Title page

Comparative analysis of the barriers to smart sustainable practices adoption in the construction industry of Hong Kong and Nigeria

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Data Availability Statement

Data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Interest

None

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Abstract

The deployment of digital systems has facilitated process improvement in building construction, including for green practices implementation. However, it has encountered several challenges that have limited its use and hindered the diffusion of sustainable practices. Hence, this study aims to identify and assess the major barriers to smart-sustainable practices (SSP) adoption and evaluate its likely impact. A quantitative research method using empirical questionnaire surveys to solicit stakeholders' perceptions in Hong Kong and Nigeria to understand whether there is a commonality in the identified barriers between the two contexts. The collated data were analysed using descriptive statistics such as mean and inferential statistics (factor analysis), while fuzzy synthetic evaluation was used to develop the predictive models. Using non-probability sampling techniques, 97 and 69 responses were gotten from respondents in Hong Kong and Nigeria, respectively. The results revealed that workforce expertise, hesitancy to change from working practices, technical know-how, and inadequate understanding of the SSP process as the most critical barriers to SSP diffusion in Hong Kong and Nigeria. Also, impact evaluation models were developed as a predictive tool to evaluate and respond to the impact of these barriers. It is recommended for industry practitioners and policymakers to collaborate to create local context-based guidelines for facilitating SSP diffusion and monitor its implementation.

Keywords: barrier; BIM; construction industry; digital system; predictive tool; sustainability practices; fuzzy synthetic evaluation.

1. Introduction

Buildings are a major product of the construction industry, where more than 80% of human's daily activities are spent. The construction sector is notable for its huge use of raw materials, carbon emissions, and waste generation, which negatively impact the environment (Purvis *et al.*, 2018) on the environment. The industry also accounts for 6% of the global gross domestic product, consumes 50% of global steel, and over 3 billion tonnes of raw materials (World Economic Forum, 2016). In Hong Kong, construction wastes have been a major environmental sustainability concern over the past decade (Wong and Fan, 2013). Meanwhile, Nigeria's urban population surge has led to the continual depletion of non-renewable resources (Daptardar and Gore, 2019). The emergence of digital technologies has been taunted to help alleviate some of these sustainability concerns (Li *et al.*, 2022) and transform the way buildings are built and operated; however, it comes with its barrage of challenges. Also, the persistent problems of conflicting stakeholders' interests, coordination, and expertise are seen as possible blockages to using these innovative systems in the industry (Bouhmoud and Loudyi, 2020; Li *et al.*, 2022).

In practical cases, where digital systems like BIM, RFID, cloud-BIM, and other internet of things (IoT) have been deployed for sustainability analysis: challenges relating to non-uniform standard definition for green practices implementation (Zanni *et al.*, 2017), larger emphasis on environmental issues, especially energy (Attia *et al.*, 2009; Illankoon *et al.*, 2017), immaturity of these IoT technologies (Zhang *et al.*, 2020) crops up. Meanwhile, Martin *et al.* (2018) reported that there is little empirical verification of the capability of digital tools to resolve sustainability problems. In that vein, Martin *et al.* (2019) proposed a 'Triangulum initiative' to integrate environmental and digital initiatives, which is expected to ease the management of the smart-sustainability implementation. Similarly, Zhang *et al.* (2018) explored the use of BIM as a digital tool to facilitate lean construction and reduce construction waste. Industry practitioners, academics, and environmental organisations alike have highlighted the several benefits of implementing smart-sustainable practices (SSP) in buildings to address climate change and reduce carbon emissions (Hu *et al.*, 2020). However, the benefits will not be realised without addressing the bottlenecks limiting SSP diffusion and implementation in building projects. For instance, in Malaysia, Manzoor *et al.* (2021) discussed some implementation barriers to using BIM to facilitate sustainable building projects and identified the absence of standards and guidelines as the most critical barriers.

Hence, two research gaps in SSP implementation must be addressed to resolve these bottlenecks. Firstly, the extant literature mostly emphasises cost, interoperability issues, and top management commitment as the barriers to green practices implementation in the industry. However, challenges relating to compatibility, security risks, and data are growing in practice (Turk and Klinc, 2017; Ansah *et al.*, 2019). These emerging and others will be investigated in the current study. Secondly, the technological 'digital-divide' among countries (Saka and Chan, 2019a) has resulted in varied diffusion in the use of innovative systems for sustainability analysis globally (Jung and Lee, 2015).

Therefore, the current study aims to investigate whether there is a commonality in the barriers affecting SSP implementation between developed and developing countries using Hong Kong and Nigeria as case studies. In achieving the study aims, (i) the key SSP barriers and barrier clusters in both contexts will be identified, and (ii) a predictive tool (impact evaluation models) will be developed to help professionals recognise and respond to the identified SSP barriers. Hong Kong has advanced significantly in its use of digital systems for sustainability system (Chan *et al.*, 2019a), apart from its being a major financial hub in Asia. In contrast, Nigeria has the largest economy in sub-Saharan Africa (Terwase *et al.*, 2014), with a huge prospect for SSP diffusion in its construction market.

Moreover, previous studies were reviewed, which led to the consolidated SSP barriers (Table 1) and data from questionnaires and its subsequent analysis: using mean ranking to identify the key barriers, factor analysis (to deduce the factor clusters) helped establish the commonality in the key barriers between Hong Kong and Nigeria. More so, a combination of normalisation and fuzzy synthetic evaluation tools were used in developing the study's predictive tool, which is presented in subsequent sections. The overall research model for this study is depicted in Figure 1, while further discussions and comparative analysis on the top 6 barrier factors were undertaken. The study findings are expected to provide stakeholders with a valuable, objective, and predictive tool to evaluate and benchmark the impact of the identified SSP barriers in their projects and provide empirical support for policymakers and firms in tackling the challenges of smart sustainable construction among others.

2. Literature review

2.1 Smart sustainable practices: Overview of its implementation challenges

Smart sustainable practices involve using digital tools to achieve sustainability (Olawumi *et al.*, 2018). Due to the many benefits derivable from BIM and green building tools, construction stakeholders have sought to use it to mitigate the effect of buildings and infrastructure on the environment (Maskil-leitan *et al.*, 2020). A desktop literature review revealed that BIM is the most commonly used digital tool to drive building sustainability strategies. For instance, Carvalho et al. (2020) utilised BIM for some sustainability analysis involving both lifecycle assessment and green building evaluation. Using a building case study in Portugal, the study shows the possibility of digital tools like BIM to process sustainability data for decision making.

However, the lack of building material data and immaturity of existing tools harpers the reliability of the analysis (Carvalho *et al.*, 2020).

As buildings contribute significantly to global carbon emissions (about 40%), of which the embodied carbon emissions of building materials (especially those of existing building stocks) have a higher proportion. Hence, the unavailability of data on building materials constitutes a critical barrier. There has recently been momentum to apply artificial intelligence (AI) for green buildings (Debrah *et al.*, 2022), and AI relies heavily on data. Apart from BIM, other digital tools such as RFID (Fang *et al.*, 2016), simulation (Penna *et al.*, 2015), cloud-BIM (Wu and Issa, 2012), and big data analytics-based framework (Shukla and Mattar, 2019) have been used in studies to address sustainability issues. A common barrier to the use of these tools is the capital costs of investing in them and retraining staff (Olawumi and Chan, 2022a).

Meanwhile, addressing these sustainability concerns spans beyond the design of buildings to their operation and final demolition. Hence, the need for a smart digital system that can embed building data across its lifecycle. From this smart-sustainability fix lies another bottleneck of green practices diffusion in the built environment, as there is no current system that can achieve that. Ansah et al. (2019) pointed out that BIM, despite being the "go-to" system for sustainability analysis; its model databases can only store quantitative data. In the quest to address this comes the need for an integrated hub of digital solutions, which leads to more complicated problems such as the issues of incompatibility, data interoperability, legal and contractual bottlenecks, immaturity of technology, need for technical support, lack of operational standard as well as an attendant increase in cost to the construction company (Olawumi *et al.*, 2018; Bouhmoud and Loudyi, 2020). Also, using a case study of India, Daptardar and Gore (2019) posited that innovation in SSP practices which hitherto has been limited to environmental issues, should be extended to social equity and economic aspects of buildings.

2.2 Status of development of smart-sustainable practices in Hong Kong and Nigeria

There are varying levels of smart-sustainable practices in the construction industry of Hong Kong and Nigeria due to the convergence of diverse factors such as government support, level of BIM and IoTs awareness and adoption, standards, and guidelines, among others. Hong Kong, in particular, has recorded significant milestones in SSP diffusion because of intentional approaches in its construction industry over the years (Olawumi and Chan, 2022b). One of the key development areas in the Hong Kong Government Smart City's Blueprint is the smart environment in which green, energy-efficient and intelligent buildings represent a major area of concern (HKGov, 2020). Also, the availability of BEAM plus for green building assessment, BIM policies, the industry readiness and support from organisations are key contributors. Thus, SSP has been gaining more attention in practice and research in Hong Kong.

For instance, per Shmelev and Shmeleva (2019), Hong Kong is ranked as one of the top smart megacities that prioritize environmental concerns, which is reflected in its construction sector and other economic sectors. However, Kang et al. (2022) identified a deficit in the use of IoT and smart BIM to address sustainability issues like waste. On the other hand, the construction industry in Nigeria is still grappling with the implementation of technologies such as BIM and green practices, which are still widely employed. This results from a lack of government-driven initiative and support for BIM, high capital cost, unavailability of standards, and resistance to change in the industry (Olawumi and Chan, 2020; Ojo *et al.*, 2021).

Similarly, there are no uniform standards for green building assessment in Nigeria, except for the recent BSAM scheme, which is yet to be widely adopted (Olawumi *et al.*, 2020). Dos Santos and Mota (2019) further discussed some of these bottlenecks to smart green practices in Africa (Nigeria inclusive) to include issues ranging from economic, social, environmental, and political ills. Consequently, the current level of SSP in Nigeria lags that of the Hong Kong construction industry. Hence, this paper intends to bridge these research gaps and investigate the disparity between these countries in terms of the key barriers to SSP implementation.

3. Research methodology

The study examines the barriers to SSP implementation from a post-positivist research paradigm (Chilisa and Kawulich, 2012) as the perceptions of the invited respondents on the subject matter stem from and are influenced by their own experience and culture of their organisation. Hence, this study uses the fuzzy synthetic evaluation method to minimise such biases and objectify the subjectiveness when developing the predictive models. Also, a deductive research approach (Villiers and Fouché, 2015) was employed in which existing background knowledge of SSP practices is evaluated in a new context to arrive at definite facts.

According to Chilisa and Kawulich (2012), methodologies such as quantitative research methods such as questionnaires, experiments, and observations are best used with this type of research philosophy. Hence, a quantitative research approach was adopted to achieve the research aim, which involves an extensive review of studies, surveys, and data analysis (Figure 1) via a cross-sectional research study. Moreover, as smart-sustainable practices, diffusion is a socio-technical dimension; two key theories: the theory of planned behaviour (TPB) and the technology acceptance model (TAM), can be applied. Both TAM and TPM adequately addressed the intention and attitude useful in predicting behaviours of technological diffusion (Mathieson, 1991; Cheng, 2019). However, TAM does not consider the social construct which TPM depends on in predicting behaviour. Hence, TPM represents a suitable theoretical lens for this study. Also, TPM provides insights into the role of external variables in behavioural intentions (Cheng, 2019; Clubbs *et al.*, 2021). Prior to the questionnaire distributions, the survey instrument was pre-tested. Fourteen experts (7 each from academics and industry practitioners) were involved in pre-testing the survey instruments. Two-thirds of the experts have at least 11 years of experience in the construction industry.

The study extended a list of key barriers to smart-sustainable practices (SSP) highlighted in Olawumi and Chan (2020) by investigating it within the context of Hong Kong and Nigeria. The approach of reusing list of factors or constructs is commonplace in the extant literature, which has helped improve the replicability of research and extend the scope of the previous research. For instance, Mom et al. (2014) reused the research variables on BIM adoption in Taiwan that Tsai *et al.* (2014) investigated. However, Cheng and Phillips (2014) recommended that the original variables be recoded before reusing the factors for new studies. Hence, Table 1 shows the list of the barrier factors examined in this study.

3.1 Selection criteria and sampling methods

The population for the study is construction professionals – academics and practitioners alike in the built environment; as it is common in construction studies (Xu *et al.*, 2010; Chan *et al.*, 2014) to include survey/interview participants from both areas of practice towards facilitating cross-fertilisation of ideas and bridging the differing perspectives. Hence, Hong Kong and Nigerian construction professionals constitute the sampling frame for this research. According to Taherdoost (2016), there are two sampling techniques: probability and non-probability sampling. The best approach is to consider the whole population while undertaking research. However, as that is practically impossible, selecting the appropriate sample (subset) (Acharya *et al.*, 2013) of the population is very important.

Moreover, as the current research requires specific expertise and characteristics from the respondents, a non-probability sampling (NPS) method is appropriate. This is especially important when these sets of people hold important views of ideas or issues at stake (Campbell *et al.*, 2020). Hence, purposive and snowballing sampling (a type of NPS) was used in selecting the respondents that met the selection criteria. According to Rai and Thapa (2015) and Bernard (2017), when using an NPS technique, the selected sample is based on a set of criteria: specialist knowledge, capacity, willingness to participate, and ability to communicate experience and opinions. Hence, the two selection criteria were defined, which are (i) knowledge and experience in BIM and sustainability practices and (ii) working knowledge of the construction industry in Nigeria or Hong Kong. As the goal of an NPS is to randomly select samples from the population (Etikan, 2017), it is not representative of the population but is constructed to serve the research design or a specific purpose of the research (Rai and Thapa, 2015).

Given the above, the questionnaire forms were distributed to Hong Kong and Nigerian construction professionals that fit the criteria. The survey form was distributed over a six-month period. Demographic information was requested in the survey form. The invited respondents were also to rank the identified barriers on a 5-point Likert scale (1=*strongly disagree, 3=neutral, 5=strongly agree*). Distribution means such as emails, LinkedIn, and ResearchGate were used to administer the survey. The authors requested their support to send the survey form to their colleagues that fit the selection criteria. Therefore, it was impracticable to determine the number of respondents reached.

Moreover, 69 and 97 survey responses were received from Nigeria and Hong Kong respondents, respectively. The sample sizes are deemed adequate compared to previous studies, which averaged 20–30 responses (Osei-Kyei and Chan, 2018; Chan *et al.*, 2019a).

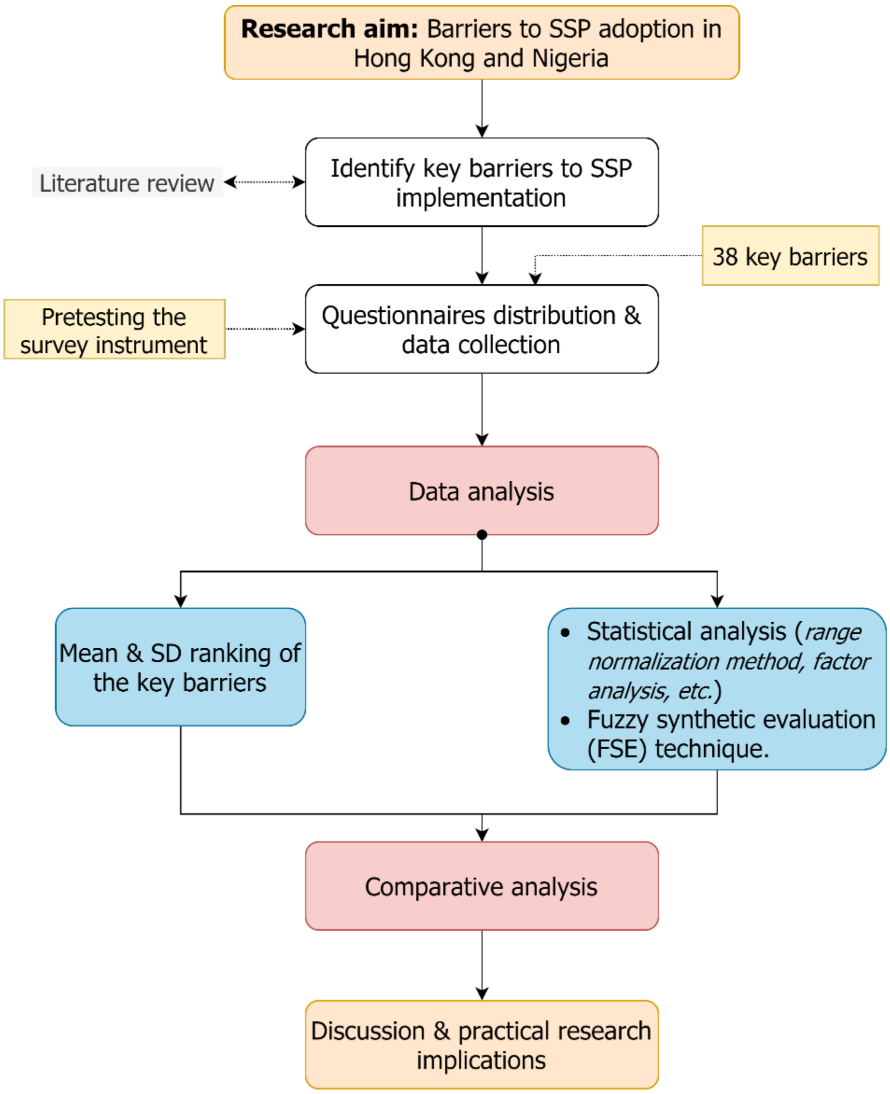

Figure 1: Overall research design of the study

Table 1: Barriers to the adoption of SSP. Adapted from (Olawumi and Chan, 2020)

Code	Key barriers	References
KB1	Varied market readiness across organizations and geographic locations	1, 2, 3, 4
KB2	Industry's resistance to change from traditional working practices.	2, 3, 5, 6
KB3	Lack of client demand and top management commitment	7, 3, 4
KB4	Lack of support and involvement of the government	8
KB5	Low level of involvement of BIM users in green projects	1, 9
KB6	Societal reluctance to change from traditional values or culture	7, 3, 4
KB7	The lack of awareness and collaboration among project stakeholders	1, 8, 2, 9
KB8	Inadequacy of requisite experience, knowledge, and skills from the workforce	7, 2, 3
KB9	Longer time in adapting to new technologies (steep learning curve)	7
KB10	Lack of understanding of the processes and workflows required for BIM and sustainability	7
KB11	Low level of research in the industry and academia	7, 1, 4
KB12	Inadequate in-depth expertise and know-how to operate sustainability-related analysis software programs	10, 1, 2
KB13	Shortage of cross-field specialists in BIM and sustainability	9
KB14	The high cost of BIM software, license, and associated applications	7, 3
KB15	The high initial investment in staff training costs	7, 3
KB16	Recurring need for additional and associated resources and high economic expenses	11
KB17	Lack of initiative and hesitance on future investments	2
KB18	Fragmented nature of the construction industry	1, 2, 3, 4
KB19	Organizational challenges, policy, and project strategy	12
KB20	Difficulty in assessing environmental parameters of building properties	13
KB21	Difficulty in accessing sustainability-related data (such as safety, health, and pollution index, etc.)	1, 14
KB22	The risk of losing intellectual property and rights	3, 4
KB23	Difficulty in allocating and sharing BIM-related risks	3
KB24	Lack of legal framework and contract uncertainties	7, 4
KB25	Increased risk and liability	3
KB26	Lack of suitable procurement policy and contractual agreements	7
KB27	Non-uniformity of sustainability evaluation criteria and measures	1
KB28	Lack of a comprehensive framework and implementation plan for sustainability	4
KB29	Absence or non-uniformity of industry standards for sustainability	12
KB30	Inaccuracy and uncertainty in sustainability assessments for projects	1, 10
KB31	Incompatibility issues with different software packages	1, 3
KB32	Absence of industry standards for BIM	1, 4
KB33	Insufficient level of support from the BIM software developers	4
KB34	Inadequacy of BIM data schemas to semantically represent sustainability-based knowledge	5, 6, 15
KB35	Lack of supporting sustainability analysis tools	13
KB36	Non-implementation of open-source principles for software development	9
KB37	Domination of the market by commercial assessment tools	9
KB38	User-unfriendliness of BIM analysis software programs	10

References: 1= Antón and Díaz (2014); 2= Gu and London (2010); 3= Kivits and Furneaux (2013); 4= Redmond et al. (2012); 5= Chan et al. (2019a); 6= Chan et al. (2019b); 7= Aibinu and Venkatesh (2014); 8= Zahrizan et al. (2013); 9= Hope and Alwan (2012); 10= Ahn et al. (2014); 11= Aranda-Mena et al. (2009); 12= Boktor et al. (2014); 13= Akinade et al. (2017); 14= Olawumi and Chan (2019a); 15= Olawumi and Chan (2019c);

3.2 Statistical analysis tools

Statistical methods employed in analysing the collected data include Cronbach's alpha reliability test (α-value), means item score (MS), standard deviation (SD), factor analysis, and fuzzy synthetic evaluation (FSE) method. The α-value ranges from 0 to 1 and was used to test the reliability of the survey instrument (Field, 2009) and an α-value of 0.7 and above is considered adequate (Saka and Chan, 2019b). The α-value for this study is 0.971 (Hong Kong) and 0.921 (Nigeria). The MS is the average value of the responses and is a measure of the central tendency. The MS and SD values were used in ranking factors; where the factors have the same MS values, the factor with smaller SD values are ranked higher (Olatunji *et al.*, 2017). The factor analysis (FA) is a technique used in analysing the underlying relationships in measured variables by reducing the large variables to manageable sizes and explaining difficult concepts (Xu *et al.*, 2010). A pre-test evaluation is carried out using the Kaiser-Meyer-Olkin (KMO) tests, Bartlett's test of sphericity (BTS), and the correlation matrix (Chan and Choi, 2015).

Fuzzy Synthetic Evaluation is an application of fuzzy theory to assess multicriteria decision-making (Osei-Kyei and Chan, 2018). The FSE technique deals with human judgement and accounts for the fuzziness, thereby objectifying the subjectiveness. As the FSE method is a fuzzy-based approach, it uses mathematical computing to quantify and analyse linguistics criteria or variables during decision-making. Readers interested in the FSE technique are referred to Liao et al. (2019). Given this, the respondents ranked the key barriers of SSP according to the linguistic terms (Likert scales) which were categorized into different groups using the FA and the FSE techniques as discussed in the next section. The results from Nigeria and Hong Kong contexts form the basis for the comparative analysis.

4. Results of data analysis

The results of the data analysis are presented in this section.

4.1 Survey respondents' demographics

Figure 2 illustrates the distribution of the respondents based on their working experience in the construction industry. The respondents are from diverse backgrounds ranging from academics to industry practitioners. Majority of Hong Kong respondents are from public sector clients (38 respondents) and main contractors (24), while those in Nigeria are mostly academics (34) and consultancy firms (13). In terms of working experience in the construction industry, 47% (Hong Kong) and 33% (Nigeria) of the respondents have more than 10 years of experience. Particularly, 30 respondents from Hong Kong have more than 20 years of working experience. The demographic analysis provides evidence of the expertise of the respondents; hence, their responses can be relied upon for further analysis.

Also, both set of respondents regards the planning and design stages as the most suitable stage of a building project to implement smart-sustainable practices. As experience in the construction industry might not be proportionate to expertise or awareness of the SSP concept. Data were collected on the respondents' awareness of BIM and sustainable practices

(Figure 3). Majority of the respondents in Hong Kong and Nigeria do have adequate experience and awareness in SSP, which further lends credence to the collated data.

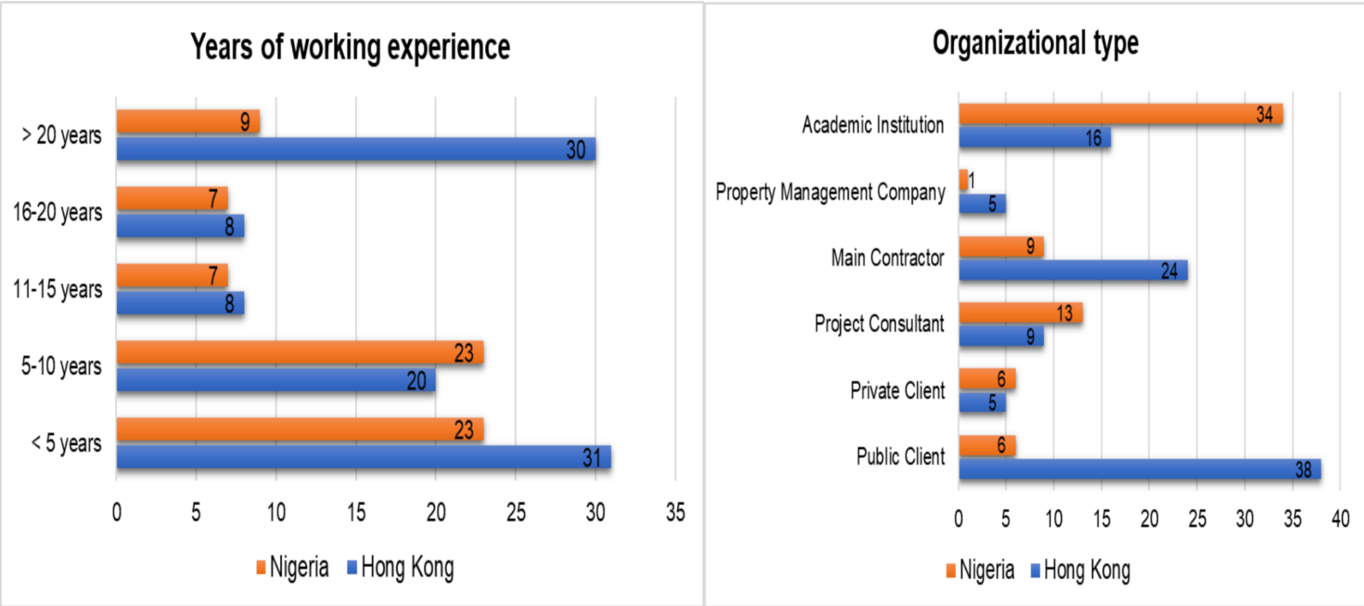

Figure 2: Respondents' demographics
Data source: Authors' survey

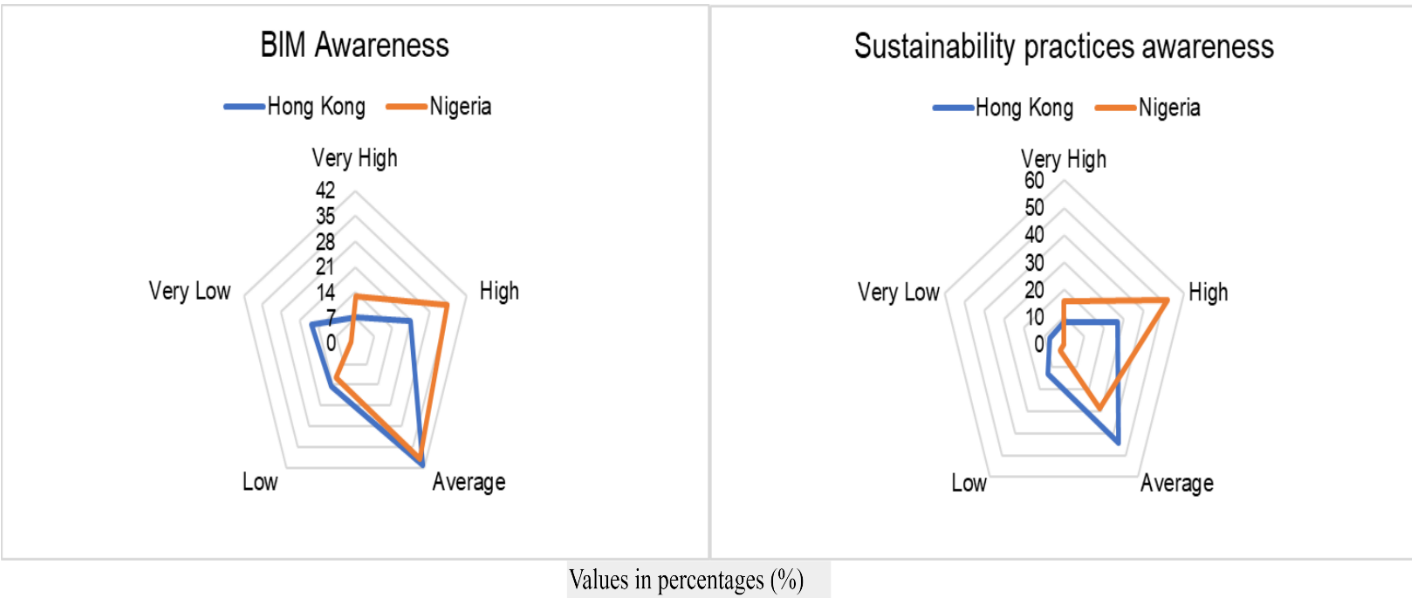

Figure 3: Respondent's level of BIM and sustainability practices awareness
Data source: Authors' survey

4.2 Ranking and normalization of the key barriers to SSP adoption

Table 2 shows the overall ranking of the key barriers from the Hong Kong and Nigeria contexts. The top-ranked barrier is *"Inadequacy of requisite experience, knowledge, and skills from the workforce'* (KB8) with MS=3.90 (Hong Kong) and MS=4.41 (Nigeria), while the least ranked are "*Increased risk and liability"* (KB25) and "*User-unfriendliness of BIM analysis software programs*" (KB38) with MS=3.28 and MS=3.46 in Hong Kong and Nigeria, respectively.

Factor normalization. The MS of the key barriers were normalized using the range normalization method (N_m), as shown in equation 1 (Olawumi and Chan, 2022b). The key factors with N_m values>0.5 are considered the most significant barriers to SSP (Xu *et al.*, 2010). Based on the analysis of N_m results, 17 and 21 of the barrier factors are considered as the key barriers in Hong Kong and Nigeria, respectively.

$$N_m = \frac{M_n - M_{min}}{M_{max} - M_{min}} \quad ------------------ (1)$$

Where M_n= MS for the selected barrier factor; M_{min}=minimum MS for the set of barriers; and M_{max}=maximum MS for the set of barrier factors.

Pearson correlation analysis of the key barrier factors in Nigeria shows that KB29 is correlated to KB27 (ρ=0.628), KB15 is correlated to KB16 (ρ=0.517), and KB14 is correlated to KB16 (ρ=0.524). Thus, KB16 replaced KB14 and KB15 whilst KB27 replaced KB29 to avoid the multiplier effect. Therefore, 18 of the barriers are considered most significant in the Nigeria context after the removal of KB14, KB15, and KB29.

Table 2: Overall ranking of the barriers to SSP adoption between Hong Kong and Nigeria

Hong Kong					Nigeria				
Barriers	**Mean**	**SD**	**Rank**	**N_m**	**Barriers**	**Mean**	**SD**	**Rank**	**N_m**
KB8	3.90	0.93	1	1.000	KB8	4.41	0.81	1	1.000
KB9	3.87	0.92	2	0.950	KB14*	4.35	0.80	2	0.938
KB15	3.87	0.93	3	0.950	KB2	4.33	0.70	3	0.923
KB13	3.86	0.98	4	0.933	KB4	4.29	0.81	4	0.877
KB14	3.78	0.98	5	0.817	KB3	4.28	0.80	5	0.862
KB1	3.76	0.84	6	0.783	KB10	4.26	0.76	6	0.846
KB2	3.76	1.00	7	0.783	KB15*	4.20	0.78	7	0.785
KB12	3.73	0.90	8	0.733	KB7	4.19	0.77	8	0.769
KB10	3.71	0.87	9	0.700	KB9	4.19	0.83	9	0.769
KB31	3.70	0.87	10	0.683	KB19	4.14	0.79	10	0.723
KB16	3.69	0.83	11	0.667	KB1	4.12	0.78	11	0.692
KB19	3.68	0.76	12	0.650	KB13	4.12	0.90	12	0.692
KB32	3.67	1.03	13	0.633	KB28	4.09	0.78	13	0.662
KB29	3.64	0.74	14	0.583	KB12	4.07	0.93	14	0.646
KB18	3.63	0.91	15	0.567	KB16	4.00	0.84	15	0.569
KB17	3.62	0.88	16	0.550	KB29*	4.00	0.87	16	0.569
KB27	3.60	0.77	**17**	**0.517**	KB32	4.00	0.91	17	0.569
KB7	3.58	0.96	18	0.483	KB18	3.97	0.95	18	0.538
KB33	3.58	0.83	19	0.483	KB27	3.96	0.83	19	0.523
KB35	3.57	0.79	20	0.467	KB5	3.96	0.88	20	0.523
KB37	3.56	0.83	21	0.450	KB6	3.96	1.04	**21**	**0.523**
KB28	3.55	0.76	22	0.433	KB30	3.93	0.81	22	0.492
KB3	3.55	0.92	23	0.433	KB21	3.90	0.84	23	0.462
KB5	3.54	0.94	24	0.417	KB31	3.90	0.99	24	0.462
KB34	3.53	0.87	25	0.400	KB34	3.86	0.94	25	0.415
KB21	3.52	0.86	26	0.383	KB17	3.84	0.85	26	0.400
KB30	3.51	0.79	27	0.367	KB26	3.84	1.02	27	0.400
KB24	3.51	0.87	28	0.367	KB20	3.83	0.84	28	0.385
KB20	3.49	0.83	29	0.350	KB24	3.77	1.00	29	0.323
KB6	3.49	0.98	30	0.350	KB35	3.74	0.96	30	0.292
KB36	3.47	0.86	31	0.317	KB23	3.72	0.98	31	0.277
KB26	3.45	0.96	32	0.283	KB11	3.70	1.05	32	0.246
KB4	3.43	1.06	33	0.250	KB33	3.70	1.05	32	0.246

Hong Kong					Nigeria				
Barriers	Mean	SD	Rank	N_m	Barriers	Mean	SD	Rank	N_m
KB23	3.41	0.88	34	0.217	KB36	3.68	0.99	34	0.231
KB11	3.35	0.92	35	0.117	KB37	3.67	1.13	35	0.215
KB38	3.33	0.94	36	0.083	KB25	3.58	0.98	36	0.123
KB22	3.29	0.96	37	0.017	KB22	3.55	1.06	37	0.092
KB25	3.28	0.84	38	0.000	KB38	3.46	1.12	38	0.000

*Note: *barrier factors which correlate (at p<0.05) were removed from the key barriers.*
Data source: Authors' survey

4.3 Factor analysis

The principal component analysis (PCA) was adopted to classify the key factors. These factor categories (FC) were extracted based on their eigenvalues (≥1), resulting in 3 and 6 FC for the Hong Kong and Nigeria contexts, respectively. The α-value of the constructs is 0.971 (Hong Kong) and 0.921 (Nigeria) which are above the minimum threshold of 0.70 (Olatunji *et al.*, 2017). Validation tests were carried out using KMO and the BTS tests. The BTS shows the chi-square value to be 1254.028 (p-value=0.000, df=136) in Hong Kong and chi-square of 415.764 (p-value=0.000, df=153) in Nigeria. The BTS results show that the factors are related and not an identity matrix (Olawumi and Chan, 2022b). Also, the KMO values for Hong Kong and Nigeria are 0.908 and 0.690, respectively, making the data suitable for structure detection via the FA.

All the factor loadings are above the 0.5 recommended value, as shown in Table 3 (Nigeria) and Table 4 (Hong Kong). Each category was given a distinct label to reflect its underlying factors' general theme. The three and six-factor categories extracted for the Hong Kong and Nigeria contexts represent 68% and 69% of the total variance, which are above the minimum threshold of 60% (Hair *et al.*, 2010).

Table 3: Factor structure for the key barriers (Nigeria context)

Key barriers	Factor loadings	Eigenvalue	% Variance explained	Cumulative % of variance explained
BCN1 - Experience and technical know-how		4.747	26.374	26.374
KB12	0.777			
KB13	0.732			
KB8	0.701			
KB10	0.684			
KB9	0.645			
BCN2 - Stakeholders' hesitancy and commitment		1.921	10.670	37.045
KB6	0.735			
KB4	0.694			
KB5	0.625			
KB3	0.621			
BCN3 - Technology and financial constraints		1.721	9.559	46.604
KB16	0.713			
KB32	0.681			
KB7	0.560			

Key barriers	Factor loadings	Eigenvalue	% Variance explained	Cumulative % of variance explained
BCN4 - Business process complexity		1.483	8.240	54.844
KB18	0.845			
KB19	0.665			
BCN5 - Non-standardised data and models		1.241	6.894	61.738
KB27	0.835			
KB28	0.623			
BCN6 - Insufficient industry uptake		1.120	6.220	**67.957**
KB1	0.821			
KB2	0.608			

Note: The full descriptions for the barrier factor codes are shown in Table 1.
Data source: Authors' survey

Table 4: Factor structure for the key barriers (Hong Kong)

Key barriers	Factor loadings	Eigenvalue	% Variance explained	Cumulative % of variance explained
BCH1- Limited cross-field expertise		9.464	55.671	55.671
KB12	0.811			
KB8	0.811			
KB13	0.772			
KB2	0.683			
KB10	0.670			
KB9	0.646			
KB1	0.582			
KB17	0.533			
KB18	0.512			
BCH2 - Non-standardised data and compatibility issues		1.225	7.206	62.877
KB31	0.816			
KB19	0.728			
KB29	0.717			
KB32	0.710			
KB27	0.639			
BCH3 - Financial constraints		1.049	6.173	**69.050**
KB15	0.881			
KB14	0.829			
KB16	0.671			

Data source: Authors' survey

4.4 Weighting and membership function of clustered barriers

The weighting and membership function for the barriers' categories (level 1) and for each key barrier factor in each category (level 2) were generated in this section. The weighting is calculated using equation 2.

$$W_i = \frac{MS_i}{\sum_{i=1}^{5} MS_i} \quad where\ 0 \leq W_i \leq 1, \qquad and\ \sum W_i = 1 \quad ------(2)$$

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

For instance, BCN3 *"technology and financial constraints"* (ΣMS value=12.19) in the Nigeria context, which include KB16 (MS=4.00), KB32 (MS=4.00), and KB7 (MS=4.19); the weighting for BCN3 can be calculated as:

$$W_{BCN3} = \frac{4.19}{4.00 + 4.00 + 4.19} = \frac{4.19}{12.19} = 0.344$$

The calculation is repeated for all the key barriers and categories.

4.4.1 Membership functions of the barriers categories

The membership functions (MF) of the key barriers (level 2) are calculated prior to evaluating the factor categories. MF is the degree of an element membership in a fuzzy set, and the value ranges from 0 to 1. The MF of level 2 is determined by the ratings of the experts based on grades (g_1=strongly disagree, g_3=neutral, and g_5=strongly agree). Thus, the MF for factor KB12 in the Nigeria context where 1% of the respondents rated the factor as 'strongly disagree', whilst 6, 13, 44, and 36% of the respondents rated it as *'disagree', 'neutral', 'agree' and 'strongly agree'* respectively as computed:

$$MF_{KB12} = \frac{0.01}{g1} + \frac{0.06}{g2} + \frac{0.13}{g3} + \frac{0.44}{g4} + \frac{0.36}{g5}$$

The MF for KB12 is expressed as (0.01, 0.06, 0.13, 0.44, 0.36). Similarly, the MF for the 18 and 17 key barriers were computed for Nigeria and Hong Kong, respectively. The MF at level 3 is computed using equation 3 (Xu *et al.*, 2010).

$$F = W_i{\circ}R_i \qquad ----------(3)$$

W_i is the weighting of all the barriers within each category and R_i is the fuzzy evaluation matrix. For instance, the MF level 1 for BCH3 in the Hong Kong context is computed as:

$$F_{BCH3} = \begin{vmatrix} 0.341 \\ 0.333 \\ 0.325 \end{vmatrix} \times \begin{vmatrix} 0.02 & 0.05 & 0.23 & 0.44 & 0.26 \\ 0.02 & 0.07 & 0.27 & 0.38 & 0.26 \\ 0.02 & 0.03 & 0.33 & 0.47 & 0.15 \end{vmatrix} = (0.02 \quad 0.05 \quad 0.28 \quad 0.43 \quad 0.22)$$

The MF function for other categories (level 1) in Nigeria and Hong Kong contexts was computed using the same approach.

4.5 Defuzzification of clustered barriers

The MF at level 1 is defuzzify to determine the impact index of these barriers of SSP adoption for decision-makers assessment using equation 4.

$$II_{BC} = \sum_{I=1}^{5} F \times g \quad ---------------(4)$$

Where II_{BC}= Impact Index

For instance, the II_{BC} for BCH3 in the Hong Kong context is computed as:

$$II_{(BCH3)} = (0.02, 0.05, 0.28, 0.43, 0.22) \times (1, 2, 3, 4, 5) = 3.79$$

Similarly, other MF is defuzzify for the two contexts, as shown in Table 5. The coefficient is computed using equation 5.

$$^{y}Coefficient = \left({}^{II\ for\ BCN/BCH} \Big/ {}_{\sum II\ for\ BCN/BCH} \right) - - - - - - - - - - - - - - \text{(5)}$$

Table 5: Impact Index for BCN/BCH for SSP adoption between Nigeria and Hong Kong

Barrier categories	Impact Index (II_{BC})	Coefficients (μ)
Nigeria		
BCN1- Experience and technical know-how	4.22	0.170
BCN2- Stakeholders' hesitancy and commitment	4.14	0.167
BCN3- Technology and financial constraints	4.06	0.164
BCN4- Business process complexity	4.08	0.165
BCN5- Non-standardised data and models	4.04	0.163
BCN6- Insufficient industry uptake	4.23	0.171
Total	**24.76**	**1.000**
Hong Kong		
BCH1- Limited cross-field expertise	3.77	0.336
BCH2- Non-standardised data and compatibility issues	3.66	0.326
BCH3- Financial constraints	3.79	0.338
Total	**11.22**	**1.000**

Data source: Authors' survey

4.6 Overall impact evaluation models

An additive and linear approach was adopted in developing the overall impact models (B_{ii}) for the SSP adoption in the two contexts. The factor categories form the independent variables for the linear equation, which is useful in evaluating the impact of the key barriers on SSP implementation. According to Hu et al. (2016), a linear equation can be used when the underlying factors do not correlate as such equations are easier to apply.

The impact level of each factor category is normalized using equation 5, which sums up to unity. The B_{ii} evaluation of the key barriers in the Nigeria context is derived from Table 5 as shown:

$$B_{ii} = (0.170 \times Experience\ and\ technical\ know-how) \\ + (0.167 \times Stakeholders'\,hesitancy\ and\ commitment) \\ + (0.164 \times Technology\ and\ financial\ constraints) \\ + (0.165 \times Business\ process\ complexity) \\ + (0.163 \times Non-standardised\ data\ and\ models) \\ + (0.171 \times Insufficient\ industry\ uptake) ------------ (6)$$

Similarly, for the Hong Kong context:

$$B_{ii} = (0.336 \times Limited\ cross-field\ expertise) \\ + (0.326 \times Non-standardised\ data\ and\ compatibility\ issues) \\ + (0.338 \times Financial\ constraints) -------------- (7)$$

5. Discussion of analytical results

The impact evaluation models presented in Section 4.6 evidently show that the critical barriers to SSP implementation in Nigeria and Hong Kong stem from the clusters of barriers under the factor groups “insufficient industry uptake” (μ=0.171) and “Financial constraints” (μ=0.338), respectively. When adopted by industry stakeholders, the impact models will provide them with a metric to objectively measure the influence of these barrier clusters on their quest to apply smart sustainability practices in construction projects.

Moreover, to allow for comparative analysis of these barrier clusters (factor groups) based on the findings from Hong Kong and Nigeria – the authors introduce four cluster labels. Each cluster label contains factor groups from Hong Kong and Nigeria in which the constituent barrier is somewhat similar. These comparison cluster labels are (i) “Industry uptake and technical know-how”, which comprises factor groups such as BCN6, BCN1 (Nigeria) and BCH1 (Hong Kong). (ii) “Business process complexity and non-standardised data”, which comprises BCN4, BCN5 (Nigeria) and BCH2 (Hong Kong). (iii) “Technology and financial constraints”, which includes BCN3 (Nigeria) and BCH3 (Hong Kong). (iv) “Stakeholders’ hesitancy and commitment”, which consists only of BCN2 (Nigeria). As cluster label #4 only includes factor groups from Nigeria and none from Hong Kong, it will not be discussed further.

Furthermore, to conserve space, the discussion of the comparative analysis between Hong Kong and Nigeria in this study will focus on the top-two comparison cluster labels – which comprise 6 barrier factor groups and 9 barrier factors.

5.1 Industry uptake and technical know-how

The issue of workforce expertise (Factor KB8) has been a concern in the quest for the construction industry to adopt and implement SSP, and this is not just a central issue in developing countries like Nigeria (Bouhmoud and Loudyi, 2020) but a global concern in the built environment (Cao *et al.*, 2017). The experts from Hong Kong and Nigeria highlighted this factor as the most critical barrier hindering SSP implementation in their regions. Although, the situation in Hong Kong is less severe than that of Nigeria due to various governmental and industry initiatives to facilitate the awareness of BIM and sustainability in the Hong Kong construction industry (Chan *et al.*, 2019b). These initiatives might have a significant influence on cultural issues – resulting in lesser resistance to change in working practices (factor KB2) in Hong Kong compared to Nigeria – where most firms and stakeholders due to various concerns such as lack of government/management support (Ojo *et al.*, 2021), technological constraints (Bouhmoud and Loudyi, 2020) had continued their traditional approach to housing delivery. Until recently, there have been few avenues/initiatives by professional bodies in Nigeria to drive the diffusion of SSP in the country. Hence, a multi-stakeholder approach backed up by legislative policies, and government funding is critical to lessen the hesitancy of construction stakeholders in switching from current practices to innovative ones that benefit the industry and are climate friendly.

Another major barrier both sets of experts identified is the inadequate understanding of the SSP process (factor KB9). As SSP needs the human factor to be successfully implemented in the built environment, adequate knowledge and comprehensive guidelines on strategically using it to drive change are important. However, this factor has been identified to have severely limited SSP diffusion in both contexts. For instance, per Huong et al. (2021), many stakeholders misunderstand BIM – most perceive it as software rather than a system to manage the entire building process across its lifecycle. This aligns with the findings of Saka and Chan (2019a). They reported that some of the professionals in Nigeria still misunderstand SSP initiatives. As digital technologies like BIM are crucial to the seamless application of sustainable principles (Martin *et al.*, 2018), local context-based guidelines must be adopted to facilitate SSP and monitor its implementation.

Without a doubt, the influx of several digital systems in the past decade has made it difficult for stakeholders to learn to use them, resulting in another critical barrier – the steep learning curve (factor KB10). Learning curve is a concept introduced in the 1930s by Wright (Martin, 2021) and a recent study by Olawumi and Chan (2022a) shows that if stakeholders used digital systems such as cloud-based systems, BIM for sustainability issues, an efficiency rate of between 20-25% is obtainable. However, the combined effects of shortage of technical skills and rapidly changing digital tools have made this unattainable in the industry – as seen in the case of Hong Kong and Nigeria.

5.2 Business process complexity and non-standardised data

Organisation issues (factor KB19) have been acknowledged in several studies (Ogwueleka and Ikediashi, 2017; Dos Santos and Mota, 2019) that examined the prospects of innovative systems in the construction industry. In Hong Kong and Nigeria, although this issue was not ranked in the top 5 significant barriers, it was identified as a barrier in which its effect must be minimised. Some of the organisation issues are risk-sharing (Ogwueleka and Ikediashi, 2017), legal problems with data models, unclear strategy to implement new concepts, and inadequate technical support, among others. Hence, new business models and policies that support it should be formulated to ease the SSP diffusion in the industry. However, that seems not to be the case in most construction firms in Hong Kong and Nigeria, as some firms have struggled with the level of requirement and standards necessary to implement it (Cao *et al.*, 2021). Chan et al. (2019b) also reported the nonexistence of business units or departments to support its adoption within construction organizations in Hong Kong. Also, one of the global bottlenecks to SSP diffusion is the non-uniformity in sustainability metrics across regions and even countries (Illankoon *et al.*, 2017). Nigeria, for instance, has not made much progress in developing a uniform sustainability standard (Olawumi and Chan, 2019b). Ogwueleka and Ikediashi (2017) attributed this to the broader issues of lack of collaboration and coordination among stakeholders. In Hong Kong, the barrier is mitigated (Chan *et al.*, 2019b).

6. Conclusions

The current paper evidenced that despite the construction industry's quest to leverage innovative systems to facilitate sustainability practices, some deep-rooted issues have hindered its uptake by the industry. Using Hong Kong and Nigeria as study areas, data were gathered from relevant experts in both contexts to examine the key barriers and improve SSP diffusion in the industry. Despite the digital divide in SSP implementation in Hong Kong and Nigeria, most of the major bottlenecks in both contexts were considered critical by the respondents.

The study findings identified barriers related to workforce expertise, cultural issues – relating to hesitancy to change traditional working practices, steep learning curve, inadequate understanding of SSP processes, varied market readiness, technical know-how, organisational issues, and non-uniformity in sustainability metrics as the most critical barriers to SSP diffusion in Hong Kong and Nigeria. Hence, achieving the first objective of the study. The comparative analysis further revealed that there is still a shortage of required expertise in SSP among Hong Kong and Nigeria construction stakeholders. Although the issues of the unwillingness of stakeholders and organisations to switch to new working practices are more prevalent in Nigeria, this can be related to the digital divide between developing and developed countries. The developed models B_{ii} (predictive tool) – objective #2 – underscores the significance of stakeholders' technical know-how, attitude, and the market demand pressures in the Nigeria context (Eqn. 6), whilst for Hong Kong (Eqn. 7), the emphasis was the need for cross-field expertise, standardised data models to improve SSP implementation significantly.

The impact evaluation model is proposed in this study as a predictive tool for organizations and stakeholders to evaluate and respond to the likely impact of these barriers to their SSP initiatives. It can also be a basis to benchmark and compare the performance of SSP initiatives in projects. For academics and government agencies, the study has helped highlight possible barriers to SSP diffusion in a project for further in-depth investigation. The evaluation models will be more useful at the planning and design stage of a project to pinpoint likely bottlenecks to SSP implementation in the project. The findings also provide empirical support for policymakers in tackling the challenges of sustainable construction and further contribute to the existing knowledge base by exploring the contexts of Hong Kong and Nigeria while providing recommendations for advancing SSP initiatives.

As the study was carried out in Nigeria and Hong Kong, it may limit the wider application of the research findings. However, as either scenario might be applicable in other countries with similar socio-economic issues, it can make the extrapolation of the study more relevant. Future studies can examine these barriers factors in other countries and different project types.

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