools	Provide ad hoc BIM training for the subcontractors
Phase of Usage score	
Planning and Preliminary Design	Present the benefits of adopting BIM at early stage
Detailed Design	Encourage the design team to adopt BIM across board
Construction phase	Provide resources to adopt BIM in the construction phase

Fig. 6. Generated Final Report for Case Study A

Case Study B

Case study B is a new project (an institutional project) located in the southwestern part of Nigeria and belongs to a public client. The proposed project duration is 3 years, and an open tendering was adopted for its procurement. The KBDSS was sent to the coordinating firm (Architectural firm) appointed by the client to evaluate the suitability of the project for BIM suitability. Fig. 7 shows the interface for the computed SDSI, and Fig. 8 shows the final report.

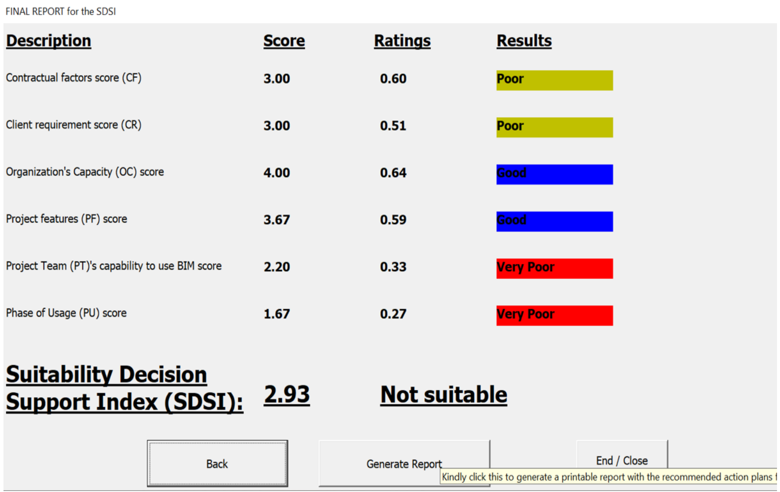

Fig. 7. Computed SDSI for Case Study B during the validation process

BIM Suitaibility Decision Support Report for SMEs Project

Project Name: **Case Study B**

	Score	VL	L	M	H	VH	Rating	Result
Contractual factors score (CF)	3.00						0.60	Poor
Client requirement score (CR)	3.00						0.51	Poor
Organization's Capacity (OC) score	4.00						0.64	Good
Project features score	3.67						0.59	Good
Project Team (PT)'s capability to use BIM score	2.20						0.33	Very Poor
Phase of Usage score	1.67						0.27	Very Poor

Suitability Decision Support Index (SDSI)

The index ranges from 0 to 5

Disapprove for BIM: SDSI ≤ 2.5
Not suitable: SDSI ≤ 3.00
Neutral: SDSI ≤ 3.5.00
Suitable for BIM: SDSI ≤ 4.00
Very Suitable: SDSI ≤ 5.00

Suitability Decision Support Index (SDSI): 2.93 Not suitable

Action plans for consideration to improve the suitability of the project

Contractual factors score (CF)	
Design-Build	Highlight the setbacks of employing other procurement routes to the client or client's representative(s).
Quality and clarity of contract conditions	Present the consequences and the implications of the contract conditions. Provide alternative statements and clauses where necessary in tandem with standard
Client requirement score (CR)	
Request from client to use BIM	Prepare a brief on the importance of BIM and benefits of implementing BIM to the client or client's representative(s)
Client involvement in the project	Maximize the benefits of client or client's representative(s) involvement as necessary
Type of client	Ensure there is mutual understanding between the client or client's representative(s) and parties involved
Design control responsibility of the client	Ensure there is a clear understanding of design control responsibility of the client or client's representative(s)
Organization's Capacity (OC) score	
Experience on previous similar projects	Identify similar projects and learn from the project executions. Engage employees with experience on such projects
Available workforce	Employ the sufficient qualified staff with knowledge, skills, and expertise about BIM implementation
Project features score	
Total project construction cost	Excellent
Political, social, economic and cultural sensitivity	Not applicable
Complexity of design (in terms of building shape)	Ensure the project are designed to available standard. Ensure the project execution is feasible
Availability of information and data	Excellent
Clarity of project scope	Excellent
Project type	Not applicable
Project Team (PT)'s capability to use BIM score	
Project manager's interest and willingness to adopt BIM	Provide ad hoc BIM training for the project management team
Project team's composition (diversity and quantity)	Maximize the benefit of diversity in the project team and strategize for effective collaboration
Site engineers' interest and willingness to adopt BIM	Provide ad hoc BIM training for the site engineer's team
Design firm's use of BIM	Set minimum BIM usage on project
Subcontractors' capability in using BIM tools	Set minimum BIM requirements for Subcontractors to be engaged on the project
Phase of Usage score	
Planning and Preliminary Design	Not applicable
Detailed Design	Present the benefits of BIM to detailed design
Construction phase	Encourage usage of BIM during the construction Phase

Fig. 8. Generated Final Report for Case Study B

5. Discussion of study findings

5.1 Determinants of BIM Implementation on SME projects in developing economies.

The top-rated DMFs which are considered 'very important' are '*total project construction cost*' (PF1), '*client request for BIM use'* (CR1), and '*design firm's use of BIM'* (PT4). This is similar to the findings of Won, et al. [30], however, the study does not consider total project construction cost as a DMF. The aforementioned factors could be a result of the SMEs having limited access to resources especially in developing economies, thus, BIM is often perceived to be more applicable to big projects per Hosseini, et al. [13]. Lam, et al. [53] opined that BIM is applicable to projects of all values in SMEs, however, this does not resonate with the findings of this study. A possible explanation could be that BIM is applicable to all projects in the SMEs of developed economies but risky in low-value pilot projects in developing economies; after expertise has been achieved it could be applied to all projects. Panellist 3 submitted during the interview that '*We prefer to use BIM on our big project(s) and especially when the design firm had used BIM, it would be easy to collaborate with such firms*' and corroborated by Panellist 4 '*It does not make business sense to use of BIM on small projects as pilot projects for the SMEs, medium-sized and big projects are much better*'. The client request for BIM use is also deemed very important because it would necessitate the use of BIM on the project as the '*…he who pays the piper calls the tune'* (Panellist 4). Albeit these DMFs are deemed important, however, there has been lack of request for BIM from the clients and most of the design firms are not using BIM, which often makes adoption by the SMEs difficult.

Complex projects in terms of design and shape are easier to execute in BIM than the traditional approach which is in tandem with Won, et al. [30]. Also, clarity of scope will affect the decision to adopt BIM as it is riskier to adopt a risky innovation in SMEs when the scope is vague [39]. Similarly, when the SMEs have worked on a similar project using the traditional approach, implementing BIM on such a project would be easier because of their experience, this is in agreement with the findings of Won, et al. [30]. The phase of usage is ranked in the order of planning and preliminary design, detailed design, and construction, this shows that the SMEs in developing economies prefer to make use of BIM from an early stage of the project. Lam, et al. [53] opined that early involvement would lead to reaping more benefits and improves collaborative engagement which would impact the project performance.

The '*operation and maintenance'* (PU4), '*location of the projects'* (PF6), and '*current workload*' (OC2) are rated 'somewhat important' factors. Albeit the operation and maintenance phase stand to gain more from the rich BIM models, however, the adoption in this phase has been slow. This is particularly true in the context of developing economies where the FM sector is still at the infant stage and most extant projects did not make use of BIM during design and construction [80]. It leaves the FM sector no other choice than to return to the traditional approach of managing the building because developing BIM for existing BIM is still a growing area of research that is capital intensive for FM sector in developing economies [80]. Also, the location and current workload are not major DMFs when the other factors are favourable. Panellist 9 added '*The location is not important compared to other factors, for instance, if the client requested for BIM use on a project, the location is of little relevance as we would have taken cognisance of this during the preliminary stage…*'. Similarly, Panellist 13 opined that '*…in house BIM experts would be engaged on a pilot project or outsourced where there are no in-house experts*', which implies that the current workload of the SMEs is not of high importance compared to other factors.

5.2 FSE outcomes and implications

Top-ranked DMFs in each of the categories are subsequently used for further analysis in developing the SDSI. In the project features category, '*total construction cost'* (PF1), and '*complexity of the design'* (PF3) are the most important factors whilst the '*location of the project'* (PF6) is the least ranked and dropped from further analysis. The client category logically reveals that request from the client to use BIM (CR1) and the '*design control responsibility of the client*' (CR4) are the most important factors whilst the '*type of client*' (CR2) is the least ranked factor. This shows that the type of client is not of significant importance in deploying BIM when the client has requested for BIM use. This reflects the findings of Lam, et al. [53] that both private and public clients are significant. However, all the factors in the client requirement category are deemed key and useful for developing SDSI. The experience on previous projects and available workforce were ranked as the most and least important factor in the organization's capacity category respectively whilst OC2 '*current workload in hand*' is dropped. The phase of usage category is in concordance with the finding of Lam, et al. [53] that the Design phase (PU1 and PU2) is the most important phase for the implementation of BIM in SMEs. Similarly, '*clarity of contract conditions*' (CF5) and '*Design-Build*' (CF1) are the most important factors in the contractual factors category. This shows that design-build procurement is the best route to implement BIM in SMEs compared to '*Design-Bid -Build*' (CF2).

In summary, client requirements and cost of the construction projects are major determinants in SMEs coupled with the phase of usage, procurement route and project team capability. The findings underscore the preferences of implementing BIM at an early stage and through the design-build procurement as compared to the design-bid-build route that is common in developing economies. Although the Integrated Project Delivery (IPD) route is the best route for easy implementation of BIM, it is farfetched in the developing economies and a pragmatic approach would be to make use of the design and build route. The project team's capability is also highlighted as an important determinant to reduce resistance to change. Lastly, the SDSI was developed from the DMFs and presented in a linear form. The SDSI revealed that contractual factors are the most significant factors in determining BIM usage followed by client requirements. This corroborates extant studies [29,13] that the major challenges of BIM implementation in SMEs stem from a lack of enabling contractual conditions and a lack of client requests.

5.3 Knowledge-based decision support system for construction projects in SMEs

The KDBSS was developed via the integration of an expert system that was built based on literature and expert interviews with the decision support engine that was built based on an expert survey and FSE. The developed system was subsequently validated with a completed project and a new project in SMEs. Fig. 9 shows the comparison of the two case studies employed in the validation. The post-construction evaluation of project A revealed that the developed KBDSS aligns with the project decision of implementing BIM on the project. Similarly, the KBDSS reported the unsuitability of project B for BIM which also aligns with the lack of BIM implementation on the project. Beyond automating the computation of the SDSI, this system provided the SMEs with a tool to evaluate BIM suitability from the perspective of decision-making process and revealed areas for improvement in the different DMF categories. For instance, even though the organisation's capacity for the two projects was rated similarly, the decision and suggested outcomes for these two projects are different.

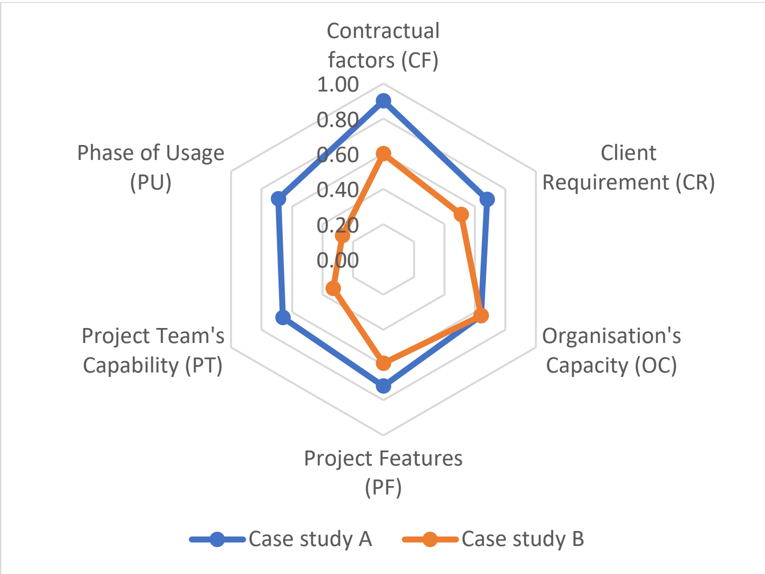

Fig. 9. Comparison of the Case Studies

This serves as an edge and a significant contribution to extant knowledge-based decision support systems in the AEC industry where there is often no differentiation between projects with the same computed index in the decision support system. For instance, if the final computed SDSI for two projects is 4.50, extant decision support systems would provide the same recommendations and decisions for the projects. However, different action plans would be provided in this proposed KBDSS which are more useful to support decision making and benchmarking for decision-makers.

6. Conclusions

Several factors and conditions must converge to render BIM suitable for SMEs seeking to implement BIM on their projects. However, there are no systematic approaches guiding this decision in SMEs and there is a prevalent perception of the unsuitability of BIM for SMEs' projects. Thus, this study examined the BIM suitability from a decision-making perspective by evaluating DMFs of BIM-based projects in the most disadvantaged SMEs. This is contrary to extant approaches of focusing on adoption/acceptance models to evaluate BIM usage. It conceptualized BIM suitability as a multi-criteria decision making and employed a mixed research approach to identify and evaluate the DMFs and developed a KBDSS for BIM-based projects in SMEs.

The major scientific contributions of this study are in two folds of conceptual and empirical contributions. Conceptually, this study explored the decision-making factors (DMFs) for BIM which are fundamentally different from critical success factors (CSFs) being explored in extant studies. It conceptualized BIM suitability from a decision-making perspective against the prevalent adoption/acceptance perspective which asummed suitability of the context as precondition. It further examined and consolidated the DMFs into categories (project features, client requirements, organization's capacity, phase of usage, and contractual factors) for quantitative evaluation and provided metrics to show the relative importance of these categories in the research context. Empirically, hitherto, no systematic approaches are guiding the SMEs in evaluating BIM suitability for SMEs' projects. Oftentimes, SMEs do not even consider BIM on their projects because of their intuitioned perceptions that BIM is unsuitable for their projects which is based on the lack of a clear guide for evaluation. This study provided an effective tool (KBDSS) based on multi-criteria affecting BIM suitability for projects. Thereby providing an empirical tool for SMEs that were previously not considering BIM and support for SMEs that were previously considering BIM (but without a systematic approach). Also, this study provided solid empirical support for BIM in SMEs under the right contextual conditions in developing economies which are often facing compounded challenges. Thus, right project features, client requirements, organization's capacity, phase of usage and contractual factors would improve BIM propensity in these SMEs.

Furthermore, this study has significant managerial, theoretical and policy implications. The findings underscore that implementation of BIM in SMEs is possible and can be supported beyond anecdotal evidence with empirical evidence. It implies that managers in SMEs should focus on influencing the decision-making environment that would encourage and improve BIM suitability such as contractual factors, client requirements, and the project team's capability. Also, SME managers should not rush to implement BIM on all construction projects but on suitable projects from which they will learn and gain expertise. This is because projects are of varying attributes and some are more suitable than others as revealed in this study. Theoretically, the consolidated integrated framework of decision-making factors would augment efforts to develop a technology suitability theory for digital technologies in construction. This implies that this study provides groundwork by proposing DMF categories for BIM suitability, further empirical studies can be conducted on other technologies/approaches to evaluate the DMFs affecting their suitability for projects. Thus, the theory of technology suitability could be proposed and validated based on this study and subsequent empirical studies. This would be of utmost importance in leveraging the right technology for the right projects and improving project success in the construction industry.

As regards the policy implications, although democratizing accessibility to BIM has been a common theme in policy, there is still a BIM divide between SMEs and large firms, and between developed and developing economies. The findings of this study imply that there is little or no effect of policy on current BIM usage in developing economies, especially in SMEs. The government's BIM mandate is not considered a DMF (removed based on unanimous agreement during expert review) because there are no existing government framework and policies to support BIM proliferation. The findings also imply the need for BIM localization as DMFs in a particular context may not be considered as DMFs in another context. Thus, there exists a pressing need for policies supporting BIM in SMEs and these policies should be context conscious. Lastly, albeit this study focused on developing economies, the proposed research approach can be applied to identify context-specific DMFs in developed economies to aid SMEs. Also, with more BIM-based projects in SMEs, artificial intelligence (AI)-based models can be developed and validated for predicting BIM suitability in future construction projects and with multi-user function. Further studies could also be carried out on technology suitability on projects towards consolidating a technology suitability theory.

Research Data

All data, models or code that support the findings of this study are available from the corresponding author upon reasonable request.

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