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Developing project evaluation models for smart sustainable practices initiatives in construction projects: A case of Nigeria and Hong Kong

Abstract

Purpose: The purpose of this paper is to identify the key facilitating factors for smart sustainable practices (SSP) and develop a project evaluation model (PEM) for SSP implementation in Nigeria and Hong Kong. SSP is coined from the integration of digital technologies such as Building Information Modelling (BIM) to facilitate sustainability.

Design/methodology/approach: The study employed a quantitative research design approach using empirical questionnaire surveys to solicit the opinions of 69 and 97 construction practitioners in Nigeria and Hong Kong. Purposive and snowball sampling techniques were used to identify the potential survey respondents. The fuzzy synthetic evaluation technique was used to develop the PEMs.

Findings: The findings revealed that adequate knowledge and technical expertise of the SSP processes are critical to enhancing its implementation in Hong Kong and Nigeria; as well as the provision of training programs for cross-field specialists in smart and sustainable initiatives. Meanwhile, the study's findings revealed that for an SSP-enabled construction project, its project performance is mostly influenced by the client's satisfaction level and the early involvement of the project teams. However, in Nigeria, effective partnership, which considers the involvement of green-conscious project stakeholders, a supportive organizational structure is a key influencing factor.

Practical implications: Construction stakeholders in developing and developed countries can utilize the PEMs to determine and track SSP initiatives implementation in building projects in a reliable and practical way. The study also provides project teams with a checklist of key factors to consider when digital tools are employed to facilitate sustainability in construction works.

Research limitations: The study's results are limited to the Nigeria and Hong Kong construction industries.

Originality/value – No tool has been developed for evaluating SSP initiatives at the project level in the construction industry. Using case studies of Hong Kong and Nigeria, PEM indices were developed to measure and track SSP implementation in construction projects. More so, the proposed PEMs provide a common basis to compare the implementation levels of SSP in construction projects.

Keywords: BIM; construction projects; fuzzy synthetic evaluation; smart sustainable practices; Nigeria; Hong Kong

1. Introduction

Globally, there has been increased attention and growing initiatives by international and non-governmental organizations, environmental groups, countries, and other stakeholders to stem the tide of climate change, greenhouse gas emissions, global warming, waste generation, among others. The construction industry itself is a major contributor to these environmental issues. As buildings are constructed yearly, more energy is consumed, and there are increased carbon emissions (Tam *et al.*, 2019). Also, enormous resources such as materials and energy are expended in producing a building product (Ljungberg, 2007), most of which goes for its production and transportation than what is used for such product itself.

For instance, buildings in the United States contribute 48% of its total greenhouse gas (GHG) emissions, while construction wastes constitute a larger percentage of Hong Kong's environmental waste (Wong and Fan, 2013). Generally, the global contributions of the construction industry to these sustainability challenges stand at 40% for solid waste generation (UNEP, 2011), 32% for energy consumption (IPCC, 2007), and 35% for material usage (Ürge-Vorsatz *et al.*, 2007).

Due to the growing concerns about these environmental challenges, green buildings and sustainable practices implementation (Olawumi and Chan, 2020b) has emerged as a key project objective in the construction industry. Also, technological approaches are being advanced as an enabling tool towards implementing sustainable principles in the building environment (Blagojevic and Tufegdzic, 2016). For instance, BIM can be used to embed relevant sustainable design information to improve the building performance, efficiency, and cost. A study by Wong and Fan (2013) shows BIM is useful in selecting the best design solutions that offer better energy and resource consumption. In Europe, the European Commission has proposed using smart systems to drive sustainable development (Russo *et al.*, 2016), one of which is investment in the 'Lighthouse' initiative, which seeks to facilitate smart-sustainable development in European cities (European Union ODP, 2018).

In some countries, there has been the development of green building rating systems (GBRS) to facilitate the assessment and rating of building projects and guide developers and project teams on aspects to focus on in delivering a green building project. For instance, we have BEAM Plus in Hong Kong (HKGBC, 2019), the BSAM Scheme in Nigeria (Olawumi *et al.*, 2020), BREEAM, and LEED in the UK and USA (BRE, 2016; USGBC, 2018), respectively. Also, there has been the application of BIM software for energy analysis, daylighting, and assessing building sustainability performance (Motawa and Carter, 2013). Other applications of technologies for smart-sustainable practices implementation include the use of radio frequency identification (RFID) and BIM (Fang *et al.*, 2016) for indoor localization; BIM for energy simulation (Oloke, 2021), and most recently, blockchain technology is being adopted to facilitate sustainability in the construction supply chain (Shojaei *et al.*, 2019). Also, Dall'O' et al. (2020) explored the integration of Green-BIM and city information modelling to design and manage buildings and infrastructures to achieve sustainability and smart schemes. Based on the review of several digital technologies used for sustainability implementation in construction projects, BIM is mostly adopted for its application. One of the reasons for the increased use of BIM for SSP implementation; apart from its adoption rate (which is higher than most other digital tools used in the construction industry) – is that BIM produces better useful data along with relevant information in the forms of visualizations and simulations (Motawa and Carter, 2013).

Hence, smart-sustainable practices are considered 'digital technocentric' approaches to facilitating sustainable principles, green and sustainable buildings or cities, and improving the overall construction process (Martin *et al.*, 2019; Olawumi and Chan, 2019a). Along with this perspective, Banihashemi *et al.* (2017) utilized the innovation diffusion theory to identify key drivers that affects the integration of sustainability for project management practices in developing countries; while Antón and Díaz (20140 and Lu *et al.* (2017) explored that application of BIM for green buildings. Also, Olawumi and Chan (2019b) developed a benchmarking model to assess BIM implementation in developing countries, while Tai et al. (2020) evaluated key criteria that influence BIM adoption in China.

Moreover, Zhao *et al.* (2016) developed a risk assessment model for green building projects in Singapore, which share similar characteristics with Hong Kong; and Aghimien *et al.* (2020) examined the challenges of smart city development in developing countries in Nigeria. However, no studies have considered how to measure the level of application of SSP in construction projects and the influence of key facilitating factors on SSP implementation. Having a PEM metric system in place to measure SSP implementation will guide construction practitioners on identifying the requirements and factors that affect its application and how to move toward higher adoption of SSP initiatives in construction projects.

Given the above, this paper aims to address these research gaps by identifying and assessing the key facilitating factors and developing a project evaluation model (PEM) for smart sustainable practices implementation in Nigeria and Hong Kong. The project evaluation models for Nigeria and Hong Kong are developed in this study using the fuzzy synthetic evaluation (FSE) technique. The study's findings will present construction practitioners in both countries with a checklist of key facilitating factors for SSP implementation, which can be useful as a consultative tool to drive green building development. More so, the proposed PEM in this study will provide project teams, clients, and other critical stakeholders with a metric system in measuring the level of application of SSP in construction projects. More so, the proposed PEMs provide a common basis to compare the implementation levels of SSP initiatives construction projects. It is expected that the practical deliverables of this study will improve the adoption and implementation of smart-sustainable practices in Nigeria and Hong Kong.

Moreover, in the extant literature and practice, in assessing the global construction industry, two main dimensions are usually employed – either based on (i) classification by regions or (ii) level of development (developing or developed countries). The level of development is more of a homogenous classification that has gained traction in usage among authors and international organizations such as the World Bank and International Monetary Fund. Some key indices used to classify countries into developed and developing countries include countries which share similar: (i) macroeconomic environment (Austin, 2002; Toor and Ofori, 2008; Saini and Singhania, 2018); (ii) socio-political conditions (Austin, 2002; Saini and Singhania, 2018); (iii) human capital and technological gap (Toor and Ofori, 2008; Goswami and Saikia, 2012; Alam and Shah, 2013). Moreover, World Bank (2020) used the Gross National Income per capita of US$ 12,536 or less to classify countries into developing countries and vice versa. Hence, these indices were used to classify Nigeria and Hong Kong in this study and form the basis for recommending the possible application of the proposed smart sustainable practice PEMs to other developing and developed countries that share these key indices with Nigeria and Hong Kong.

Scope. Hong Kong was used as a case study in this research (apart from being a financial hub in the Asia region); it is also one of the very few countries globally which have advanced the use of BIM (Chan *et al.*, 2019a) and sustainability in the construction industry. For developing countries, especially in Africa, Nigeria has the largest economy (Terwase *et al.*, 2014) and the biggest construction market, making it suitable as a focal point for investigation. Also, there is a growing awareness of BIM and sustainability practices in the country. Moreover, BIM being the most popular digital technology adopted globally in the construction industry (Jung and Lee, 2015), was considered the prime digital tool in the context of "digital technology" in developing the PEMs for smart-sustainable practices in this study.

2. Background

2.1 Overview of smart sustainable practices

The concept of sustainability is widely accepted across various spectrums of stakeholders. However, there are divergent opinions regarding how to apply sustainable practices in the built environment, especially the construction industry. One of the reasons advanced for the ununiformed approach to sustainability is its complexity (Clark, 2002) and because it involves a mix of conceptual and quantitative metrics (Ekins *et al.*, 2003; Mahmoud *et al.*, 2019). As a result, environmental sustainability received much concern from developed nations while socio-economic sustainability criteria are given preference in developing countries (Ahmad and Thaheem, 2017). Moreover, this is also evident in the various sustainability standards and guidelines developed in these countries – for example, the GBRS available in countries such as the United States, United Kingdom, Hong Kong, Australia, and the like are focused on building-related environmental issues (Olawumi *et al.*, 2020).

Sustainability concepts in the built environment are usually associated with terms such as green buildings (Ahmad and Thaheem, 2017), sustainable design and construction (Jalaei and Jrade, 2015), zero-carbon buildings (Gupta *et al.*, 2014), and the like. These sustainable initiatives in buildings have helped mitigate some environmental and socio-economic problems associated with the conventional building process (Maleki and Zain, 2011). Although sustainable development is multidimensional and integrated in scope (Slimane, 2012), its application in built assets and infrastructure has mostly been unidirectional. More so, the construction industry faces problems in delivering green and sustainable projects due to a mirage of several factors (Zhao *et al.*, 2015; Shi *et al.*, 2016).

As a result, digital technologies and tools are being advanced to help solve the challenge involved in delivering green building projects and infrastructure (Martin *et al.*, 2018) and facilitate the integration of sustainable designs. This development has brought about the concept of smart-sustainable practices, which is fast becoming a key driver for facilitating green building and other sustainable initiatives in the built environment (De Jong *et al.*, 2015). The digital technocentric approach to the delivery of sustainable initiatives in construction projects can also help facilitate an automated construction process, digitalized supply chains, and smart buildings and cities.

A few digital technologies have been adopted in extant literature to integrate SSP in practices. For instance, Jeong *et al.* (2016) explored the implementation of BIM and simulation tools to incorporate sustainability principles in building designs and construction projects as well as incorporating the future needs of end-users. Giglio (2010) stressed the capabilities of BIM to be deployed across the building stages for energy analysis, data capture, and visualizations, and in cloud-based environments. Hence, this offers the clients and project team a cost-advantage because the data from a previous building analysis at an earlier stage could be useful at a later stage without a need for reinvestment. Meanwhile, Rivera *et al.* (2015) attempted to investigate the intersections of using technological solutions for smart-sustainable initiatives. The study stressed the need for adopters to understand the lock-in effects and vulnerabilities associated with using digital tools for SSP and recommended that the adopted technologies be seen as a neutral facilitator that carries no implicit values (Rivera *et al.*, 2015).

The capability of BIM to aid in smart-sustainable initiatives lies in its nD functionality, especially the 7D BIM, which provides the best avenue to incorporate relevant sustainable designs and practices in building projects. Moreover, some studies envisioned that big data has future prospects of supporting the smart-sustainable initiatives in the built environment (Bibri, 2019; Shukla and Mattar, 2019). Despite the benefits and prospects of adopting SSP initiatives in the built environment, adopters must factor in the related challenges associated with its implementation (Belli *et al.*, 2020). In contributing to the existing knowledge base of smart sustainable practices, the current study presents SSP project evaluation models that assist measure and keep track of its implementation.

2.2 Smart sustainable practices in Nigeria and Hong Kong

The city of Hong Kong has significantly made milestones in the areas of smart-sustainable practices compared to Nigeria. For instance, the BEAM Plus green building rating system was launched in 1996 in Hong Kong, and four green buildings were assessed the same year using the BEAM Plus (BEAM Society, 2021). Currently, the BEAM Plus has been used to assess more than 500 buildings in the city. Meanwhile, the first GBRS system in Nigeria was developed in the year 2019. Although it has been used to evaluate four building projects in the country (Olawumi and Chan, 2020a), it is yet to gain traction in usage among industry folks. Also, digital technologies such as BIM are being advanced in the city by industry and professional organizations such as the Construction Industry Council (CIC) and the Hong Kong Institute of Building Information Modelling (Chan *et al.*, 2019b).

Although BIM is still at its early stages of adoption in Hong Kong, it has found significant usage in mega projects like Hong Kong airport, the mass transit rail, and among private property developers (Wong *et al.*, 2009; Chan *et al.*, 2019b), and more recently in the first hybrid modular construction project in Hong Kong – “InnoCell.” These projects' success has enhanced the acceptance of SSP initiatives in the ‘eyes of the clients.’ Although the level of awareness of BIM in the Nigerian construction industry is quite above average, the usage rate does not commensurate (Hamma-adama *et al.*, 2018). As noted by Olawumi and Chan (2019a), the level of BIM implementation in a project has a significant resultant effect on the adoption of smart sustainable practices in such projects. Moreover, unlike in Nigeria, there is a government mandate to adopt BIM in public construction projects in Hong Kong. Its use is also currently high among the private sector players (Chan *et al.*, 2019b). Also, As promoted by CIC Hong Kong, there are some BIM standards for different construction works. Given the above, the adoption level of smart sustainable practices in both contexts varies – while it is low in Nigeria and other African countries, it is rated between medium-high level in Hong Kong (Jung and Lee, 2015; Olawumi and Chan, 2018).

Govada *et al.* (2020) reviewed the various efforts directed towards implementing smart sustainable practices in Hong Kong, including environmental policies in areas like green building, zero-carbon buildings, and smart technologies. Adopting these SSP initiatives is imperative in a densely compact city of over 7 million residents in less than 1200km2 land areas. However, the city is still lacking in areas like energy savings and recycling (Govada *et al.*, 2020). Furthermore, a comparative study of the SSP initiatives implemented in 14 global megacities was undertaken by Shmelev and Shmeleva (2019). In the comparative analysis, Hong Kong was ranked fifth behind major cities like Singapore and Sydney on environmental initiatives. Meanwhile, for economic initiatives, Hong Kong was ranked third behind Tokyo and London; however, as regards social and smart initiatives, Hong Kong was ranked outside the top-five megacities (Shmelev and Shmeleva, 2019). Moreover, a study by Chan and Marafa (2018) presented divergent results from that of Shmelev and Shmeleva (2019), in that the sampled Hong Kong residents opined that the city is performing “smarter” than “greener.” These studies show that although Hong Kong is pulling its weight in the global SSP initiatives, there are still many improvements to be made. Hence, developing a PEM to measure and track smart sustainable initiatives in Hong Kong is imperative.

Meanwhile, an analysis of the SSP initiatives in selected countries by Estevez *et al.* (2016) shows that Nigeria is still a long way from adopting these initiatives with just one smart-sustainable initiative implemented in the country, compared to four in neighboring Ghana as well as in Kenya. The US, Korea, and China topped the list with 11, 6, and 5 initiatives, respectively. Hence, Adamu *et al.* (2017) stressed the need for Nigeria’s cities to implement relevant SSP initiatives as the country faces an upsurge in urban dwellers (Antwi-Afari *et al.*, 2021) with its attendant environmental and social challenges. More so, similar to Hong Kong, Nigeria is also faced with issues such as environmental wastes and energy (Adamu *et al.*, 2017; Govada *et al.*, 2020) as well as transportation challenges. Sustainable transportation is a key assessment criterion in major GBRS like LEED, BREEAM, BEAM Plus, and the BSAM scheme (HKGBC, 2016; BRE, 2018; USGBC, 2018; Olawumi *et al.*, 2020). Meanwhile, Adamu *et al.* (2017) proposed ways in which Nigeria could achieve the smart-sustainable initiative, while Soyinka *et al.* (2016) investigated the applicability of using smart concepts to facilitate the implementation of sustainable practices in Lagos, a key commercial hub in Nigeria. Most African countries also face similar challenges as Nigeria, as captured by Lampreia *et al.* (2019) in the study’s review of challenges faced in Africa in implementing SSP initiatives.

2.3 Fuzzy synthetic evaluation

The fuzzy synthetic evaluation (FSE) technique was used in this study to develop the proposed project evaluation models for SSP implementation in Hong Kong. The study in developing the PEMs relies on data based on the survey respondents' perceptions, which are often subjective and ambiguous (Shan *et al.*, 2015). Hence, the application of fuzzy set theory using FSE to objectifies the survey respondents' judgement. The fuzzy set theory provides the capability to reduce issues relativity to ambiguity, uncertainty, and subjectivity in the decision-makers' judgement (Pedrycz *et al.*, 2010).

It also has an advantage over the artificial neural network technique as regards the precision of its resultant data (Liao *et al.*, 2019), as fuzzy methods use mathematical operators to quantify the available data (Zhao *et al.*, 2016; Aghimien *et al.*, 2020). It also utilizes linguistics variables to analyze subjective viewpoints which might occur in the decision-making process. More so, per (Xu *et al.*, 2010), FSE is very suitable for a decision-making process involving multiple stakeholders. Thus, the FSE approach is considered appropriate in developing the PEMs for SSP implementation in Nigeria and Hong Kong. Moreover, the FSE technique has found applications in the development of models and indexes in areas like green buildings (Zhao *et al.*, 2016), BIM (Liao *et al.*, 2019), project performance (Hu *et al.*, 2016; Osei-Kyei and Chan, 2018), among others. In general, the FSE technique's strength lies in evaluating data involving several variables across different levels. The subsequent section discusses the analytical approaches and equations adopted in employing the FSE technique in developing the PEMs for smart sustainable practices for Nigeria and Hong Kong.

3. Research methodology

A quantitative research design approach was employed in this study using empirical questionnaire surveys to aggregate construction practitioners' responses in Nigeria and Hong Kong and apply relevant statistical tools in developing the PEMs for smart-sustainable practices implementation. The overall research design for this study is illustrated in Figure 1. The questionnaire items are based on a shortlist of key factors adapted (*see* Table 1) from a previous study (Olawumi and Chan, 2020c), where the drivers of smart sustainable practices in the construction industry were examined from a global perspective. The reuse of an itemized list of factors is common in the literature, such as a study by Darko et al. (2018), who reused and adapted a list of measurement constructs from their previous studies for further analysis. Other instances are in the extant literature is a two-part research study published in Tsai et al. (2014) and Mom et al. (2014), in which the latter study is a continuation of the former research on BIM adoption in Taiwan.

Insert Figure 1

Moreover, for this study, taking into cognizance the guidelines provided by Cheng and Phillips (2014) in conducting such research work, the current study adopted a research question-driven approach, which involves recoding the original variables. The key differences in this study and those reported in Olawumi and Chan (2020c) are that the current study examined the key factors based on the context of two countries – Nigeria and Hong Kong, rather than a global perspective. Secondly, this study analyzed a set of survey data to develop a metric system to measure SSP implementation in Nigeria and Hong Kong. In contrast, the previous study focused on ranking the critical factors based on an inter-group comparison of key professionals worldwide. Thus, the current study differs in scope and objectives.

Insert Table 1

3.1 Demographics of the survey respondents

Selection criteria and sampling. An empirical questionnaire survey was conducted with experts in Hong Kong and Nigeria who have requisite practical knowledge and experience in sustainability practices or BIM adoption in construction projects. Nigeria and Hong Kong are chosen as the research area due to the authors' established contacts within these countries' construction industries. The respondents known to the authors were contacted directly via a purposive sampling approach, and other responses were obtained using the snowball sampling technique. For the snowballing sampling, practitioners' email addresses in government agencies and construction firms were gleaned from their organization websites. These respondents were sent personalized emails inviting them to participate in the survey if they have the requisite experience required to participate in the survey. The authors' established industry contacts were also requested to help in the further circulation of the survey forms within their professional circuits. Some of the emails sent to organizations were forwarded to the managers to help circulate them among relevant professionals in their company. Prior to distributing the questionnaire survey form, it was pretested to validate the questionnaire items and its relevance to the research objective.

Meanwhile, relevant information was solicited from the survey respondents, which was used to validate their relevant expertise in the subject matter, as illustrated in Table 2. The survey was conducted over six months. The respondents were also requested to rate their agreement on the significance of the key factors based on a five-point Likert scale (*1 = strongly disagree, 3 = neutral, and 5 = strongly agree*). About 50 percent of the survey forms were distributed by hand or via postal mail in Hong Kong, while the survey forms were distributed via email and other online platforms (such as network groups, Google form) for the Nigeria context. The respondents from Nigeria were mainly from key commercial cities like Lagos, Ogun, Abuja, Ibadan, and the like. Overall, 69 and 97 survey respondents in Nigeria and Hong Kong returned valid and completed survey forms, which are used for further analysis in this paper.

The study's sample size can be considered adequate as it is above the average range of 20 to 30 survey responses seen in published literature (*see* Chan & Chan, 2012; Osei-Kyei & Chan, 2018). As shown in Table 2, the survey respondents have relevant expertise and knowledge of implementing BIM and sustainability practices which lends credence and reliability to the data received. Based on the analysis of the organization's setup of the survey respondents, they are mainly from six types of organizations. The bulk of Hong Kong respondents are from government agencies (39%) and contracting firms (25%). Meanwhile, those in Nigeria are mostly from academic institutions (49%) and project consultancy firms (19%). As reported by Dall'O' et al. (2020), organizations that adopt Green-BIM would have the ability and skillset to further integrate sustainable practices in building designs than those who do not. Thus, these statistics might have a say in the higher level of smart sustainable practices implementation in Hong Kong than what is obtainable in Nigeria, as government agencies and contractors are better positioned to implement it in construction projects than academics.

The survey respondents in Nigeria and Hong Kong share a similar opinion that the planning and design stages of a building represent the best opportunity to implement smart sustainable practices in construction projects. Majority of the two sets of respondents have a good level of awareness on how to implement BIM and sustainability practices in the built environment. Examining the average years of experience of the survey respondents from both countries, respondents in Hong Kong have more practitioners with at least 11 years of working experience in the construction industry than those in the Nigeria context.

Insert Table 2

3.2 Data analysis tools

The data collated via the questionnaire surveys were analyzed using SPSSv23 and Microsoft Excel software. The SPSS software was used to determine the mean score (MS) of each driver, perform factor analysis (FA), and analyze the respondents' demographics. Microsoft Excel software was employed to model the fuzzy synthetic evaluation (FSE) analysis of the data and calculate the range normalization values for the driver. The mean score method, a relatively popular statistical tool, was used to rank the factors based on the level of importance (Olatunji *et al.*, 2017).

Factor analysis is a statistical technique capable of reducing a large number of variables to a manageable set by assessing the interrelationships between them (Hair *et al.*, 2010). It is also useful to explain difficult concepts (Xu *et al.*, 2010) and was used to regroup the set of drivers into small groups via the principal component analysis (PCA). As recommended by Xu *et al.* (2010), a Pearson correlation analysis was used in analyzing the perception of the respondents of the key factors before subjecting the data to further analysis via factor analysis. Pearson correlation helps to detect whether any two factors share a linear relationship, that is, whether one of the factors can be explained by the other. However, no statistical relationship (p> 0.05) was discovered in this study's data for the Hong Kong dataset. The factor clusters were extracted using the varimax rotation method. Preliminary tests such as the Kaiser-Meyer-Olkin (KMO) tests, correlation matrix, and Bartlett's test of sphericity (BTS) were conducted to determine the factor model's adequacy for factor analysis.

Fuzzy synthetic evaluation is an analytical tool that applies the fuzzy set theory to quantify multi-attribute and multi-evaluation (Xu *et al.*, 2010; Ameyaw and Chan, 2015b). It has found application in risk analysis and allocation (Ameyaw and Chan, 2015a), construction management (Hu *et al.*, 2016; Osei-Kyei and Chan, 2018), among others within the built environment. Like other fuzzy methods, the FSE objectifies the decision-makers' subjective judgements on a subject matter. Hence, it was selected as the appropriate statistical technique in this study. The FSE as a decision-making process, according to Lam et al. (2007), consists of linguistics variables, membership functions, fuzzy evaluation matrix, weighting vectors, and the computation of the natural language.

The FSE technique is the main statistical tool used in this study to develop the project evaluation models, based on the FSE modelling approach adopted in the extant literature (Hu *et al.*, 2016; Osei-Kyei and Chan, 2017):

Firstly, the key drivers (criteria) were denoted as $\pi = \{d_1, d_2, d_{3,} \ldots d_n\}$; where n represents the number of the criteria. The 5-point Likert scale measurement used in the survey form to evaluate the drivers represents the set of grade categories and are labelled as $C = \{C_1, C_2, C_{3,} \ldots C_n\}$. Where C_1 = strongly disagree, C_3 = neutral, and C_5 = strongly agree. Hence, to calculate each criterion's weighting (driver), we use equation (Eq. 1) and relevant values based are on the data from the survey responses.

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

Where W_i = weighting; MS_i = mean score of a selected criterion (driver), and $\sum MS_i$ = summation of the mean ratings of the selected drivers.

A fuzzy evaluation matrix for each driver is expressed as $R_i = (r_{ij})_{m \times n}$; where r_{ij} is the degree to which the grade categories, C_j satisfies the driver, d_j. The second-level membership function (R_i) of each driver is based on the percentage rating for each C_j from the collated data. The first-level membership functions of the FSE evaluation model (F) is obtained by evaluating the weighting vectors (W_i) of the criteria cluster and its fuzzy evaluation matrix (R_i) as expressed in Eq. 2:

$$F = W_i{}^{\circ}R_i \qquad ------------(2)$$

Where ° is the fuzzy component operator;

The resultant fuzzy evaluation results are normalized to 1, and the PEM index (PEM_i)can be calculated using Eq. 3:

$$PEM_i = \sum_{I=1}^{5} F \times C \quad -----------------(3)$$

These FSE approaches were employed systematically to analyze the survey data and develop the PEMs useful in measuring SSP implementation in Hong Kong and Nigeria's construction industry.

4. Results of statistical analyses

This section presents the results of the various statistical analysis employed in this study. It involves selecting the key drivers (D); establishing the drivers' groupings (DG); generating the weightings and membership functions for each driver and DG and developing the PEMs for smart sustainable practices implementation in construction projects Hong Kong and Nigeria. The data obtained from survey respondents in Nigeria and Hong Kong were analyzed separately and discussed in this section.

4.1 Selecting the key drivers – normalization & correlation analysis

Table 3 shows the ranking by mean score and standard deviation of the drivers for smart sustainable practices implementation in Hong Kong and Nigeria. The mean score values range from MS=3.53 ("*D25– Availability and affordability of cloud-based technology*") to MS=4.12 ("*D1– Technical competence of staff*") for Hong Kong; and MS=3.90 ("*D6– Adequate construction cost allocated to BIM*") to MS=4.54 ("*D1– Technical competence of staff*") for construction projects in Nigeria.

Meanwhile, to select the key drivers, the range normalization method (N_m) was employed, and only drivers with normalized values of 0.5 and above are considered for further factor analysis and FSE analysis. The drivers selected via this mechanism are considered the most significant and critical factor (Xu *et al.*, 2010; Osei-Kyei and Chan, 2017)

$$N_m = \frac{MS_i - MS_a}{MS_b - MS_a}$$

Where MS_i = mean score for the selected driver; MS_a= minimum MS for the set of drivers; and MS_b= maximum MS for the set of drivers.

As shown in Table 3, 18 factors and 15 factors in Nigeria and Hong Kong are rated as critical drivers, respectively, as they have normalized values of 0.5 and above.

Further analysis of these key factors using Pearson correlation analysis shows that for Nigeria's context – factor (D25), "a*vailability and affordability of cloud-based technology*" was highly correlated with D26 "*interoperability and data compatibility*" at a 5% significance level (ρ=0.725). Also, factor (D12), "*development of appropriate legal framework for BIM use and deployment in projects,*" was highly correlated with D16 "*appropriate legislation and governmental enforcement & credit for innovative performance*" (ρ=0.736). Hence, only key drivers (D16 & D26) were selected and used for further analysis to avoid the multiplier effect between the variables. Therefore, 16 key drivers are deemed critical within the Nigerian context, and 15 key drivers for the Hong Kong context.

Insert Table 3

4.2 Establishing the drivers' groupings

The FA technique using the PCA approach was used to classify the key drivers. The driver groupings (DG) for the Nigeria context were extracted based on the factors' eigenvalues. However, for the Hong Kong context, eigenvalues extraction of factors was not used because it extracted only two clusters – one of which contains factors that are heterogeneous in their characteristics. Hence, FA was used to extract a fixed number of groups without considering the groups' eigenvalues.

The Cronbach alpha analysis (Field, 2009; Olatunji *et al.*, 2017) for the dataset revealed α-value of 0.977 and 0.949 for Hong Kong and Nigeria, respectively, which is higher than the recommended value of 0.70. It also indicates the questionnaire measures the right construct. Further preliminary test using KMO statistics which measures sampling adequacy, and BTS test shows a KMO value of 0.856 and 0.942 for Nigeria and Hong Kong, respectively, indicating the generated cluster is distinct and reliable. For the BTS analyses, it revealed a high statistic value (chi-square= 1301.230) and small significance value (p=0.000; df= 105) for the Hong Kong context. For the Nigeria context, the BTS value is the chi-square value of

800.946 and p-value of 0.000 (df=120). This indicates that the two contexts' correlation matrix is not an identity matrix (Chan and Choi, 2015).

As shown in Tables 4 and 5, the drivers' factor loadings are above the recommended value of 0.5. The higher the factor loading of each driver, the higher the driver's significance with its underlying DG (Chan and Hung, 2015). Meanwhile, an identifiable label was attached to each DG which are clusters of the individual factors (Sato, 2005), although these labels are subjective. The four-factor groupings extracted for the Nigeria context using PCA represents 70% of the total variance (Table 4), while for the Hong Kong context, it is 81% (Table 5). These values are above the minimum threshold of 60% (Hair *et al.*, 2010; Chan, 2019).

The four separate factor groupings extracted for the Hong Kong context include knowledge (DDG1), technical specifications (DDG2), project performance and collaboration (DDG3), and finance/cost (DDG4). Each cluster contains at least three underlying factors. For instance, DDG1 consists of D3, D2, D23, and D1; whereas, DDG2 has D10, D28, D15, and D29 has its underlying factors. DDG3 comprises D24, D21, D22, and D27; while DDG4 consists of D6, D7, and D5.

Insert Table 4

Insert Table 5

4.3 Generating the weightings and membership functions for each key driver and drivers' groupings

For the FSE modelling, two levels are defined. The first level is the drivers' groupings (DGs/DDGs) level, while the second level is the key drivers (Ds) level – which are the underlying factors within each DG.

4.3.1 Determining the weightings of Ds (second level) and DGs/DDGs (first level)

The weightings of the Ds and the DGs/DDGs are calculated using Eq. 1, which are based on the mean scores of the factors analyzed from the survey responses (Table 6). For instance, for the Nigeria context, DG4 "*Project performance*" comprises three Ds with a total mean score of 13.06, the weighting of criteria "*D22 – Client satisfaction level on BIM projects*" can be obtained as follows:

$$W_{DG4} = \frac{4.25}{4.25 + 4.46 + 4.35} = \frac{4.25}{13.06} = 0.325$$

Therefore, the weightings for all the drivers and driver groupings for the Hong Kong and Nigeria contexts were calculated using Eq. 1.

Insert Table 6

4.3.2 Determining the membership functions of Ds and DGs/DDGs

Meanwhile, the membership functions for Ds and DGs/DDGs for level 2 and level 1 were derived for the Hong Kong and Nigeria contexts. Membership function values range between 0 and 1 and represent the degree of an element's membership in a fuzzy set (Ameyaw and Chan, 2015a). The membership function of the underlying criteria (Ds) for level 2 is calculated first before evaluating the membership functions of the DGs/DDGs (level 1). The membership functions are derived based on the ratings of the set of grade categories (that is, C_1 = strongly disagree, C_3 = neutral, and C_5 = strongly agree). For example, in the Nigeria context, 1% of the expert *strongly disagree* with driver "*D26 – Interoperability and data compatibility*" being a key driver for smart sustainable practices implementation. Meanwhile, 2, 10, 42, and 45 percent of the expert also ticked "*disagree*," "*neutral*," "*agree*," and "*strongly agree*" to the significance of the D26 as a key driver, respectively. Hence, the membership function (MF) of D26 is computed as follows:

$$MF_{D26} = \frac{0.01}{c1} + \frac{0.02}{c2} + \frac{0.10}{c3} + \frac{0.42}{c4} + \frac{0.45}{c4}$$

This MF for D26 is expressed as (0.01, 0.02, 0.10, 0.42, and 0.45). Likewise, the MF for the 15Ds and 16Ds for the Hong Kong and Nigeria contexts, respectively, can be derived using the same approach (Table 7). Having derived the MF at level 2, the MF at level 1 can be calculated using Eq. 2. Hence, using the driver groupings "*DDG4 - Finance/Cost*" of the Hong Kong context as an example, its MF can be evaluated as follows:

$$F_{DDG4} = \begin{vmatrix} 0.334 \\ 0.334 \\ 0.333 \end{vmatrix} \times \begin{vmatrix} 0.02 & 0.06 & 0.17 & 0.53 & 0.22 \\ 0.02 & 0.01 & 0.25 & 0.53 & 0.19 \\ 0.02 & 0.02 & 0.26 & 0.49 & 0.21 \end{vmatrix} = (0.02 \quad 0.03 \quad 0.23 \quad 0.52 \quad 0.21)$$

Similarly, the remaining 3DDGs of the Hong Kong context and the 4DGs of the Nigeria context were derived, as shown in Table 6 (column 4).

Insert Table 7

4.3.3 Defuzzify the membership functions of DGs/DDGs

The next step in the FSE modelling is the defuzzification of the membership functions at level 1, which will help decision-makers adopt smart sustainable practices. The defuzzification of the MFs of the DGs/DDGs results in the PEM_i for each of the driver groupings. Eq. 3 was used to defuzzify the MFs. For example, the PEM_i for "*DDG2 – Technical specifications*" of the Hong Kong context is computed as follows:

$$P11_{(DDG2)} = (0.02, \ 0.01, \ 0.19, \ 0.57, \ 0.20) \times (1, 2, 3, 4, 5) = 3.91$$

The same equation was used to defuzzify the MFs of the DGs/DDGs for the Nigeria and Hong Kong contexts, as shown in Table 8.

Insert Table 8

4.4 Developing the overall PEMs for smart sustainable practices implementation in Nigeria and Hong Kong

The final step in the FSE modelling is the development of the overall PEM_imodels, whereby the PEM_i of the DDGs/DGs are used in formulating the linear equation model. Linear and additive model was used for the overall PEM_i modelling because the DDGs/DGs for the Nigeria and Hong Kong contexts do not correlate; that is, there are not linear (Osei-Kyei and Chan, 2017). More so, per Hu et al. (2016) and Yeung et al. (2009), using a linear equation model will make it easier to use and understand by industry practitioners and other users.

Meanwhile, before developing the composite linear model, the PEM_i, for the DDGs/DGs are normalized to ensure the sum of the resultant coefficients equal to one or unity (Table 8). Normalizing the PEM_i is logical and valid (Osei-Kyei and Chan, 2017), as it helps to illustrate better the relative activity between the criteria in the linear equation. Essentially, it allows the differing scale of measurements to be used when assessing the key drivers for smart sustainable practices implementation in construction projects.

The PEM for smart sustainable practices implementation in Hong Kong's construction industry can be expressed as:

$$\begin{aligned} PEM_i = {} & (0.255 \times Knowledge) + (0.249 \times Technical\ specifications) \\ & + (0.250 \times\ Project\ performance\ \&\ collaboration) \\ & + (0.246 \times Finance/cost) \qquad ---------(4) \end{aligned}$$

Also, the PEM for smart sustainable practices implementation in Nigeria's construction industry is:

$$\begin{aligned} PEM_i = {} & (0.253 \times Knowledge\ \&\ Enforcement) + (0.250 \times Effective\ partnership) \\ & + (0.246 \times\ Technical\ specifications) \\ & + (0.251 \times Project\ performance) \qquad ---------(5) \end{aligned}$$

5. Discussion of results and practical implications

The PEM_i models as presented in Eqs. 4 and 5 revealed: "Knowledge" (0.255) and "Knowledge & Enforcement" (0.253) with the highest coefficient for the Hong Kong and Nigeria contexts, respectively. Ranked second for Hong Kong and Nigeria are the "Project performance & collaboration" (0.250) and "Project performance" (0.251) respectively;

meanwhile, “Effective partnership” (0.250) is ranked third in PEM for Nigeria and is partly similar to ‘*collaboration*’ (2nd ranked in the Hong Kong context). “Technical specifications” (0.249) is the third-ranked in the Hong Kong context but ranked fourth with a coefficient of 0.246 in Nigeria’s PEM. The sum of all coefficients in each of the two PEMs equals one (Table 8).

The developed PEMs equations and models would substantially enable industry practitioners and other stakeholders to practically evaluate the implementation level of smart sustainable practices in their construction projects. More so, the PEM_imodels provide a common basis for its users to compare the SSP implementation levels in construction projects. Furthermore, the driver groupings that constitute the PEMs for Hong Kong and Nigeria will be discussed in the following sub-sections.

5.1 Driver groupings

5.1.1 Knowledge and Enforcement

The driver grouping (DG1) accounts for 46.243% of the total variance for the Nigeria context and also has the highest PEM_ivalue of 4.40, with a coefficient of 0.253. Similarly, for the Hong Kong context, the driver grouping (DDG1 – “Knowledge”) has the highest PEM_i value of 4.00 with a coefficient (ρ) of 0.255. The two related driver groupings – *DG1 and DDG1* – have two underlying factors in common, which are “*technical competence of staff*” (D1) and “*more training programs for cross-field specialists in BIM and sustainability*” (D3). These key factors are ranked top-three in the Hong Kong and Nigeria contexts (Table 3). The mean ranking and PEM_i analyses reveal that to enhance the adoption of SSP initiatives, the training, awareness, and expertise of relevant practitioners must be thoroughly emphasized by construction organizations, professional bodies, and even the government.

Morlhon *et al.* (2014) and Chan *et al.* (2019a) underscored the importance of knowledge and awareness of construction stakeholders, academics, and practitioners in improving the adoption of SSP initiatives in the built environment. The studies further stressed the significance of coercive pressures or mandates by government and private clients in ensuring the implementation of SSP in construction projects. To put it in context, when practitioners are knowledgeable and skilled in how and when to apply smart and sustainable initiatives, there are more inclined to adopt them for future construction projects. More so, when project teams, contractors, and other critical components of the construction supply chain are aware that to secure a contract, it would be expected of them to show evidence of being sustainability conscious. They would facilitate their staff's training and provide relevant financial and organizational support in improving their SSP status. Other key factors within the driver groupings include “*establishment of a model of good practice for BIM and* *sustainability execution*" (D10) and "*appropriate legislation and governmental enforcement*" (D16) under DG1 of the Nigeria context as well as "*supportive organizational culture and effective leadership*" (D23) and "g*reater awareness and experience level within the firm*" (D2) under DDG1 of the Hong Kong context.

The driver, "*D1– technical competence of staff*", has the highest weightings and mean ranking within the groupings (DG1– *W=0.259, MS=4.54*; DDG1– *W=0.258, MS=4.12*). In the Nigerian construction industry, as well as other developing countries, the little or lack of 'expected' level of technical competency in deploying BIM infrastructure and integrating sustainability issues in projects have impeded the progress being made to adopt the SSP initiatives (Hamma-adama *et al.*, 2018; Lampreia *et al.*, 2019). As evident in other regions such as North America and Europe, where significant efforts and resources have been deployed in improving the overall technical and professional expertise of construction stakeholders (Jung and Lee, 2015; Olawumi and Chan, 2018); which has resulted in the development of more greener cities and buildings.

It is envisioned that if construction firms and government agencies in Nigeria and other developing countries devote resources in equipping construction workers with the relevant skillset to deploy SSP initiatives, it will produce similar results as seen in the advanced worlds. Although the adoption of smart sustainable practices implementation is above average in Hong Kong compared to Nigeria (Chan *et al.*, 2019a), this factor is still a key driver in Hong Kong. As reported by Govada *et al.* (2020), Hong Kong lags in implementing digital technologies to implement energy savings and recycling. Hence, efforts should be directed towards these areas in Hong Kong. More so, as pointed out by Ozorhon and Karahan (2016) and Rogers et al. (2015), the more the number of professionals with requisite experience in SSP, the easier its implementation.

Another key factor in the groupings is "*D3 – more training programs for cross-field specialists in BIM and sustainability*" is somewhat related to D1 given that such training programs would further enhance the technical competence of such specialists (Jalaei and Jrade, 2014). It is the second-ranked driver in the Nigerian context and third-ranked in the Hong Kong context. The provision of required training and workshops (Succar *et al.*, 2013) in the various aspects of sustainability and innovative tools like BIM will equip such staff and practitioners with skills and knowledge to facilitate smart sustainable practices. Specifically, in Hong Kong, a supportive structure and leadership (D23) are considered key drivers to its implementation. D23 is somewhat linked to D10, which is a key driver in Nigeria. Hence, it is important for construction firms, stakeholders to develop in-house strategies and guidelines for its implementation (Won and Lee, 2010). Also, the *development of useful models of good practice* (D10) for smart sustainable practices (Antón and Díaz, 2014), such as the development of the BSAM scheme green building rating system for sub-Saharan Africa (Olawumi *et al.*, 2020). Notably, there is a need for regulatory and professional enforcement (D16) of its implementation in the Nigerian construction industry.

5.1.2 Project performance and Effective partnership

The DDG3 "*project performance & collaboration*" is the second-ranked driver grouping (PEM_i= 3.92, ρ=0.250) in the Hong Kong context while DG4 "*project performance*" (PEM_i= 4.36, ρ=0.251); and DG2 "*effective partnership*" (PEM_i= 4.34, ρ=0.250) which are the second and third-ranked driver groupings within the Nigeria contexts are discussed in this section under a combined driver grouping "*project performance and effective partnership (PPEP)*." Majority of the underlying drivers in this driver cluster (PPEP) are ranked within the top ten-ranked drivers in both the Hong Kong and Nigeria context. D21 is ranked third among the key drivers in the Nigeria context but ranked sixth in the Hong Kong context (Table 3).

The driver "*D21 – early involvement of project teams*" (Kassem *et al.*, 2012) is a significant driver in both contexts. It is the highest-ranked in both the DG2 and DG4 groupings (*W=0.342, MS=4.46*) of the Nigeria context and ranked second in the DDG3 (*W=0.252, MS=3.94*) of the Hong Kong context. The contractual arrangements for most construction projects have been identified as a key barrier to implementing innovative and disruptive concepts (Saka *et al.*, 2019) such as BIM and sustainability. The most common, which is traditional procurement, only allows the contractor to bid for the job. As such, the contractor and some other relevant stakeholders have no influence on the project design. Hence, there is a need for a unique procurement route that will involve the participation of relevant stakeholders, including external stakeholders such as environmental groups, to facilitate the implementation of SSP initiatives.

More so, there is a need to create a stimulating and conducive environment that will support and encourage collaboration and coordination (D9) among the project stakeholders (Hanna *et al.*, 2014). It will be counterproductive to engage the relevant project stakeholders early in a project without providing common data and a collaborative working environment to facilitate their decision-making on SSP implementation in the construction project. More so, the level of client's satisfaction (D22) as regards the SSP initiatives implemented in the construction project (Ahn *et al.*, 2014; Rogers *et al.*, 2015) provides a good indicator to measure its success and could facilitate the implementation of SSP by the clients in future projects.

5.1.3 Technical specifications

The driver grouping (DDG2) is the third-ranked driver grouping in the Hong Kong context (PEM_i= 3.91, ρ=0.249) while DG3 is ranked fourth in the Nigeria context (PEM_i= 4.28, ρ=0.246). There are two related drivers in both contexts, which are D15, "*Establishment of BIM standards, codes, rules, and regulations,*" and D29, "*Availability of BIM and sustainability databases*" and factor (D15) is well ranked in both contexts (Table 3). There are three key drivers of the SSP initiatives in the Nigeria context and four in the Hong Kong context. These key drivers can be considered significant, with their mean scores ranging from MS=3.88 (D10) to MS=4.30 (D15). Essentially, to advance the implementation of smart sustainability practices in the built environment, there is a need to develop, provide, and streamlined the necessary technical specifications required to ease its adoption.

Key driver (D15) is the most significant driver in both contexts (DG3– *W=0.335, MS=4.30*; DDG2– *W=0.255, MS=3.99*). The inadequacy or nonexistence of relevant standards and regulations to guide BIM adoption, according to Redmond *et al.* (2012) and Chan *et al.* (2019b), has derailed the implementation of smart sustainable practices in most countries. Currently, there are no industry BIM standards in Nigeria; although there are some relevant BIM standards in Hong Kong developed by the CIC, it has not received an industry-wide acceptance. As BIM is a critical component of smart sustainable practices implementation (Wong and Zhou, 2015), as advanced in this study, stakeholders should devout resources towards developing BIM standards that suit their local context.

Similarly, there is a need to enhance the information sharing protocol between relevant software and processes (D26). Saxon (2013) emphasized that issues relating to interoperability and data incompatibility hinder information processing and effective collaboration. More so, as the implementation of smart sustainable practices relies heavily on information processing, this driver is considered very significant in enhancing its uptake. Meanwhile, the provision and availability of relevant BIM and sustainability databases (D29) are considered a significant driver (Abolghasemzadeh, 2013) to implement SSP initiatives in Nigeria and Hong Kong. The availability of these databases will ensure uniformity in the file naming, data formats, and BIM object identification, which will ease the coordination of its implementation. It is important to note that prompt and efficient support from software vendors (D28) will also aid SSP implementation.

5.1.4 Finance/Cost

Driver grouping (DDG4) is the fourth-ranked in the Hong Kong context (PEM_i= 3.86, ρ=0.246) and comprises of three underlying drivers (D6, D7 & D5). D5 has the least mean score and weightings (*MS=3.85, W=0.333*), and factor D7 is ranked the most significant driver in the grouping. As earlier postulated, smart sustainable practices are heavily reliant on information management via the various BIM and associated software. Hence, there is a need for strategic policies by construction firms and relevant stakeholders to allocate funds to purchase relevant BIM software and licenses (D7). Nanajkar and Gao (2014) argued that commitment to investing in technology infrastructures and software by top management would aid the implementation of smart sustainable practices in construction projects.

Furthermore, the support from the government via direct funding, subsidies, incentives (D5) construction firms will aid their adoption of smart sustainable practices (Suermann and Issa, 2009; Abubakar *et al.*, 2014). It is recommended that the bulk of such start-up funds for construction firms should be allocated for small and medium-scale firms. In a similar vein, such funding should be provided for firms with a strategic framework to implement SSP initiatives in their construction projects. Meanwhile, a significant barrier to its implementation is the cost of integrating BIM and associated tools in construction projects. Hence, to ameliorate this limitation, Kivits and Furneaux (2013) and Olawumi and Chan (2020c) pointed out that the client should allocate sufficient funds for BIM implementation in the project. As such, in future projects, when such a construction firm has achieved a satisfactory level of smart sustainable practices, the percentage sum allocation for BIM and other associated software will invariably reduce overtime.

5.2 Practical research implications

The proposed PEMs for smart-sustainable practices (Eqs. 4 & 5) were developed in this study using the FSE technique to objectively quantify the various key factors that influence SSP in Nigeria and Hong Kong's construction industry, respectively. By adopting the PEMs, construction practitioners are provided with a useful tool to measure the level of application of smart-sustainable practices in construction projects. The implementation level of a given construction project can be determined by using the PEM models to calculate the index of each DG/DDG in the equations for Nigeria and Hong Kong, respectively. Its users could adopt two approaches to determine the index of each driver groupings: (i) the practitioners should assess the degree/level of achievement of the underlying key drivers of each driver groupings on a scale of measurement (that is, 5-, 7-, or 9-point scale). Furthermore, the average PEM_i for each DG/DDG should be determined and substituted in the PEMs (Eqs. 4 & 5). (ii) Another approach is for the practitioners to redo the entire fuzzy synthetic evaluation method presented in this study using a new dataset.

Meanwhile, using the PEMs (Eqs. 4 & 5), practitioners in Hong Kong and Nigeria can reliably and objectively compare the implementation levels of smart sustainable practices in construction projects. The comparison can also be used for benchmarking purposes. The key drivers and driver groupings provide useful indicators and checklists for practitioners, clients, government agencies, and other stakeholders on the core areas to focus and allocate resources towards enhancing SSP implementation in Hong Kong and Nigeria. The identified key drivers can also be useful as a consultative toolkit to aid the implementation of green and sustainable buildings and cities.

The PEM models developed for Hong Kong would benefit the local construction industry and could be applicable in other regions. Similarly, developing countries in Africa and other regions would find the PEM model developed for Nigeria applicable to their local context to measure the level of implementation of smart-sustainable practices in their construction projects. It will also improve the adoption and implementation of SSP initiatives in these regions.

The authors recommend using smart-sustainable practices PEMs to evaluate construction projects at the pre-construction phases – especially at the design and post-tender stages before the project is contracted out. It is also advised for the PEM re-evaluation of construction projects to be undertaken again midway within the construction process to validate the actual implementation of smart-sustainable practices in the project.

Moreover, the proposed smart-sustainable practices PEMs being a project-based tool would be most beneficial and useful for the clients/employer and project teams to evaluate the construction project. Also, in a design and build contract, where the main contractor is involved early in the project planning and decision-making process, the PEM could be a useful tool for the contractor to plan and assess the construction project's SSP initiatives.

According to Yuan *et al.* (2019), shaping clients' adoption behaviors is critical in improving BIM adoption for sustainability. One of the approaches identified in the study is the provision of tools, technical requirements, and other resources to guide practitioners (Elhendawi *et al.*, 2019; Yuan *et al.*, 2019) – which the current study has achieved with the (i) development of the PEM tool for smart-sustainable practices implementation and (ii) the provision of a checklist of key factors to consider when digital tools are being employed to facilitate sustainability in construction works

6. Conclusions

The construction industry in Nigeria and Hong Kong has been making significant steps towards integrating smart and sustainable practices in the built assets and infrastructure in relation to the fast-paced development in its urban cities. However, both contexts are still not close to achieving it, as evident in previous studies and practice. Although previous studies attempted to conceptualize the challenges faced by Nigeria and Hong Kong’s built environment, none has presented a tool or model to measure the level of application of SSP in construction projects. Hence, the current study attempts to bridge this gap via the development of PEMs for SSP in both contexts.

The PEMs for smart-sustainable practices implementation was developed in this study using the FSE technique, which is a derivative of the fuzzy set theory. The FSE method was useful in handling the subjective opinions of the survey respondents that were used in the development of the PEMs and via the use of mathematical operators help to achieve precise evaluation. More so, as the invited practitioners provided their responses in linguistic forms, using the FSE, the proposed project evaluation models were developed with less subjectivity and ambiguity. Moreover, as discussed in section 5.2, the proposed PEMs can be considered objective, practicable, and applicable within the context of Nigeria and Hong Kong, respectively. The proposed PEMs also provide a common basis for practitioners to measure or compare SSP initiatives' implementation levels in construction projects. The study also presents practitioners with a checklist of key facilitating factors for SSP implementation, which can be useful as a consultative tool to drive green and sustainable building development. The proposed PEMs developed in this study also contribute to existing knowledge and practice by assisting clients and other stakeholders in measuring and tracking the levels and stages of their implementation of SSP initiatives.

The 30 key factors of SSP were used in the questionnaire survey, of which 69 and 97 responses were received from practitioners in Nigeria and Hong Kong, respectively. After subjecting the collected data to various statistical analyses, including the Pearson correlation test and normalization tests - only 16 key factors were used to develop the PEM for the Nigerian context. Meanwhile, 15 critical factors were used for the PEM development for the Hong Kong context. Using factor analysis, the two sets of key factors were categorized into four groups each. The results obtained for the key factors indicated that "technical competence of staff," "more training programs for cross-field specialists in BIM and sustainability," "early involvement of project teams," and "greater awareness and experience level within the firm" are significant adoption drivers of SSP in Nigeria and Hong Kong based on their mean values. More so, based on the index value of the driver groupings derived using the FSE technique – "knowledge and enforcement" and "collaboration and value" in Nigeria; and "knowledge" and "project performance and collaboration" in Hong Kong are critical to their achievement of SSP initiatives.

A limitation of the study is that the research was conducted in Nigeria and Hong Kong and may not be directly applicable to other developing or developed worlds, respectively. However, since these contexts share similar sociopolitical and economic features with other countries, this study's research outputs might still be relevant beyond the scope of Nigeria and Hong Kong, respectively. As the current study is a case study of Hong Kong and Nigeria, future research can focus on using and supplementing the factors in this study to facilitating comparison in other climes. A practical application of the smart sustainable practices' PEM in some case study projects is proposed to advance its use by practitioners in the construction industry.

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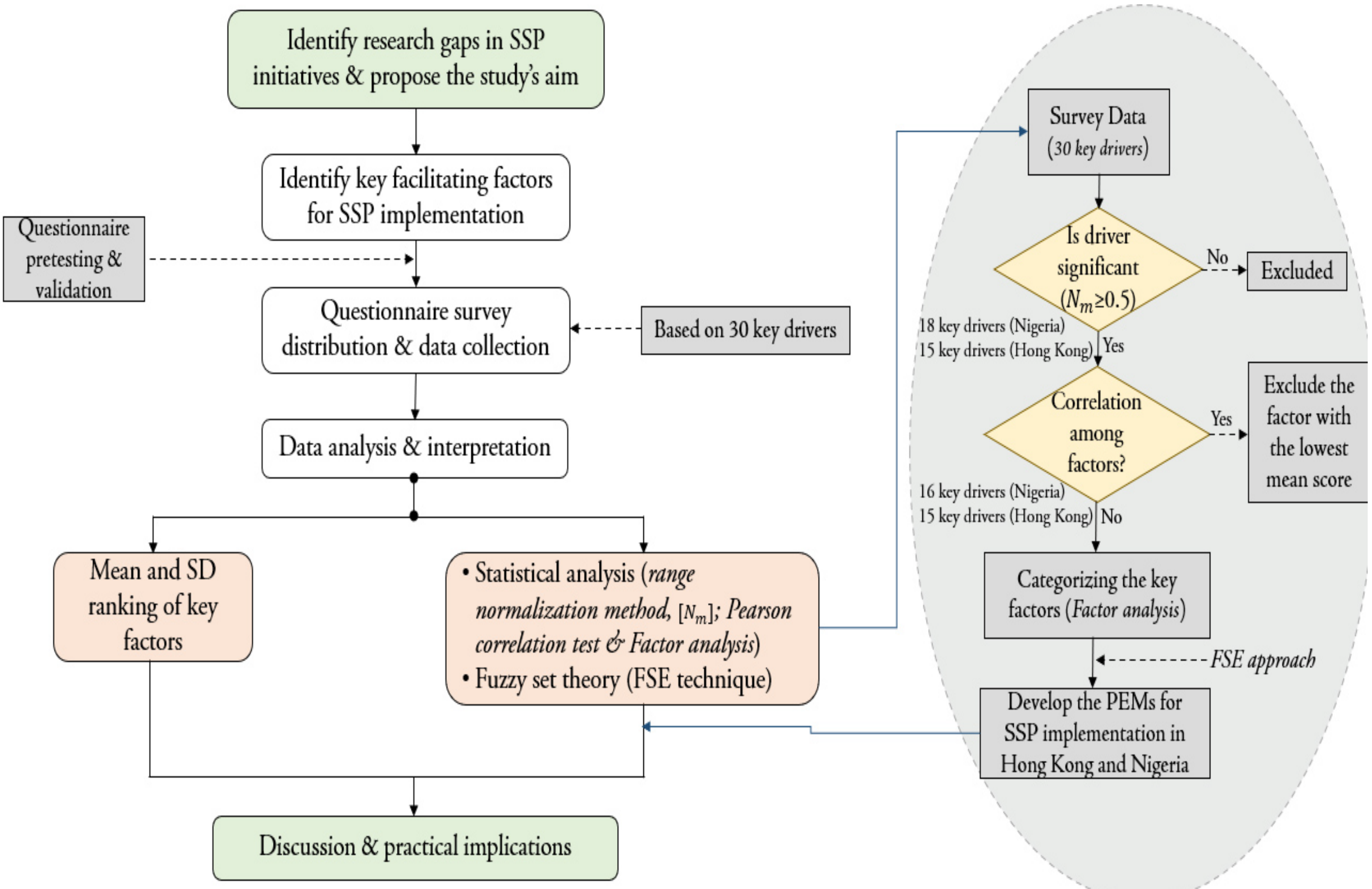

Figure 1: Overall research design for the study

Table 1: Key factors affecting the SSP implementation. Adapted from Olawumi and Chan (2020c).

Code	Key drivers	References
D1	Technical competence of staff	Gu and London (2010); Tsai et al. (2014); Deutsch (2011)
D2	Greater awareness and experience level within the firm	Chan (2014); Kassem et al. (2012)
D3	More training programs for cross-field specialists in BIM and Sustainability	Wong and Fan (2013); Jalaei and Jrade (2014)
D4	Increased research in the industry and academia	Abdirad (2016); Bolgani (2013)
D5	Government establishment of start-up funding for construction firms to kick-start BIM initiatives	Abubakar et al. (2014)
D6	Adequate construction cost allocated to BIM	Gu and London (2010); Kivits and Furneaux (2013)
D7	Availability of financial resources for BIM software, licenses, and its regular upgrades	Nanajkar and Gao (2014)
D8	Information and knowledge-sharing within the industry	Azhar (2011); Chan et al. (2019b)
D9	Effective collaboration and coordination among project participants	Antón and Díaz (2014); Hanna et al. (2014)
D10	Establishment of a model of good practice for BIM and sustainability execution	Antón and Díaz (2014); Adamus (2013)
D11	Availability and a well-managed in-house database of information on similar projects	Aibinu and Venkatesh (2014); Becerik-gerber and Kensek (2010)
D12	Development of appropriate legal framework for BIM use and deployment in projects	Aibinu and Venkatesh (2014); Azhar (2011)
D13	Security of intellectual property and rights	Kivits and Furneaux (2013)
D14	Shared risks, liability, and rewards among project stakeholders	Chan (2014); Park et al. (2013)
D15	Establishment of BIM standards, codes, rules, and regulations	Redmond et al. (2012)
D16	Appropriate legislation and governmental enforcement & credit for innovative performance	Antón and Díaz (2014); Hope and Alwan (2012)
D17	Increased involvement of project stakeholders in green projects	Alsayyar and Jrade (2015)
D18	Clarity in requirements and measures for achieving sustainable projects	Aibinu and Venkatesh (2014)
D19	Number of subcontractors experienced with BIM projects	Chan (2014)
D20	Client requirement and ownership	Ahn et al. (2014); Chan et al. (2019a)
D21	Early involvement of project teams	Kassem et al. (2012)
D22	Client satisfaction level on BIM projects	Ahn et al. (2014); Chan (2014)
D23	Supportive organizational culture and effective leadership	Yeomans et al. (2006)
D24	Project complexity (regarding building shape or building systems)	Hope and Alwan (2012); Kivits and Furneaux (2013)
D25	Availability and affordability of cloud-based technology	Ahn et al. (2014); Yeomans et al. (2006)
D26	Interoperability and data compatibility	Adamus (2013); Saxon (2013)
D27	Standardization & simplicity of BIM and sustainability assessment software	Akinade et al. (2017); Aksamija (2012)
D28	Technical support from software vendors	Redmond et al. (2012)
D29	Availability of BIM and sustainability databases	Abolghasemzadeh (2013); Antón and Díaz (2014)
D30	Open-source software development	Hope and Alwan (2012)

Table 2: Demographics of survey respondents

Characteristics	Nigeria	Hong Kong
	Percentage (size)	Percentage (size)
Years of working experience		
< 5years	33.3% (23)	32% (31)
5-10 years	33.3% (23)	21% (20)
11-15 years	10.1% (7)	8% (8)
16-20 years	10.1% (7)	8% (8)
> 20 years	13.0% (9)	31% (30)
Type of organization		
Public Client	8.7% (6)	39.2% (38)
Private Client	8.7% (6)	5.2% (5)
Project Consultant	18.8% (13)	9.3% (9)
Main Contractor	13.0% (9)	24.7% (24)
Property Management Company	1.4% (1)	5.2% (5)
Academic Institution	49.3% (34)	16.5% (16)
Level of awareness of sustainability practices		
Very High	15.9% (11)	8.2% (8)
High	52.1% (36)	26.8% (26)
Average	28.9% (20)	44.3% (43)
Low	2.8% (2)	13.4% (13)
Very Low	0% (0)	7.2% (7)
Level of awareness of BIM process		
Very High	13% (9)	7.2% (7)
High	34.7% (24)	20.6% (20)
Average	39.1% (27)	41.2% (40)
Low	11.5% (8)	14.4% (14)
Very Low	1.4% (1)	16.4% (16)
When best to implement smart sustainable practices?		
Planning stage	66.6% (46)	42.2% (41)
Design stage	31.8% (22)	47.4% (46)
Construction stage	1.4% (1)	9.2% (9)
Facility management stage	0% (0)	1% (1)

Table 3: Ranking of the drivers for smart sustainable practices implementation in Nigeria and Hong Kong

Nigeria					Hong Kong				
Drivers	**MS**	**SD**	**Rank**	N_m	**Drivers**	**MS**	**SD**	**Rank**	N_m
D1	4.54	.655	1	1.000	D1	4.12	.869	1	1.000
D3	4.46	.655	2	.886	D2	4.02	.816	2	.825
D21	4.46	.677	3	.886	D3	4.00	.791	3	.789
D2	4.42	.651	4	.818	D15	3.99	.823	4	.772
D9	4.41	.734	5	.795	D27	3.98	.777	5	.754
D4	4.35	.744	6	.705	D21	3.94	.911	6	.684
D23	4.30	.692	7	.636	D28	3.90	.835	7	.614
D17	4.30	.713	8	.636	D10	3.88	.781	8	.579
D15	4.30	.734	9	.636	D22	3.87	.799	9	.561
D10	4.30	.792	10	.636	D29	3.87	.824	10	.561
D18	4.28	.705	11	.591	D24	3.87	.824	11	.561
D8	4.28	.765	12	.591	D23	3.86	.790	12	.544
D26	4.28	.820	13	.591	D7	3.86	.804	13	.544
D29	4.26	.902	14	.568	D6	3.86	.901	14	.544
D22	4.25	.793	15	.545	D5	3.85	.846	**15**	**.526**
D16	4.25	.812	**16**	**.545**	D18	3.82	.736	16	.491
D12*	4.22	.820	17	.500	D9	3.82	.764	17	.491
D25*	4.22	.838	18	.500	D11	3.80	.786	18	.456
D11	4.20	.778	19	.477	D16	3.79	.803	19	.439
D7	4.19	.896	20	.455	D8	3.79	.816	20	.439
D27	4.17	.857	21	.432	D30	3.78	.807	21	.421
D20	4.16	.933	22	.409	D4	3.77	.810	22	.404
D5	4.13	1.028	23	.364	D20	3.77	.848	23	.404
D14	4.12	.718	24	.341	D19	3.76	.801	24	.386
D13	4.07	.846	25	.273	D17	3.76	.826	25	.386
D28	4.07	.846	25	.273	D12	3.75	.791	26	.368
D19	4.06	.838	27	.250	D26	3.75	.817	27	.368
D24	4.06	1.013	28	.250	D14	3.70	.915	28	.281
D30	4.04	.992	29	.227	D13	3.64	.844	29	.175
D6	3.90	1.002	30	.000	D25	3.54	.890	30	.000

*NB: *drivers which correlate (at $p<0.05$) were removed from subsequent analysis.*

Table 4: Factor structure for the key drivers (Nigeria context)

Key drivers	Factor loadings	Eigenvalue	% of variance explained	Cumulative % of variance explained
DG1 – Knowledge & Enforcement		7.399	46.243	46.243
D10 - Establishment of a model of good practice for BIM and sustainability implementation	0.811			
D1 - Technical competence of staff	0.746			
D3 - More training programs for cross-field specialists in BIM and Sustainability	0.629			
D16 - Appropriate legislation and governmental enforcement & credit for innovative performance	0.609			
DG2 – Effective partnership		1.488	9.298	55.540
D18 - Clarity in requirements and measures for achieving sustainable projects	0.740			
D23 - Supportive organizational culture and effective leadership	0.735			
D17 - Increased involvement of project stakeholders in green projects	0.657			
D9 - Effective collaboration and coordination among project participants	0.598			
D2 - Greater awareness and experience level within the firm	0.558			
D8 - Information and knowledge-sharing within the industry	0.537			
DG3 – Technical specifications		1.235	7.719	63.260
D26 - Interoperability and data compatibility	0.778			
D29 - Availability of BIM and sustainability databases	0.745			
D15 - Establishment of BIM standards, codes, rules, and regulations	0.724			
DG4 – Collaboration and Value		1.061	6.631	**69.890**
D22 - Client satisfaction level on BIM projects	0.844			
D21 - Early involvement of project teams	0.700			
D4 - Increased research in the industry and academia	0.541			

Table 5: Factor structure for the key drivers (Hong Kong context)

Key drivers	Factor loadings	Eigenvalue	% of variance explained	Cumulative % of variance explained
DDG1 – Knowledge		9.804	65.358	65.358
D3 - More training programs for cross-field specialists in BIM and Sustainability	0.748			
D2 - - Greater awareness and experience level within the firm	0.711			
D23 - Supportive organizational culture and effective leadership	0.571			
D1 - Technical competence of staff	0.543			
DDG2 – Technical specifications		1.011	6.740	72.098
D10 - Establishment of a model of good practice for BIM and sustainability implementation	0.718			
D28 - Technical support from software vendors	0.654			
D15 - Establishment of BIM standards, codes, rules, and regulations	0.650			
D29 - Availability of BIM and sustainability databases	0.594			
DDG3 – Project performance & collaboration		0.823	5.490	77.588
D24 - Project complexity (regarding building shape or building systems)	0.809			
D21 - Early involvement of project teams	0.707			
D22 - Client satisfaction level on BIM projects	0.651			
D27 - Standardization & simplicity of BIM and sustainability assessment software	0.583			
DDG4 – Finance/Cost		0.511	3.407	**80.995**
D6 - Adequate construction cost allocated to BIM	0.885			
D7 - Availability of financial resources for BIM software, licenses, and its regular upgrades	0.795			
D5 - Government establishment of start-up funding for construction firms to kick-start BIM initiatives	0.652			

Table 6: Weightings for the Ds and DGs for smart sustainable practices implementation

Nigeria					**Hong Kong**				
Drivers	MS_d	W_{DG}	MS_{dg}	W_{DG}	**Drivers**	MS_d	W_{DG}	MS_{ddg}	W_{DDG}
D10	4.30	0.245			D3	4.00	0.250		
D1	4.54	0.259			D2	4.02	0.251		
D3	4.46	0.254			D23	3.86	0.241		
D16	4.25	0.242			D1	4.12	0.258		
DG1 – Knowledge & Enforcement			17.55	0.253	**DDG1 – Knowledge**			16.00	0.272
D18	4.28	0.165			D10	3.88	0.248		
D23	4.30	0.165			D28	3.90	0.249		
D17	4.30	0.165			D15	3.99	0.255		
D9	4.41	0.170			D29	3.87	0.247		
D2	4.42	0.170			**DDG2 – Technical specifications**			15.64	0.266
D8	4.28	0.165							
DG12– Effective partnership			25.99	0.374	D24	3.87	0.247		
D26	4.28	0.333			D21	3.94	0.252		
D29	4.26	0.332			D22	3.87	0.247		
D15	4.30	0.335			D27	3.98	0.254		
DG3 – Technical specifications			12.84	0.185	**DDG3 – Project performance & collaboration**			15.66	0.266
D22	4.25	0.325			D6	3.86	0.334		
D21	4.46	0.342			D7	3.86	0.334		
D4	4.35	0.333			D5	3.85	0.333		
DG4 – Collaboration and Value			13.06	0.188	**DDG4 – Finance/Cost**			11.57	0.197
Total Mean for the Groupings			**69.44**		**Total Mean for the Groupings**			**58.87**	

MS_d= mean score for drivers; MS_{dg} / MS_{ddg}= Total mean score for each driver groupings

W_D = Weightings for each driver; W_{DG} / W_{DDG} = Weightings for each driver groupings

Table 7: Membership functions for all Ds and DGs/DDGs

Key drivers and Drivers' groupings	Weightings for the Ds	Membership function at Level 2 (Ds)					Membership function at Level 1 (DGs/DDGs)				
Hong Kong context											
DDG1 – Knowledge							0.02	0.01	0.16	0.54	0.26
D3	*0.250*	0.02	0.01	0.15	0.58	0.24					
D2	*0.251*	0.02	0.02	0.13	0.57	0.26					
D23	*0.241*	0.02	0.02	0.21	0.59	0.16					
D1	*0.258*	0.02	0.01	0.17	0.43	0.37					
DDG2 – Technical specifications							0.02	0.01	0.19	0.57	0.20
D10	*0.248*	0.02	0.01	0.22	0.58	0.17					
D28	*0.249*	0.03	0.02	0.15	0.61	0.19					
D15	*0.255*	0.02	0.01	0.19	0.52	0.26					
D29	*0.247*	0.03	0.01	0.20	0.59	0.17					
DDG3 – Project performance & collaboration							0.02	0.02	0.18	0.56	0.22
D24	*0.247*	0.02	0.03	0.19	0.57	0.19					
D21	*0.252*	0.03	0.03	0.16	0.52	0.26					
D22	*0.247*	0.02	0.01	0.24	0.54	0.19					
D27	*0.254*	0.02	0.01	0.15	0.60	0.22					
DDG4 – Finance/Cost							0.02	0.03	0.23	0.52	0.21
D6	*0.334*	0.02	0.06	0.17	0.53	0.22					
D7	*0.334*	0.02	0.01	0.25	0.53	0.19					
D5	*0.333*	0.02	0.02	0.26	0.49	0.21					
Nigeria context											
DG1 – Knowledge & Enforcement							0.00	0.02	0.07	0.39	0.51
D10	*0.245*	0.01	0.00	0.12	0.41	0.46					
D1	*0.259*	0.00	0.02	0.04	0.33	0.61					
D3	*0.254*	0.00	0.01	0.04	0.41	0.54					
D16	*0.242*	0.00	0.04	0.10	0.42	0.44					
DG2 – Effective partnership							0.00	0.01	0.07	0.46	0.45
D18	*0.165*	0.00	0.01	0.10	0.48	0.41					
D23	*0.165*	0.00	0.01	0.09	0.48	0.42					
D17	*0.165*	0.00	0.01	0.10	0.45	0.44					
D9	*0.170*	0.01	0.00	0.06	0.42	0.51					
D2	*0.170*	0.00	0.03	0.00	0.49	0.48					
D8	*0.165*	0.02	0.00	0.10	0.46	0.42					
DG3 – Technical specifications							0.01	0.02	0.09	0.43	0.45
D26	*0.333*	0.01	0.02	0.10	0.42	0.45					
D29	*0.332*	0.03	0.03	0.04	0.45	0.45					
D15	*0.335*	0.00	0.01	0.12	0.42	0.45					
DG4 – Collaboration and Value							0.00	0.02	0.09	0.40	0.49
D22	*0.325*	0.00	0.04	0.09	0.45	0.42					
D21	*0.342*	0.00	0.01	0.06	0.38	0.55					
D4	*0.333*	0.00	0.01	0.12	0.38	0.49					

Table 8: PEM index for DGs/DDGs for smart sustainable practices implementation

Driver groupings	**PEM index (PEM_i)**	**Coefficients^{y}**
Hong Kong context		
DDG1 – Knowledge	4.00	0.255
DDG2 – Technical specifications	3.91	0.249
DDG3 – Project performance & collaboration	3.92	0.250
DDG4 – Finance/Cost	3.86	0.246
Total	**15.70**	**1.000**
Nigeria context		
DG1 – Knowledge & Enforcement	4.40	0.253
DG2 – Effective partnership	4.34	0.250
DG3 – Technical specifications	4.28	0.246
DG4 – Collaboration and Value	4.36	0.251
Total	**17.38**	**1.00**

$^{y}Coefficient = \left({}^{PEM_i\ for\ DDG/DG}\Big/_{\sum PII\ for\ DDG/DG} \right)$