

Are there any gains in Green-tech adoption? Unearthing the beneficial outcomes of smart-sustainable practices in Nigeria and Hong Kong built environment.

Abstract

Implementing Smart-sustainable practices (SSP) is crucial to achieving environmentally-friendly buildings and cities. Adequate awareness and understanding of its benefits and impacts are essential for maximizing its implementation. Hence, this study explores and establishes the key SSP benefits in the built environment of Hong Kong and Nigeria. Factors were identified through literature survey, then data was collected using questionnaires and analysed with various methods. The common key beneficial outcomes (BT) in both contexts relate to better design products with low environmental impact and enhancement of project quality and productivity. Three main clusters were established: sustainable design and resource management, innovation and business performance, and green initiatives and productivity. Based on the rank agreement analysis, there is high consensus between Hong Kong and Nigeria experts on two clustered BTs of green initiatives and sustainable products (57%) and project productivity and efficiency (100%). It is important to be cautious when applying these findings beyond the specific contexts of Nigeria and Hong Kong. The study findings have provided practical and objective means to predict and assess the probable impacts of SSP implementation while providing clients, contractors, policymakers, and practitioners with pragmatic tools and effective recommendations to promote the delivery of smart, sustainable projects worldwide.

Keywords: Benefits; BIM; built environment; fuzzy synthetic evaluation; sustainable practices.

Nomenclature

BT – Beneficial outcomes
FSE – Fuzzy Synthetic Evaluation
RAA – Rank agreement analysis
SSP – Smart-Sustainable Practices
Green-tech – Green Technology
GHG – Greenhouse gas emissions
MC – Main contractors
PC – Public clients
3Rs – reduce, reuse, and recycle

1. Introduction

Smart-sustainable practices are gaining global acceptance by countries and construction companies, especially with the availability and use of green technology in the built environment to mitigate the impact of human and construction activities on the environment. This has been prominent due to the drive to make buildings and cities more sustainable and smarter (Ahvenniemi et al., 2017). Also, among higher education institutions, it has been a salient theme in their campus sustainability policy (Chokor et al., 2016).

Buildings, whether for residential, commercial, or industrial use, have contributed negatively to environmental issues such as carbon emissions, waste, and air quality. The embodied carbon (11% of GHG) from the production, transportation, and disposal of construction materials is a key contributor to the overall carbon footprint of a building (Olawumi & Chan, 2022) and goes against the drive to mitigate climate change. According to studies (Olawumi & Chan, 2022; Oyetunji et al., 2022), buildings account for about 40% of global energy consumption and waste, 15% of usable water, 50% of all natural resources, and its operational carbon emissions account for 28% of greenhouse gases (GHG). Moreover, only 17% of global energy consumption comes from renewable sources. These statistics show the importance of green technology in reducing building carbon footprints and promoting sustainable development. Examples of these green technologies include renewable energy sources, waste reduction and recycling technologies, water conservation techniques, and carbon capture technologies. These green-tech are part of the SSP initiatives being advanced in the built environment (Jang et al., 2018; Olawumi & Chan, 2020).

The application of green-tech and SSP can result in significant energy efficiency and improvements in buildings (Olawumi et al., 2017; Pradhananga et al., 2021), which could reduce energy consumption by up to 80-90% through efficiency measures. For instance, the Future Home Standard (FHS) 2015 of the UK government is directed towards this by improving the energy efficiency, performance of building fabric, heating and hot water system, and the like. It is expected that regulations such as FHS 2015 and other existing environmental standards can help drive innovation in low-carbon building technologies and SSP initiatives in the construction sector. Moreover, it could have secondary effects of assisting clients and contractors in evidencing the positive and beneficial outcomes of SSP implementation.

The positives of sustainability and green-tech on construction projects range from its impact on capital project planning, cost and schedule performance, design, and compliance to safety and environmental issues (Beheiry et al., 2006). Accordingly, the integration of green-tech, this can further help clients and construction organisations to allocate the scarce resource, reduce its implementation risks, and manage the balance between implementing SSP and their financial bottom line (Beheiry et al., 2006; Khan et al., 2017; Olawumi & Chan, 2021).

Currently, only a small proportion of building construction projects implement SSP initiatives, including green-tech (Jung & Lee, 2015; Oyetunji et al., 2022). A key factor for this low-level implementation is attributed to the lack of awareness by key stakeholders (such as clients, contractors, etc.) of the perceived benefits and impacts of sustainable practices and green-tech implementation in building projects (Manzoor et al., 2021). As critical stakeholders in the construction project, clients are motivated when the benefits inherent in SSP implementation are clearly defined and can be evaluated in quantitative and qualitative terms. Studies such as Bonini and Swartz (2014), Ruparathna and Hewage (2015), and Zhao and Guo (2015) have examined the benefits of sustainable practices in organisations, procurement systems in Canada, and the construction sector of China – among several studies.

However, despite the saliency of this theme to facilitating sustainable development, no studies in Hong Kong and Nigeria have explored these benefits of SSP from the perspective of construction professionals. According to (Oyetunji et al., 2022), the awareness of the SSP beneficial outcomes greatly influences the success of a sustainable-driven project. Hence, the current study explored and examined the beneficial outcomes of SSP in the built environment of Hong Kong and Nigeria. Key research questions for investigation include:

i. What are the key BTs of SSP in Nigeria and Hong Kong from the perspectives of clients and contractors?
ii. How can the significance and impact of the key BTs in a project/organisation be objectively measured?
iii. What is the level of consensus/disparity on the perceptions of respondents between Nigeria and Hong Kong on the BTs?

The rationale for scoping the study to Hong Kong and Nigeria was to explore the BTs from a developing and developed economy perspective. Nigeria has the biggest economy and construction market in Africa though lagging in SSP implementation, unlike in Hong Kong. In comparison, Hong Kong is a key financial centre in the Asia region with a higher rate of SSP implementation. The study will provide better insights into the salient BTs of SSP implementation for the benefit of every stakeholder, including policymakers, clients, and contractors. It would provide an evidential basis to promote SSP, including green-tech in Nigeria and Hong Kong built environment, which is lacking in the extant literature reviewed. The novelty of this study is also reflected in the suggested academic and industry policy implications to ensure the widespread of SSP in the contrasting context of a developing and/or developed economy.

2. Beneficial outcomes of smart-sustainable practices in the built environment

The importance of smart-sustainable practices to the built environment has been discussed in the extant literature (Sun et al., 2016), especially in the aspect of sustainable construction, energy and resource efficiency, safe communities, and low-carbon infrastructure. Azhar (2011) posited that the demand for environmentally friendly buildings and fuel-efficient transport had driven most urban policies and frameworks for housing and infrastructure. Countries in regions such as North America, Oceania, and Europe have recorded significant progress in implementing SSP initiatives and green-tech compared to other continents (Jung & Lee, 2015). Despite the advancement in these regions, there are still untapped potential and opportunities (Wu & Issa, 2014).

A study by Beheiry et al. (2006) developed a corporate sustainability commitment index (CSCI) to measure how the adoption of SSP, in turn, can lead to higher project performance, especially in aspects of cost and schedule predictability. The findings of the study revealed the direct link between higher management commitment and having a better sustainable and successful capital project. Also, from the developed CSCI metric, one of the benefits of implementing SSP in a project can be further enhanced by increased research and development investment (Beheiry et al., 2006). The importance of contractors in facilitating SSP was also reiterated, as most clients and developers have outsourced the implementation of sustainable practices to the main contractors (Olawumi & Chan, 2019b).

Moreover, research has evidenced the importance of concerted efforts by construction organisations and governments in developing countries to upskill the skill and capacity of their workforce, knowledge, and political will for the beneficial outcomes of SSP are seen in construction project works (Pradhananga et al., 2021). Also, the early integration of green-tech and implementation of SSP initiatives can impact the likelihood of having a sustainable building project (Antón & Díaz, 2014). Furthermore, the survey findings of Pradhananga et al. (2021) and Olawumi and Chan (2019a) showed that the design and construction phases represent the best time for professionals to implement SSP in projects. Also, these studies reiterated the necessity of involving the key construction stakeholders early in the life of a project to allow the analysis of the feasibility and impact of SSP implementation on the building project.

Seaton et al. (2022) explored some benefits of a digitally driven sustainability effort of using digital twins to monitor and predict the performance of buildings and manage the design and construction process while delivering sustainable principles. Some benefits include accurate data analysis for real-time decisions, provision of a synchronised platform for situational awareness of the project, and real-time analysis of the building’s impact on the environment and the long-term implications of its performance. Other SSP-related benefits include reduction of lifecycle costs through time and cost certainty, responsible material sourcing, timely management of risks, actionable insights on health and safety, and reduction of the upfront embodied carbon emissions (Seaton et al., 2022). An investigation into the benefits of SSP initiatives in building design by Wang and Adeli (2014) revealed energy and water savings, reduction of carbon emissions, and promotion of green neighbourhoods and smart technologies as the key BTs of SSP and green-tech implementation.

Moreover, according to Wu and Issa (2014), the use of green-tech can assist project teams to accomplish the project objectives, including the target sustainability goals. The upfront capital cost of a building can increase significantly with SSP's implementation. However, a study by Kats et al. (2003) revealed that projects could save up to 20% of the project's lifecycle costs when SSP are integrated into the building design and specifications, plus the added benefits of such buildings having little or no impact on the environment. More importantly, green-tech can help stakeholders collaborate in a digital environment to resolve complicated building projects (Lavikka et al., 2015; Olawumi et al., 2022). Per Hu et al. (2020), implementing SSP in buildings can reduce carbon footprints in buildings and contribute to ameliorating climate change.

Kriegel and Nies (2008) highlighted some aspects of building design that could benefit from SSP implementation to include daylighting analysis, sustainable material selection, optimising building orientation to reduce energy consumption and enhance ventilation, water harvesting, and energy modelling. As posited by Gadakari et al. (2014), a decline in resource consumption, operational efficiency, and an increase in production and investment are some advantages of buildings where green-tech is employed. Also, LEED-certified buildings are known to exhibit significant energy savings, given their use of a number of green technologies in the design, construction, and operation of buildings (Chokor et al., 2016).

Given these beneficial outcomes of SSP, these initiatives have been welcomed and at different stages of implementation in many cities (De Jong et al., 2015) with a key focus on enhancing existing infrastructure, providing more sustainable and liveable cities, reducing transport-related carbon emissions, and improve the health and well-being of communities. A good example of this concept is the "15-minute city" aimed at creating a new model of urban planning that is sustainable, equitable, and inclusive. It has been implemented in some cities such as Paris, Stockholm, Portland (Oregon, USA), Barcelona, and Melbourne – though Portland and Melbourne implemented a 20-minute neighbourhood concept. Also, in Hong Kong, the Hong Kong Green Building Council (HKGBC) encourages the use of innovative practices, technologies, and techniques to achieve sustainability objectives for buildings (HKGBC, 2019). In accordance with the reviews from existing studies, we examine and establish the key BTs of SSP in the built environment in the subsequent aspects of the study.

Figure 1 illustrates and summarises some SSP benefits gleaned from previous studies into four categories.

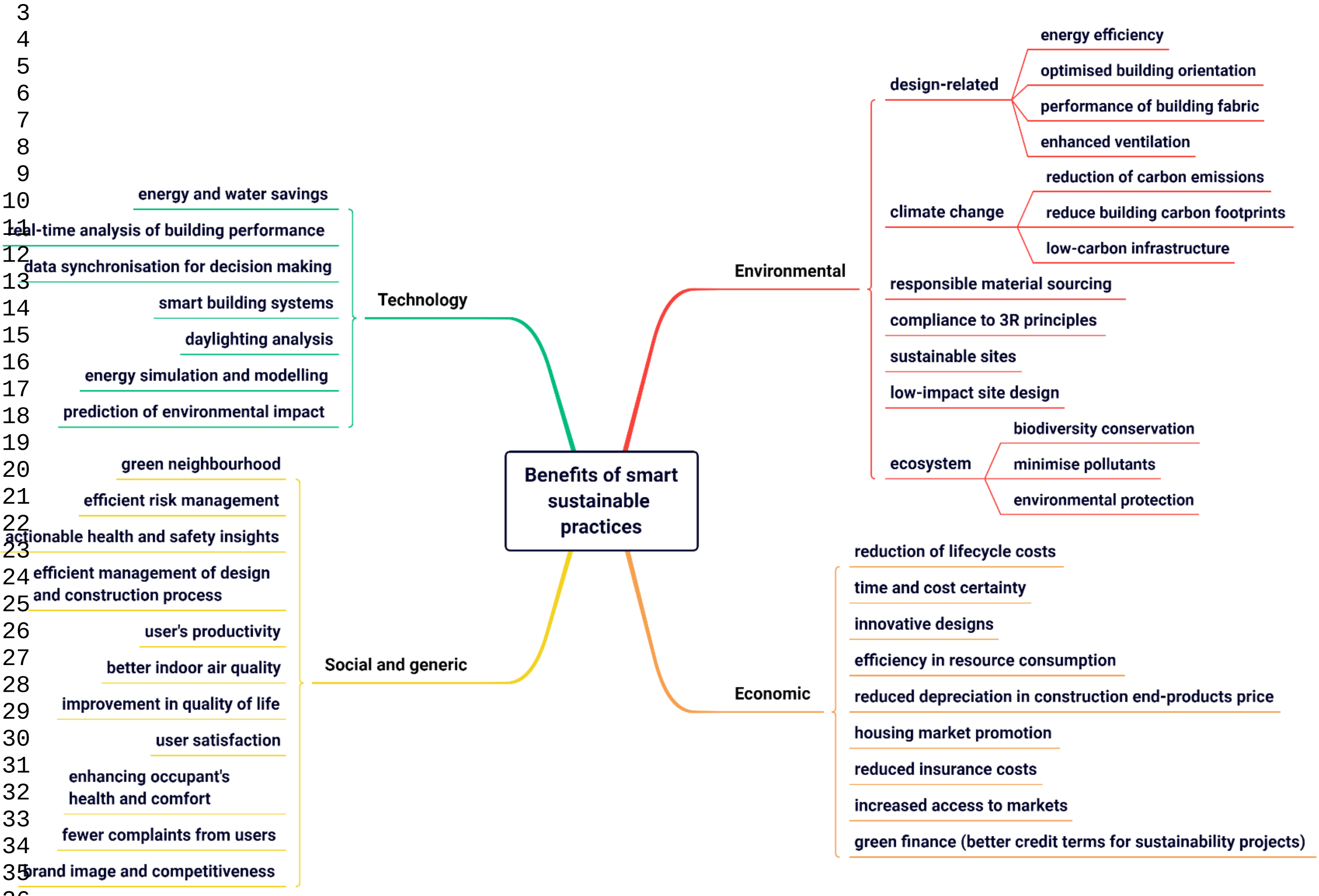


Figure 1: Summary of the building and infrastructure-centric benefits of SSP

3. Research Methods

The study adopted a quantitative research method to achieve the research aims, which involves using pre-tested and validated survey forms to solicit the perceptions of construction professionals. The current study fits within the post-positivist research paradigm (Cuthbertson et al., 2020) as the collated data from the study's respondents are likely shaped by their anecdotal experience in the industry and their workplace culture. Therefore, the fuzzy synthetic evaluation technique was utilised to remove this subjectivity and biases when developing the project evaluation models. As a result, methods such as quantitative research design (questionnaires, experiments) and case studies are the appropriate research methods (Chilisa & Kawulich, 2012).

Given this, a quantitative research method was employed in this study which involves the process of a literature survey, questionnaire survey and data analysis. Prior to distributing the survey form, as discussed in Section 3.1, the initial survey form was pre-tested with the assistance of 14 experts: 7 respondents each from the academia and practitioners, of which about 9 of them have at least 11 years of working experience. The survey questions were based on the list of factors highlighted in a previous study (Olawumi & Chan, 2019a), but this study examines the variables in the context of Hong Kong and Nigeria to allow for a thorough and country-wise investigation and comparative analysis. The concept of reusing variables is prevalent in the extant literature (Cheng & Phillips, 2014; Mom et al., 2014; Tsai et al., 2014), especially in construction studies, to extend the application of a study in other regions.

3.1 Sampling and data collection method

In research, there are two major sampling techniques for population sampling: probability and non-probability methods (Etikan, 2017). Sampling approach is mostly employed as it is often complex and time-consuming to reach the whole population, especially when they are diverse and dispersed. Construction professionals, including those employed in higher education institutions and the industry, formed the population of this study. This helps ensure the hybridization of perceptions to produce a better result. Construction studies (Dada & Jagboro, 2012; Mom et al., 2014) have also adopted the same approach in soliciting the perceptions of respondents.

In line with the requirement, the non-probability sampling method is the most appropriate for this study as it obligated the survey respondents to fulfil specific criteria (Campbell et al., 2020). These selection criteria include (i) understanding of and experience in applying digital technologies for green practices and (ii) knowledge of the construction sector in their country. Therefore, the purposive and snowball sampling method – a type of non-probability sampling technique was employed in selecting the survey respondents. Though not representative of the entire population, but useful to serve the specific research purpose (Etikan, 2017).

Using the sampling approach, the survey forms were sent to construction professionals in Nigeria and Hong Kong that fit the study's defined criteria over a 6-month period. The survey form consists of two sections: the first section solicited background data of the respondents, and the second section requested the respondent to rate the beneficial outcomes of SSP implementation (Table 1) using a 5-point Likert scale (1=strongly disagree, 3= neutral, 5=strongly agree). Social media and emails were used in distributing the survey, therefore, the total number of respondents reached cannot be determined.

The returned forms were assessed, and only a total of 166 forms were duly completed, with Hong Kong representing 59% (97) and Nigeria representing 41% (69). The sample size is deemed sufficient as the focus is on the quality of responses and expertise of the respondents rather than the quantity. Also, the sample size of this study is more than in similar studies (Chan et al., 2019b, 2019a; Osei-Kyei & Chan, 2018).

Table 1: Beneficial outcomes of smart-sustainable practices implementation

Code	Beneficial outcomes of implementing SSP	Sources
BT1	Enhance overall project quality, productivity, and efficiency	I
BT2	Schedule compliance in the delivery of construction projects	I, II
BT3	Predictive analysis of performance (energy analysis, code analysis)	III
BT4	Improve the operations and maintenance (facility management) of project infrastructure	I
BT5	Reduction in cost of construction works and improvement in project's cost performance	IV
BT6	Improve financial and investment opportunities	V, VI
BT7	Reduction in the cost of as-built drawings	VII
BT8	Facilitate sharing, exchange, and management of project information and data	VIII, IX
BT9	Facilitates resource planning and allocation	X
BT10	Reduction in site-based conflicts	XI
BT11	Ease the process to obtain building plan approvals and construction permits	XII
BT12	Support collaboration and ease procurement relationships	XIII, XIV
BT13	Reduced claims or litigation risks	XV
BT14	Increase firms' capability to comply with prevailing statutory regulations	XIII, XII
BT15	Better design products and facilitate multi-design alternatives	VI
BT16	Facilitate building layout flexibility and retrofitting	XVI
BT17	Real-time sustainable design and analysis early in the design phase	XVII
BT18	Facilitate, support and improve project-related decision-making	XVIII
BT19	Improves organization brand image and competitive advantage	XII
BT20	Enhance business performance and technical competence of professional practice	XIX
BT21	Enhance innovation capabilities and encourage the use of new construction methods	XIX
BT22	Prevent and reduce materials wastage through reuse & recycling and ensure materials efficiency	XX
BT23	Reduce safety risks and enhance project safety & health performance	XXI
BT24	Control of lifecycle costs and environmental data	V
BT25	Facilitate the implementation of green building principles and practices	XXII
BT26	Ease the integration of sustainability strategies with business planning	XXIII
BT27	Minimize carbon risk and improve energy efficiency	XXII
BT28	Improve resource management and reduce environmental impact across the value chain	XXIV
BT29	Facilitate the selection of sustainable materials, components, and systems for projects	XXV
BT30	Higher capacity for accommodating the three pillars of sustainability (social, economic & environmental sustainability)	XII
BT31	Enhance the accuracy of as-built drawings	X
BT32	Facilitate integration with domain knowledge areas such as project management, safety, and sustainability	XXVI
BT33	Allow the checking of architectural design of buildings from the sustainability point of view	XXVII
BT34	Facilitate accurate geometrical representations of a building in an integrated data environment	I
BT35	Ability to simulate building performances and energy usage	XXVIII

Code	Beneficial outcomes of implementing SSP	Sources
BT36	Encourage the implementation of clean technologies that require less energy consumption	XXIX

Sources: I= (Azhar, 2011); II= (Philipp, 2013); III= (Lee et al., 2015); IV= (Bynum et al., 2013); V= Ku and Taiebat (2011) ; VI= (Lee et al., 2012); VII= (Boktor et al., 2014);VIII= (Olatunji et al., 2017b);IX= (Wong et al., 2014); X= (Akintoye et al., 2012); XI= (Hanna et al., 2013); XII= Antón and Díaz (2014); XIII= Aibinu and Venkatesh (2014); XIV= (Olatunji et al., 2016);XV= (Bolgani, 2013); XVI= Webster and Costello (2005); XVII= Alsayyar and Jrade (2015); XVIII= (Sacks et al., 2010); XIX= (Deutsch, 2011); XX= (Akinade et al., 2017); XXI= Benjaoran and Bhokha (2010); XXII= Wu and Issa (2015); XXIII= (Autodesk, 2010); XXIV= (Ajayi et al., 2016); XXV= Jalaei and Jrade (2015); XXVI= (Kam et al., 2012); XXVII= (Abolghasemzadeh, 2013); XXVIII= (Aksamija, 2012); XXIX= Bonini and Görner (2011)

Source: Literature survey

3.2 Statistical analysis tools

The responses of the survey respondents were analysed using mean item score (MIS), standard deviation (SD), Cronbach alpha (α-value), Pearson correlation, factor analysis and fuzzy synthetic evaluation (FSE). The MIS is a measure of central tendency and represents the average value of the experts' rating for each factor. This measure has been well adopted in construction management studies (Chan, 2019; Saka & Chan, 2020) in evaluating the rank of items. MIS was adopted in this study to rank the beneficial outcomes of SSP implementation. Where two or more variables have the same MIS, the SD is used in the ranking (Olatunji et al., 2017a). The α-value depicts the internal reliability of the questionnaire items and ranges from 0 to 1. The closer the alpha value to 1, the more reliable and consistent the measure (Olatunji et al., 2017a). The Pearson correlation measures the linear relationship between variables and assesses the association between the evaluated benefits.

Factor analysis is a statistical method of reducing a large number of variables into fewer factors using different extraction methods. The principal component analysis (PCA) approach was adopted in extracting the factors, and variables under each factor were named with a general theme to reflect their relationships. This technique has been adopted in various fields in explaining complex relationships (Xu et al., 2010) to identify important underlying patterns in data and move sources of variation that are not related to the underlying factors. The Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity (BTS) were conducted to ensure that the data were fit for structure detection before using PCA for data extraction (Chan & Choi, 2015).

The **Fuzzy Synthetic Evaluation** (FSE) technique, on the other hand, is a branch of fuzzy set theory which has gained widespread adoption in varying fields of studies for its effectiveness in representing human knowledge. It is a technique used in assessing multi-level and multi-attribute decision-making. Ameyaw and Chan (2015) and Xu et al. (2010) employed it in risk assessment, while Osei-Kyei and Chan (2018) and Chan (2007) adopted it in construction management. This present study uses the FSE to evaluate the benefits of smart, sustainable practices in developed and developing countries context to develop an assessment index. The algorithm and equations used for the FSE analysis are outlined in Section 4.4.

Moreover, **rank agreement analysis** was employed to evidence the level of consensus or disparity in the viewpoints (Oyetunji et al., 2022) of the construction professionals on the ranking of the beneficial outcomes in Hong Kong and Nigeria. Rank agreement analysis (RAA) is useful when comparing and measuring the difference in views between two or more groups on the same constructs. RAA, a quantitative method, was used to determine the level of agreement of the BT factor clusters between the groups of professionals in Hong Kong and Nigeria. This helps provide insights into the benefits of SSP implementation beyond whether it is implemented in a construction project or organisation based in a developed or developing economy. The algorithm for the RAA method is presented in Section 4.6. The two key values in the RAA method are the rank agreement factor (RAF) and the agreement percentage (AP). RAF values close to zero (0) imply there is consensus in the ranking by the groups, likewise, the AP value near 100%.

4. Results and discussions

The analytical results and discussion of the major findings of the study are presented in this section.

4.1 Demographic distribution of survey respondents

Table 2 shows the distribution of the survey respondents from Nigeria and Hong Kong. All the respondents are from diverse professional backgrounds and expertise in the construction industry with varying experience at various stages of SSP implementation (planning & design to operation & maintenance). Also, most of the participating survey respondents from Hong Kong were engineers (27), quantity surveyors (22), and architects (16). In Nigeria's context, quantity surveyors, architects, and project managers, with 30, 13, and 10 respondents, respectively, formed the bulk of the survey participants. About 47% (46 respondents) and 33% (23) of the respondents have more than 10 years' experience in Hong Kong and Nigeria, respectively. This connotes that the respondents have sufficient experience in the construction industry.

Moreover, a greater proportion of the survey respondents from both contexts have adequate understanding and expertise in smart-sustainable practices, implying their opinions can be reliably used in the analysis. Majority of the respondents also opined that the planning stage (87) and the design stage (68) are the best stages to start the implementation of SSP, which is in tandem with extant studies (Kassem et al., 2012).

Table 2: Demographics of the survey respondents

Characteristics	Hong Kong	Nigeria
Main profession		
Architect	16	13
Urban Planner	5	1
Project Manager	9	10
Quantity Surveyor	22	30
Engineers	27	6
BIM/Construction Manager	14	8
Property Manager	4	1
Years of experience		
< 5years	31	23
5-10 years	20	23
11-15 years	8	7
16-20 years	8	7
> 20years	30	9
Type of working organization		
Public Client	38	6
Private Client	5	6
Project Consultant	9	13
Main Contractor	24	9
Property Management Company	5	1
Academic Institution	16	34
Optimum stage for SSP		
Planning stage	41	46
Design stage	46	22
Construction stage	9	1
Operation and maintenance stage	1	0
Level of SSP awareness		
Very High	B=7 & S=8	B=9 & S=11
High	B=20 & S=26	B=24 & S=36
Average	B=40 & S=43	B=27 & S=20
Low	B=14 & S=13	B=8 & S=2
Very Low	B=16 & S=7	B=1 & S=0 (0%)
Total	**97**	**69**

Key→ B – BIM awareness; S – sustainability practices awareness of the respondents

4.2 Ranking of the BT factors

4.2.1 Comparison between respondents' sub-groups in Nigeria and Hong Kong

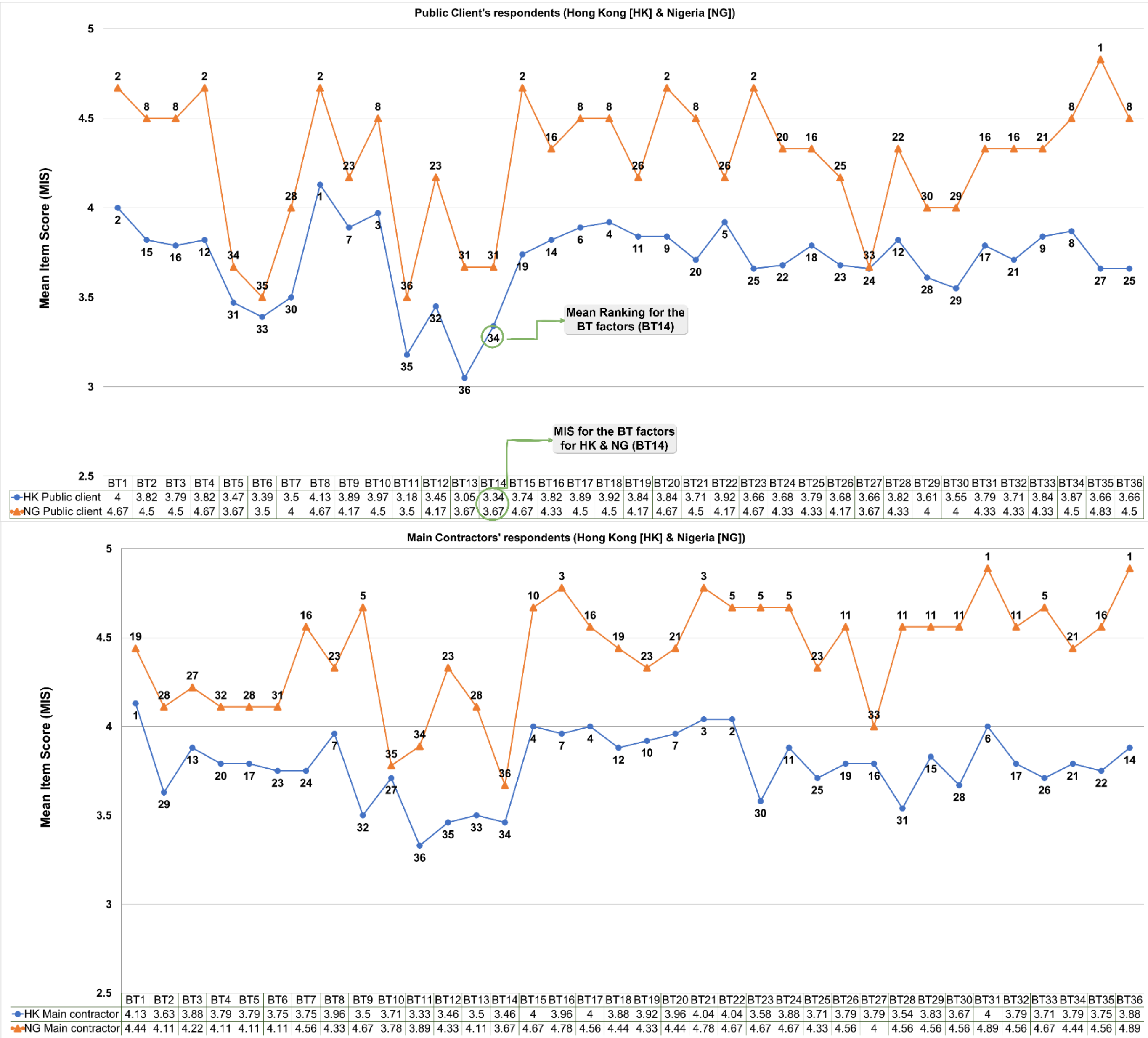
In most practical instances in the built environment when digital technologies like BIM, internet-based apps and sustainable practices are to be implemented in construction projects; the clients and contractors are key to its successful implementation (Ayegun et al., 2018; Bresnen & Marshall, 2000; Ershadi et al., 2021; Schweber, 2013). In most countries (Nigeria and Hong Kong inclusive), most projects are driven by public clients. Hence, SSP implementation could be most effective when 'client-driven' and involving participating contractors who have embedded SSP strategies within their organisations.

Figure 2 shows the ranking of the SSP beneficial outcomes as opined by construction professionals from the public client (PC) and main contractor (MC) in Nigeria and Hong Kong.

According to PC respondents in Nigeria and Hong Kong, the implementation of smart-sustainable practices in their projects tends to improve the overall productivity and efficiency in their projects (BT1) with a ranking of 2 whilst MIS of 4.67 and 4.00 in Nigeria and Hong Kong, respectively. Also, they strongly opined that SSP diffusion aided the sharing and management of project information and data in the most efficient way (BT8) with a ranking (R=[2,1]; MIS= [4.67,4.13]) in Nigeria and Hong Kong, respectively. (**Note**: R=[ranking of a factor in Nigeria context, Hong Kong context]; same as for MIS values).

Moreover, the implementation of SSP by public clients in Nigeria and Hong Kong is yet to facilitate more investment opportunities for them nor yield financial returns (BT6) as both ranked it (R=[35,33]; MIS=[3.50,3.39]), respectively. These are one of the disadvantages for early movers or adopters of innovative technologies in the construction industry. However, with more awareness, active knowledge sharing, and improvement in technologies; this can turn to their advantage (Park et al., 2020). Also, the use of SSP strategies has not yet eased the building approval process in both contexts (BT11)–(R=[36,35]; MIS=[3.50,3.18]). However, the Hong Kong government has started to introduce some incentives, such as the 10% gross floor area concession scheme (Chan et al., 2019a; Fan et al., 2018), for developers to implement green practices.

As revealed in Figure 2, there is a disparity in the opinions of MC respondents in Nigeria and Hong Kong as regards the beneficial outcomes of SSP implementations for the contractors. Nevertheless, both sets of respondents agree on three factors – BT21, BT22, and BT14. For instance, they opined that implementing SSP has enhanced their innovative capabilities and assisted them in formulating new construction methods (BT21) with a ranking (R=[3,3]; MIS=[4.78, 4.04]) in Nigeria and Hong Kong, respectively. Also, the main contractors stressed that implementing SSP has helped them reduce material wastage on-site through approaches such as reuse and recycling (BT22) (Oluleye et al., 2022).



	BT1	BT2	BT3	BT4	BT5	BT6	BT7	BT8	BT9	BT10	BT11	BT12	BT13	BT14	BT15	BT16	BT17	BT18
HK Public client	4	3.82	3.79	3.82	3.47	3.39	3.5	4.13	3.89	3.97	3.18	3.45	3.05	3.34	3.74	3.82	3.89	3.92
NG Public client	4.67	4.5	4.5	4.67	3.67	3.5	4	4.67	4.17	4.5	3.5	4.17	3.67	3.67	4.67	4.33	4.5	4.5

	BT19	BT20	BT21	BT22	BT23	BT24	BT25	BT26	BT27	BT28	BT29	BT30	BT31	BT32	BT33	BT34	BT35	BT36
HK Public client	3.84	3.84	3.71	3.92	3.66	3.68	3.79	3.68	3.66	3.82	3.61	3.55	3.79	3.71	3.84	3.87	3.66	3.66
NG Public client	4.17	4.67	4.5	4.17	4.67	4.33	4.33	4.17	3.67	4.33	4	4	4.33	4.33	4.33	4.5	4.83	4.5

	BT1	BT2	BT3	BT4	BT5	BT6	BT7	BT8	BT9	BT10	BT11	BT12	BT13	BT14	BT15	BT16	BT17	BT18
HK Main contractor	4.13	3.63	3.88	3.79	3.79	3.75	3.75	3.96	3.5	3.71	3.33	3.46	3.5	3.46	4	3.96	4	3.88
NG Main contractor	4.44	4.11	4.22	4.11	4.11	4.11	4.56	4.33	4.67	3.78	3.89	4.33	4.11	3.67	4.67	4.78	4.56	4.44

	BT19	BT20	BT21	BT22	BT23	BT24	BT25	BT26	BT27	BT28	BT29	BT30	BT31	BT32	BT33	BT34	BT35	BT36
HK Main contractor	3.92	3.96	4.04	4.04	3.58	3.88	3.71	3.79	3.79	3.54	3.83	3.67	4	3.79	3.71	3.79	3.75	3.88
NG Main contractor	4.33	4.44	4.78	4.67	4.67	4.67	4.33	4.56	4	4.56	4.56	4.56	4.89	4.56	4.67	4.44	4.56	4.89

Figure 2: Comparison between respondents' subgroups in Nigeria and Hong Kong

Note: Refer to Table 1 for the description of factors BT1 – BT36. **Data source:** Authors' survey

4.2.2 Overall ranking and factor normalization analysis

Overall Ranking. The overall ranking of the benefits is presented in Figure 3 from the Hong Kong and Nigeria contexts. Construction professionals in both countries agreed on two key factors as important beneficial outcomes they have taken advantage of in their implementation of smart-sustainable practices. They indicated that SSP diffusion in their project and organisation had enabled them to perform some sustainable design analysis in the early stages of the project (BT17 – R=[3,3]). More so, the respondents strongly stressed the importance of SSP implementation in the overall improvement in the productivity, efficiency, and quality of the construction project (BT1), which is ranked R=[2,1] in Nigeria and Hong Kong, respectively.

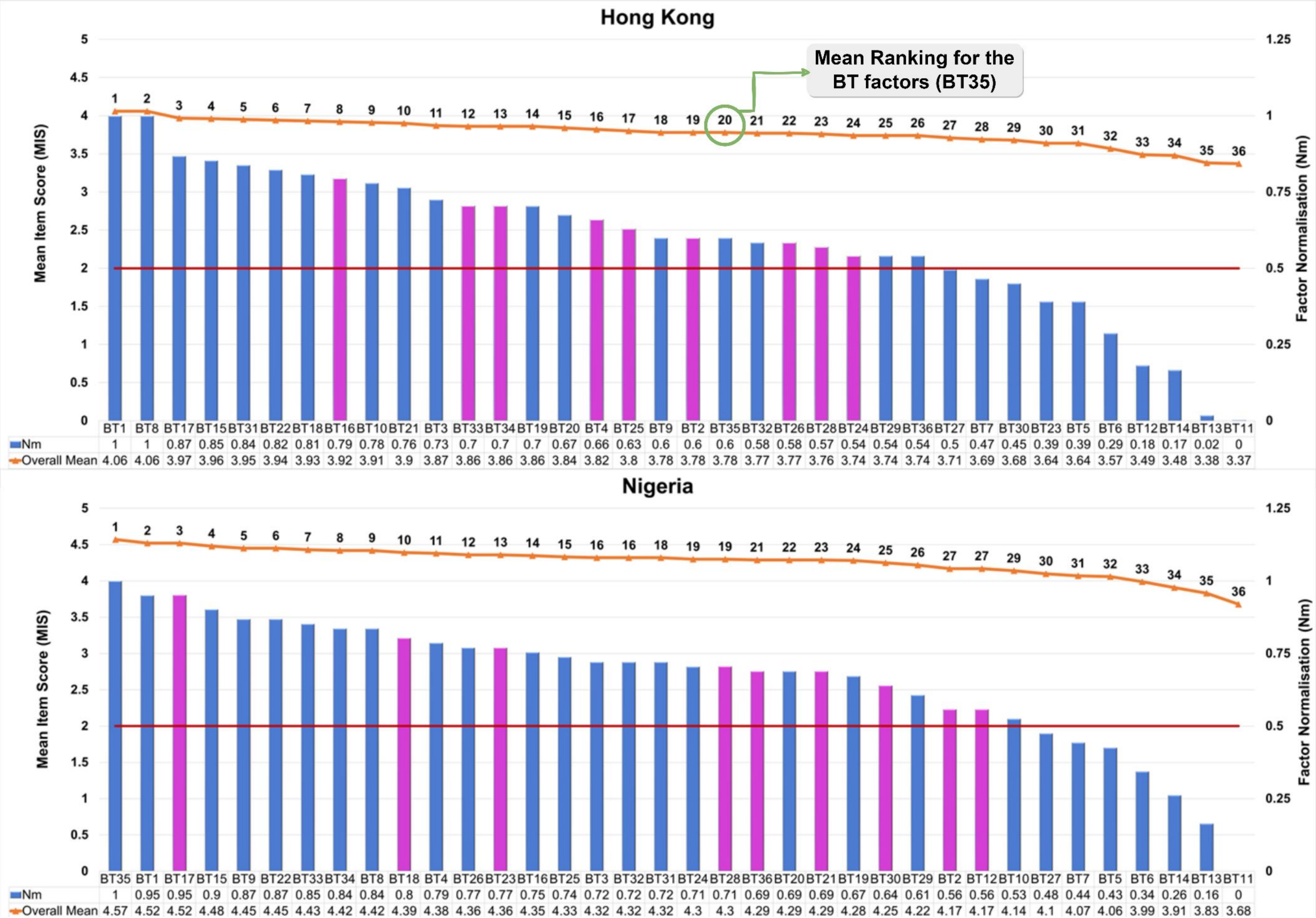
Also, construction professionals in Nigeria reiterated the benefits of SSP implementation in their ability to simulate the building performance and energy requirement (BT35), which they ranked as the topmost beneficial outcomes. As reported by Carvalho et al. (2020), the impacts of buildings are much higher during its occupancy phase due to the various installed HVAC, lighting, and other energy appliances. Therefore, it is a significant advantage for projects where the energy needs have been modelled, and energy requirements are known. Also, respondents from Hong Kong rated the benefits of collaborative sharing of project data (BT8) as a key beneficial outcome of their SSP implementation. However, as seen in Figure 3, factors such as BT14, BT13, and BT11 are considered not significant beneficial outcomes in both Nigeria and Hong Kong.

Factor normalization. Normalization (N_m) of the mean item score was conducted using equation 1 to identify the key beneficial outcomes of SSP in Nigeria and Hong Kong contexts. Factors with $N_m$values ≥ 0.5 are considered significant for further analysis. As seen in Figure 3, factors with $N_m$columns below the <u>*red horizontal line*</u> are not significant. Hence, 26 and 29 factors in Hong Kong and Nigeria N_m ≥ 0.50 are significant.

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

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

Moreover, the Pearson correlation was employed to further analyse the variables for correlation to prevent multiplier effects. In the Hong Kong context, 9 factors strongly correlated with other factors (ρ≥0.500), while in Nigeria, there are 10 factors which correlate with other key factors (indicated as '*purple-coloured columns*' in Figure 3). These correlated factors are represented in Figure 3 with yellow border columns. For instance, in Hong Kong, BT16 is correlated to BT17 (ρ=0.748), BT33 to BT35 (ρ=0.729), and BT4 to BT8 (ρ=0.608), among others. Thus, these correlated factors were removed from the 26 benefits to have 17 distinct factors in Hong Kong. Similarly, 10 related benefits were removed to have 19 distinct factors in the Nigeria context suitable for further.



Hong Kong

Rank	Factor	Nm	Overall Mean
1	BT1	1	4.06
2	BT8	1	4.06
3	BT17	0.87	3.97
4	BT15	0.85	3.96
5	BT31	0.84	3.95
6	BT22	0.82	3.94
7	BT18	0.81	3.93
8	BT16	0.79	3.92
9	BT10	0.78	3.91
10	BT21	0.76	3.9
11	BT3	0.73	3.87
12	BT33	0.7	3.86
13	BT34	0.7	3.86
14	BT19	0.7	3.86
15	BT20	0.67	3.84
16	BT4	0.66	3.82
17	BT25	0.63	3.8
18	BT9	0.6	3.78
19	BT2	0.6	3.78
20	BT35	0.6	3.78
21	BT32	0.58	3.77
22	BT26	0.58	3.77
23	BT28	0.57	3.76
24	BT24	0.54	3.74
25	BT29	0.54	3.74
26	BT36	0.54	3.74
27	BT27	0.5	3.71
28	BT7	0.47	3.69
29	BT30	0.45	3.68
30	BT23	0.39	3.64
31	BT5	0.39	3.64
32	BT6	0.29	3.57
33	BT12	0.18	3.49
34	BT14	0.17	3.48
35	BT13	0.02	3.38
36	BT11	0	3.37

Nigeria

Rank	Factor	Nm	Overall Mean
1	BT35	1	4.57
2	BT1	0.95	4.52
3	BT17	0.95	4.52
4	BT15	0.9	4.48
5	BT9	0.87	4.45
6	BT22	0.87	4.45
7	BT33	0.85	4.43
8	BT34	0.84	4.42
9	BT8	0.84	4.42
10	BT18	0.8	4.39
11	BT4	0.79	4.38
12	BT26	0.77	4.36
13	BT23	0.77	4.36
14	BT16	0.75	4.35
15	BT25	0.74	4.33
16	BT3	0.72	4.32
16	BT32	0.72	4.32
18	BT31	0.72	4.32
19	BT24	0.71	4.3
19	BT28	0.71	4.3
21	BT36	0.69	4.29
22	BT20	0.69	4.29
23	BT21	0.69	4.29
24	BT19	0.67	4.28
25	BT30	0.64	4.25
26	BT29	0.61	4.22
27	BT2	0.56	4.17
27	BT12	0.56	4.17
29	BT10	0.53	4.14
30	BT27	0.48	4.1
31	BT7	0.44	4.07
32	BT5	0.43	4.06
33	BT6	0.34	3.99
34	BT14	0.26	3.91
35	BT13	0.16	3.83
36	BT11	0	3.68

Figure 3: Overall ranking and normalisation of the beneficial outcomes of SSP implementation in Nigeria and Hong Kong

Data source: Authors' survey

4.3 Factor Analysis

The factors were extracted using the principal component analysis (PCA) technique, and pre-tests were conducted to check the suitability of the data for structure detection and to check the internal reliability of the instrument. The Cronbach's alpha is 0.966 and 0.935 for the Hong Kong and Nigeria context, respectively. The KMO is 0.90 and 0.775; the BTS shows the chi-square value to be 1047.710 at p-value of 0.000 (df = 136) in Hong Kong and a chi-square of 555.463 at p-value of 0.000 (df = 210) in Nigeria. The factor categories were extracted using the factors' eigenvalues resulting in 3 and 5-factor clusters for the Hong Kong and Nigeria context, respectively, accounting for 66% and 60% of the total variance explained, respectively.

These total variances exceed the threshold (Hair et al., 2010). The factor clustering for the key beneficial outcomes after PCA analysis is shown in Figure 4 (Hong Kong) and Figure 5 (Nigeria). Although the Nigeria context has 5 factor clusters compared to the 3 factor groupings of the Hong Kong context; their factor clusters are somewhat similar. For instance, factor clusters D3 and D4 (Nigeria) have factors with a similar description to DE3 (Hong Kong). Also, D2 and DE2, as well as D5 and D1 (Nigeria), are related to DE1 (Hong Kong), as illustrated in Figures 4 and 5. The implications of these factor clusters to SSP diffusion are discussed in Section 4.5.

4.4 Fuzzy synthetic evaluation of the beneficial outcomes

4.4.1 Weighting and membership function of the factor clusters

This weighting and membership function for the factors' cluster (level 1) and each key factor in the categories (level 2) is calculated using equation 2.

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

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

For instance, DE3 "*sustainable design and resource management*" (total mean = 19.65) in the Hong Kong context which include BT10, BT18, BT17, BT9 and BT8 with respective MIS=[3.91,3.93,3.97,3.78,4.06]; the weighting for factor BT9 can be calculated as:

$$W_{BT9} = \frac{3.78}{3.91 + 3.93 + 3.97 + 3.78 + 4.06} = \frac{3.78}{19.65} = 0.192$$

The above calculation is repeated for all the key factors and factor clusters.

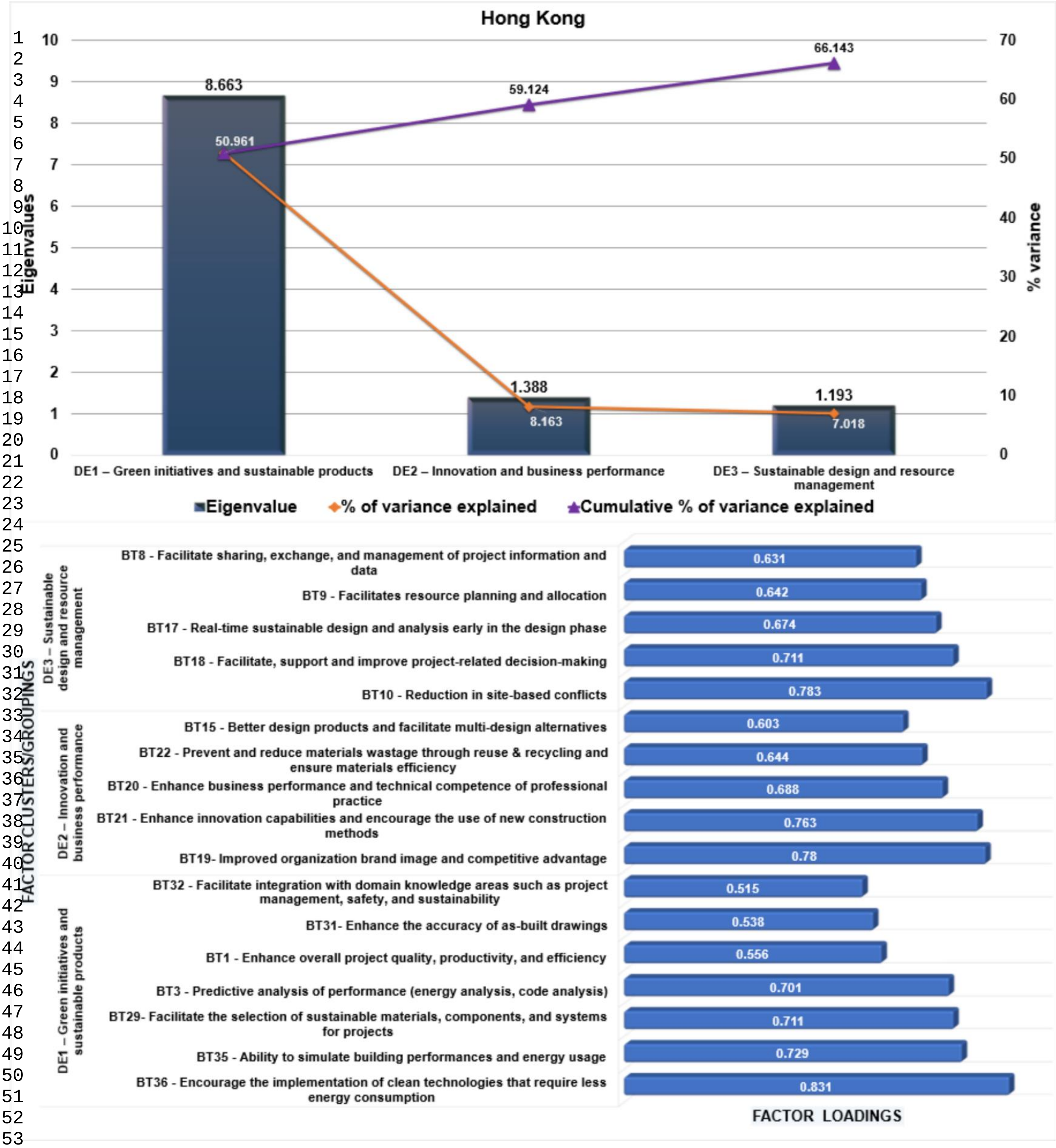


Figure 4: Factor clustering of the key SSP beneficial outcomes in Hong Kong
Data source: Authors' survey

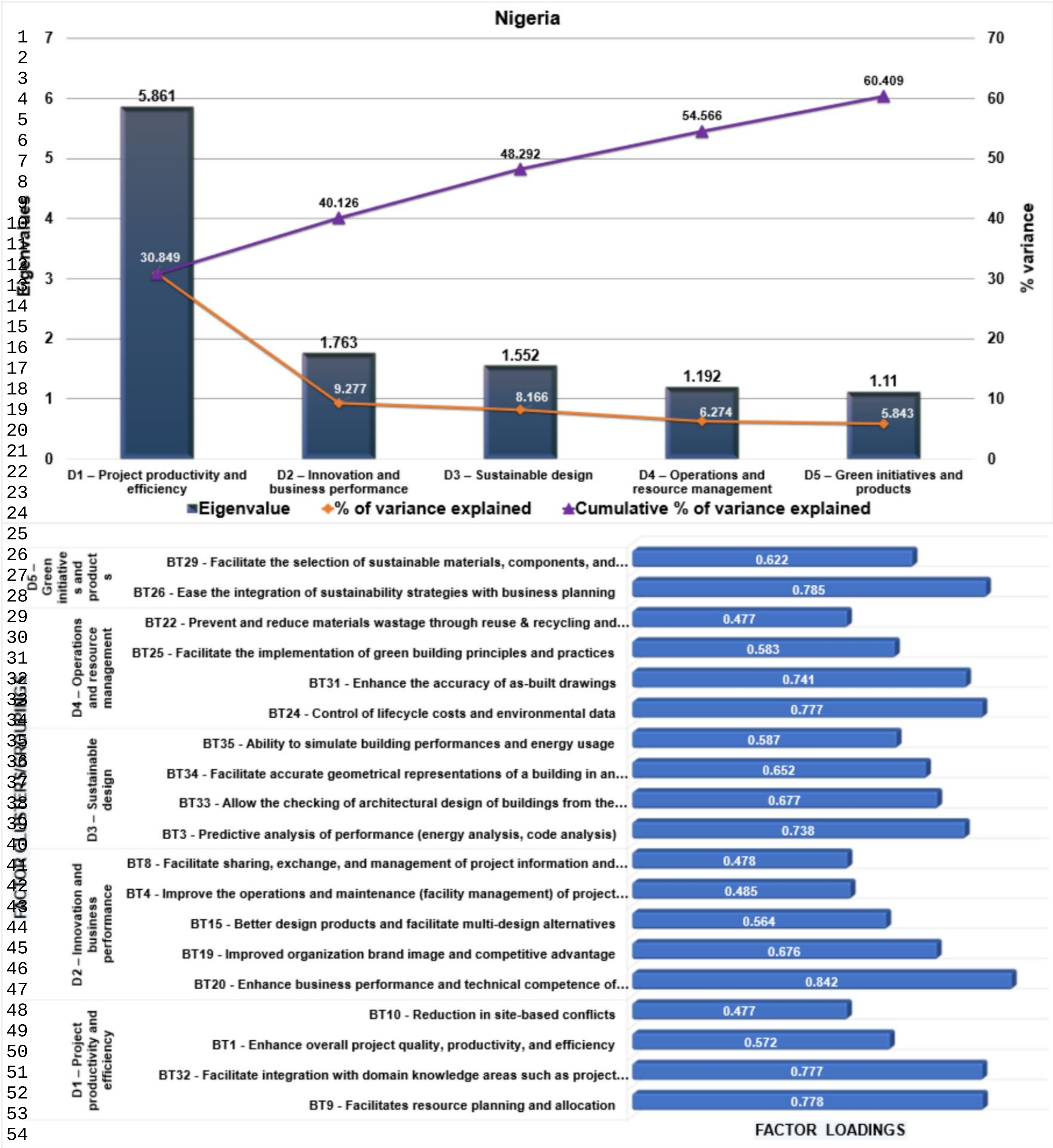


Figure 5: Factor clustering of the key SSP beneficial outcomes in Nigeria

4.4.2 Membership functions of the factor clusters

The membership functions (MF) of the key factors (level 2) are first evaluated before that of its clusters. 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 derived from the respondent's ratings of each factor based on Likert-scale values (g_1=strongly disagree, g_3=neutral, and g_5=strongly agree); i.e., $G = \{g_1, g_2, g_3, \dots, g_n\}$. Thus, MF of BT10 "*reduction in site-based conflicts"* in the Nigeria context where 1% of the experts strongly disagree that it is a key beneficial outcome, whilst 4, 13, 41, and 41 per cent ticked *'disagree', 'neutral', 'agree' and 'strongly agree'* respectively is computed as:

$$MF_{BT10} = \frac{0.01}{g1} + \frac{0.04}{\text{g2}} + \frac{0.13}{g3} + \frac{0.41}{\text{g4}} + \frac{0.41}{\text{g5}}$$

The MF for BT10 is expressed as (0.01, 0.04, 0.13, 0.41, 0.41). Similarly, the MF for the 17 and 19 benefits in Hong Kong and Nigeria are computed using the same approach. The MF at level 2 is calculated using equation 3 (Xu et al., 2010).

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

W_i is the weighting of all the benefits within each category while R_i is the fuzzy evaluation matrix.

For instance, the MF level 1 for D5 '*green initiatives and products* in the Nigeria context is computed as:

$$F_{D5} = \begin{vmatrix} 0.508 \\ 0.492 \end{vmatrix} \times \begin{vmatrix} 0.00 & 0.00 & 0.12 & 0.40 & 0.48 \\ 0.01 & 0.04 & 0.09 & 0.42 & 0.44 \end{vmatrix} = (0.00 \quad 0.02 \quad 0.11 \quad 0.41 \quad 0.46)$$

The MF function for other factor clusters (level 1) in Nigeria and Hong Kong contexts was calculated using the same process.

4.4.3 Defuzzification of factor clusters' membership functions

The factor clusters MF (level 1) is defuzzify to establish the impact index for the beneficial outcomes of SSP implementation. The impact index can be a useful evaluation tool for clients, project teams, and contractors in adopting SSP in construction projects. The BT impact index (BT_i) is calculated using equation 4.

$$BT_i = \sum_{i=1}^{5} F \times G_i \quad ---------------- (4)$$

For instance, the BT_i for D4 '*operations and resource management'* in the Nigeria context is computed as: $BT_{i_{(D4)}} = (0.00, \;\; 0.01, \;\; 0.12, \;\; 0.39, \;\; 0.49) \times (1, 2, 3, 4, 5) = 4.36$

More so, the same equation was used in defuzzifying the MF for the other factor clusters of both contexts (Table 3). The coefficient is computed using equation 5, which sums to unity.

$$^{y}Coefficient = \left({BT_i \, for \, DE/D} \middle/ {\sum BT_i for \, DE/D} \right) ------- (5)$$

Table 3: Impact index of the factor clusters of the beneficial outcomes of SPP implementation in Hong Kong and Nigeria

BT categories/cluster	Impact index (BT_i)	Coefficients (^{y})
Hong Kong		
DE1 – Green initiatives and sustainable products	3.85	0.331
DE2 – Innovation and business performance	3.88	0.334
DE3 – Sustainable design and resource management	3.89	0.335
Total	**11.61**	**1.000**
Nigeria		
D1 – Project productivity and efficiency	4.29	0.197
D2 – Innovation and business performance	4.37	0.201
D3 – Sustainable design	4.44	0.204
D4 – Operations and resource management	4.36	0.200
D5 – Green initiatives and products	4.30	0.198
Total	**21.76**	**1.000**

Data source: Authors' survey

As presented in Table 3, the FSE approach resulted in the computation of the significant indices of the BT categories for both Nigeria and Hong Kong, which are very significant. The weightings of the factor categories were not ranked as it is sensitive to the number of the underlying factors, and such metrics will be biased towards categories with larger variables.

In Nigeria, D3 "sustainable design" has the highest weighting (4.44), closely followed by D2 and D4. This is not far-fetched because Nigeria, as a developing country, was a late adopter of SSP; therefore, stakeholders are still focused on maximising its benefit for building designs and modelling as well as for their organisations. In Hong Kong, DE3 "sustainable design and resource management" accrued the highest weightings. Also, DE2 and DE1 have good weightings. Hong Kong's more advanced economy than Nigeria has benefited from increased implementation of SSP. As a result, emphasises has been placed on deriving as much benefits as possible in terms of real-time building energy modelling and performance monitoring, result-oriented project workflow management, and efficient use and management of project resources.

4.4.4 SSP impact evaluation models and significance index

Impact evaluation models. The final phase of the FSE analysis is modelling the likely impacts of the beneficial outcomes on SSP implementation using a linear equation. The project evaluation models (BT_i) are developed using additive and linear approaches as employed in similar studies (Hu et al., 2016). The factor clusters form the independent variables used in developing the linear equation, which further allows objectivity in measuring the impact of each beneficial outcome in the built environment. According to Yeung et al. (2009), the use of linear equations makes developed models easier to adopt and understandable for users (contractor & client organisations and other stakeholders). It also gives the users flexibility in using different measurement scales that differ from those used in developing the model (Olawumi & Chan, 2022).

The BT_i in the **Hong Kong** context, as computed in Table 3, can be presented as:

$$BT_i = (0.331 \times Green\ initiatives \text{ and } sustainable\ products) + (0.334 \times Innovation\ and\ business\ performance) + (0.335 \times Sustainable \text{ d}esign\ and\ resource\ management) \;---\; (6)$$

Similarly, the BT_i for the **Nigeria** context can be evaluated using:

$$BT_i = (0.197 \times Project\ productivity\ and\ efficiency) + (0.201 \times Innovation \text{ and } business\ performance) + 0.204 \times Sustainable\ design) + (0.200 \times \text{Operations and r}esource\ management) + (0.198 \times Green\ initiatives\ and\ products) \;------(7)$$

Overall significance index. Using equation 8, the weightings and the MFs of the factor cluster for both contexts and the rating scale were used to compute the overall significance index for both contexts.

$$H = W_i \, \chi \, F_i \qquad ------------ (8)$$

Where $W_{D/DE}$ represents the weights for the factor clusters for both contexts and $F_{D/DE}$ is the MFs for the clusters (level 1) for each context; and H is the overall fuzzy evaluation matrix. The overall significance index is calculated based on equation 9:

$$BT_{SI} = \sum_{I=1}^{5} H \times G_i \quad ---------------- (9)$$

$$W_{DE}\ for\ Hong\ Kong = (0.407, 0.295, 0.297)$$

$$F_{DE}\ for\ Hong\ Kong = \begin{pmatrix} DE1 \\ DE2 \\ DE3 \end{pmatrix} = \begin{pmatrix} 0.02, 0.03, 0.23, 0.54, 0.18 \\ 0.01, 0.02, 0.22, 0.57, 0.18 \\ 0.01, 0.02, 0.20, 0.60, 0.16 \end{pmatrix}$$

The overall significance index for **Hong Kong**

$$BT_{SI} = (0.01, 0.02, 0.22, 0.57, 0.18) \, \chi \, (1, 2, 3, 4, 5) = \mathbf{3.87}\ (\boldsymbol{significant})$$

Using the same approach for the **Nigeria** context:

The overall significance index is, $BT_{SI} = \mathbf{4.83}\ (\boldsymbol{very\ significant})$

The analysis of the key beneficial outcomes using the FSE approach revealed that the 17 and 19 factors in Hong Kong and Nigeria are highly recognised as significant benefits derivable in both contexts. The overall significance value of 3.87 in Hong Kong and 4.83 in Nigeria shows that when SSP is implemented in a project or organisation, there is a higher possibility of such adopters of SSP gaining these key benefits in the course of the project. As such, it behoves project managers and client representatives to ensure the implementation of SSP across the project supply chains.

Furthermore, the most significant cluster of BTs of SSP implementation in Hong Kong is *sustainable design and resource management,* with the highest impact index of 3.89 based on a rating scale of 5. Meanwhile, in Nigeria, *sustainable design* is the most pulsating BT with an impact index of 4.44, and both have the highest coefficient, as illustrated in the impact evaluation models (equations 6 & 7). The next significant BT factor cluster is *innovation and business performance* in both contexts. This is not surprising as the primary objective of construction enterprises is to improve business performance whilst innovating.

4.5 Factor structure for SSP implementation in Hong Kong and Nigeria

As earlier presented, the factor analysis yielded 3 and 5 factor structures (BT categories) in the Hong Kong and Nigeria context, which explains about 66% and 60% of the total variance in the beneficial outcomes of SSP implementation, respectively. The factor structures (clusters) include green initiatives and sustainable products (DE1), innovation and business performance (DE2), and sustainable design and resource management (DE3) in Hong Kong. In Nigeria, the factor structures are project productivity and efficiency (D1), innovation and business performance (D2), sustainable design (D3), operations and resource management (D4), and green initiatives and products (D5). The underlying BT factors for each context and its factor loadings and eigenvalue are presented in Figures 4 and 5. Since there is similarity in D3, D4 and DE3 as well as between D5, D1, and DE1; it is desirable to discuss the implications of these factor clusters for SSP implementation in both countries under three categories. This allows (i) client representatives, developers, and project managers to focus on the achievement of fewer but robust beneficial outcome clusters; and (ii) identify the key BT factors that majorly result from SSP adoption. These three BT factor clusters are discussed.

Cluster 1: Sustainable design and resource management

This factor cluster accounts for 7% and 8% of the total variance explained in Hong Kong and Nigeria, respectively. Much focus has been placed on constructing buildings and structures with less embodied carbon in both contexts. Also, the simulation of building materials and designs, the energy performance and the usage of a building can be estimated right from the design phase. According to Soetanto et al. (2006), it is important to evaluate the impact of building design and its value at the earliest project phase. Hence, these issues are captured and separately assessed by the Hong Kong Green Building Council (HKGBC) when a building is evaluated for its overall sustainability performance using the BEAM Plus rating system (HKGBC, 2019). Also, recently in Nigeria – the central government, Green Building Council Nigeria (GBCN), and other professional bodies have facilitated the awareness and upskilling of professionals towards a sustainable integrated design process.

The increased adoption of BIM and energy simulation tool has also been key in the predictive analysis of the environmental performance of buildings in Nigeria and Hong Kong. Also, SSP is being specifically applied to the construction and maintenance of buildings in Hong Kong to reduce the massive construction waste in Hong Kong, which currently constitutes over 25% of its landfills (Yu et al., 2021). Most government and professional bodies' guidelines are aligned to also improve resource planning and allocation as well as facilitate the concept of a circular economy (Oluleye et al., 2022). In Nigeria, most of the SSP benefits related to resource management are mostly achieved within the context of large construction projects with the aim of getting LEED certification.

Cluster 2: Innovation and business performance

This cluster accounts for 9% and 8% of the total variance explained in Nigeria and Hong Kong contexts. The common benefits between the two contexts are "improved organization brand image and competitive advantage, (BT19)" "enhance business performance and technical competence of professional practice," and "better design products and facilitate multi-design alternatives." This finding is quite significant as it empirically shows that the benefits of SSP implementation go beyond its contribution to the projects but also impact the participating construction organisation practices. This is in tandem with Cao et al. (2017) that image motives which reflect the business vision in competing and improving business performance are important and do determine firms' usage of smart technologies and green practices. As such, construction companies involved in SSP would be deemed as 'legitimate' among peers, which would promote their business interests. Also, companies could leverage SSP to showcase social value creation by demonstrating how their practices are improving the environment and society at large.

Albeit, there are subtle differences in the ranking of each BTs in both contexts. In the Hong Kong context, the respondents ranked *factor* BT19 higher than in Nigeria; and this could be related to the position of most construction firms to brand image in developed countries. In developed economies, construction companies do often consider the need to improve their organisational image more seriously than their counterparts in developing countries, and it is often reflected in their attitude towards corporate social responsibility and other related activities (Olanipekun et al., 2019). Also, the Environmental Protection Department (EPD) has introduced some operational guidelines (Kang et al., 2022) with particular emphasis on the 3Rs (reuse, recycling, and recovering) to accelerate the impact of *factor* BT22 in the Hong Kong construction sector. However, Nigeria is still a slower adopter of such waste reduction principles (Saka et al., 2019) and circular business models.

Cluster 3: Green initiatives and productivity

The '*green initiatives and sustainable products'* BT category accounts for 51% of the total variance in the Hong Kong context, while the '*green initiatives'* in the Nigeria context accounts for 6% of the total variance. The various green initiatives, which are the second derivates of the implementation of SSP in the construction supply chain, have positive impacts on the environment (Chan et al., 2012). More so, per Kai et al., 2012) and Olawumi and Chan (2022) highlighted some of these green initiatives to include green materials sourcing, clean and efficient building systems, environmentally friendly designs, reverse logistics, among others. SSP adoption in construction projects has facilitated the simulation of the environmental impact of various building elements leading to the selection of sustainable materials, components, and systems for the projects.

Compared to Nigeria, Hong Kong has several government establishments and professional bodies devoted to the research and development of green initiatives, such as the EPD, HKGBC, among others. This has led to the development of advanced tools, practices, and techniques towards its deployment in construction projects (Wadu Mesthrige & Kwong, 2018). This has facilitated the efficiency and productivity of such building/infrastructure projects, especially along with BIM use (Manzoor et al., 2021). This benefit is very significant, given that productivity issues have been a worrisome challenge in the construction sector. Other related benefits include reduced risks and increased safety (Li et al., 2019), occupant productivity (Olawumi & Chan, 2018) and sustainable communities (Wu et al., 2019).

4.6 Rank Agreement Analysis of the key beneficial outcomes between Hong Kong and Nigeria

The two groups compared using the RAA method are the respondents from Hong Kong (R_1) and Nigeria (R_2). From the factor normalization analysis in Section 4.2.2, there are 17 and 19 distinct and significant beneficial outcomes of SSP implementation in Hong Kong and Nigeria, respectively. Moreover, to ensure an equal basis for comparison between both contexts, only the 13 BT factors that are recognised by both sets of respondents were analysed here. These 13 BT factors were further grouped into 4 related factor clusters (JD), as presented in Table 4.

Suppose the rank of a BT factor in a factor cluster is $R_{i1}$for Hong Kong and that for the same factor in Nigeria is R_{i2}. Also, let N represent the number of the BT factors within a particular factor cluster, and k denotes the number of groups (k=2). R_i denotes the sum of the ranks of the same BT factor in the two groups while R_j is the absolute difference in ranks of the same BT factor in R_1 and R_2 and reveals the disparity in the agreement between the BT benefits. DP is the disagreement percentage.

$$R_i = R_{i1} + R_{i2} \quad ---------- (10a)$$

$$R_y = \frac{\sum_{i=1}^{k} R_i}{N} ------------- (10b)$$

$$R_j = |R_{i1} - R_{i2}| ----------- (11a)$$

$$\boldsymbol{RAF} = \frac{\sum_{i=1} R_j}{N} ----------- (11b)$$

$$R_m = |R_i - R_y| ---------- (12a)$$

$$RAF_{max} = \frac{\sum_{i=2}^{N} R_m}{N} --------- (12b)$$

$$DP = \frac{\sum_{i=1}^{N} R_j}{\sum_{i=1}^{N} R_m} x\ 100 --------- (13a)$$

$$Agreement\ percentage\ (\boldsymbol{AP}) = 100 - DP \quad -------- (13b)$$

Table 4: Rank agreement analysis of the related factor clusters for the BTs of SSP implementation between Nigeria and Hong Kong

Code	Related beneficial outcomes (BT/JD)	Hong Kong			Nigeria			Agreement Analysis				
		MIS	SD	Rank	MIS	SD	Rank	R_i	R_j	R_m	RAF	AP
BT1	Enhance overall project quality, productivity, and efficiency	4.06	0.674	1	4.52	0.532	1	2	0	1		
BT8	Facilitate sharing, exchange, and management of project information and data	4.06	0.761	2	4.42	0.755	2	4	0	1		
JD1	**Project productivity and efficiency**							R_y=3	$\sum R_j = 0$	$\sum R_m = 2$	**0.00**	**100%**
BT35	Ability to simulate building performances and energy usage	3.78	0.857	2	4.57	0.555	1	3	1	2		
BT29	Facilitate the selection of sustainable materials, components, and systems for projects	3.74	0.781	4	4.22	0.889	4	8	0	3		
BT32	Facilitate integration with domain knowledge areas such as project management, safety, and sustainability	3.77	0.784	3	4.32	0.675	2	5	1	0		
BT3	Predictive analysis of performance (energy analysis, code analysis)	3.87	0.702	1	4.32	0.675	2	3	1	2		
JD2	**Green initiatives and sustainable products**							R_y=5	$\sum R_j = 3$	$\sum R_m = 7$	**0.75**	**57%**
BT15	Better design products and facilitate multi-design alternatives	3.96	0.720	1	4.48	0.655	1	2	0	2		
BT22	Prevent and reduce materials wastage through reuse & recycling and ensure materials efficiency	3.94	0.788	2	4.45	0.718	3	5	1	1		
BT9	Facilitates resource planning and allocation	3.78	0.739	3	4.45	0.654	2	5	1	1		
JD3	**Sustainable design and resource management**							R_y=4	$\sum R_j = 2$	$\sum R_m = 4$	**0.67**	**50%**
BT19	Improves organization brand image and competitive advantage	3.86	0.854	3	4.28	0.684	3	6	0	1		
BT20	Enhance business performance and technical competence of professional practice	3.84	0.759	4	4.29	0.788	2	6	2	1		
BT10	Reduction in site-based conflicts	3.91	0.891	2	4.14	0.912	4	6	2	1		
BT31	Enhance the accuracy of as-built drawings	3.95	0.882	1	4.32	0.776	1	2	0	3		
JD4	**Innovative business models and operational performance**							R_y=5	$\sum R_j = 4$	$\sum R_m = 6$	**1.00**	**33%**

From the rank agreement analysis, there exists a wide degree of divergence in the rank of the two groups (Hong Kong and Nigeria) as regards *innovative business models and operational performance* with RAF=1.00 and 33% agreement percentage. Interestingly, this could be related to the difference in the perception of circular economy business models in the two contexts. Whilst developing economies such as Nigeria are still entrenched in linear models of construction, developed economies like Hong Kong are embracing circular economy models with diverse strategies and government initiatives (Oluleye et al., 2023). As such, developing economies stand to benefit more in terms of innovative business models & operational performance but are hindered by bottlenecks. Enhancement in the accuracy of as-built drawings (BT31) and improvement of the brand image and competitive advantage of the organisation (BT19) were equally ranked first and third, respectively, in both groups. It implies that these two beneficial outcomes are the primary derivative of SSP adoption in a construction organisation. With the recent attention to whole building lifecycle assessment, the availability and completeness of as-built models will be key to its wider industry adoption. More so, per Carvalho et al. (2019), the essence of applying technology tools such as BIM to sustainability issues is to facilitate information sharing among project stakeholders across the building lifecycle.

For the *sustainable design and resource management* cluster, there is a relative agreement (50%) among the respondents' group with the BT factor: *better design products and facilitate multi-design alternatives* (BT15), both placed first in both groups. This shows that executing SSP is a veritable way to build better green/near-zero carbon buildings with reduced embodied carbon while making contribution to the goal of reducing global warming. It also highlights the significant roles of product design in implementing a circular economy (Spreafico & Landi, 2022b). Also, it implies that the availability of eco-friendly materials for use in the construction industry would help in reaping the benefits of SSP. Moreover, regarding *green initiatives and sustainable products* cluster, the level of consensus on the ranking of beneficial outcomes was slightly higher at 57% with RAF of 0.75. with the capacity of such SSP implementation being able to facilitate the selection of sustainable materials and components for projects (BT29) ranked fourth by the two groups of construction professionals. Given this, developers, clients, and contractors that hope to guarantee that their building materials are responsibly sourced must implement appropriate plans to ensure SSP is implemented across the project supply chain. Similarly, institutions of learning should train students on design for sustainability strategies as a long-term strategy for improving SSP in the construction industry (Spreafico & Landi, 2022a).

Furthermore, under the *project productivity and efficiency* cluster, the construction experts from Hong Kong and Nigeria had a perfect consensus on these beneficial outcomes. The experts both ranked BT factors (BT1 & BT8) as first and second, respectively and considered them as an inevitable success outcome of implementing SSP in construction projects. Hence, the RAF computes as 0.00 and the agreement percentage as 100%. The perfect agreement rate is undoubtedly an acknowledgement by the respondents that implementing innovative technology and sustainable practices in the built environment had strongly impacted the overall project quality, efficiency, and productivity. Therefore, for construction organisations and clients who intend to solve the inefficiency, mismanagement, and productivity problems in their projects, SSP could be the panacea solution for them. As corroborated by Beheiry et al. (2006), commitment to sustainability and innovation practices reduces risk in project execution and ensures better project planning, including cost and time performance in capital projects.

5. Conclusions

The study investigates the beneficial outcomes of smart-sustainable practices in the built environment. Based on an in-depth literature survey and perception of construction experts, the study established the salient benefits inherent in the use of green technologies to facilitate sustainable practices. Empirical questionnaires were administered to construction professionals, including those working with main contractors and clients in Nigeria and Hong Kong. The collated data were analysed using mean ranking, factor analysis, fuzzy synthetic analysis, and rank agreement analysis. The study's findings are relevant to industry practitioners and academics, policymakers, and environmental organisations involved in the delivery of smart, sustainable buildings and cities.

The research findings show that 17 and 19 factors as the key beneficial outcomes in Hong Kong and Nigeria (out of the 36 BTs). In Nigeria, the top three benefits of SSP include facilitating the building energy performance simulation, enhancement of project quality and productivity, and better design products with low-environmental impact. Meanwhile, in Hong Kong, the top significant BTs include improvement in project quality and productivity, collaborative sharing and management of project data, and real-time sustainable design and analysis. Professionals working with public clients in Nigeria and Hong Kong also referenced these top benefits. While for main contractors, the most significant of BTs is that it has improved their creativity and helped them develop new construction techniques. Also, the MC reiterated that it has resulted in reduced material wastage on-site via the application of the 3Rs (one of SSP initiatives). Moreover, a factor analysis of the normalised BT factors via the PCA approach resulted in consolidated three-factor clusters: *sustainable design and resource management, innovation and business performance,* and *green initiatives and productivity*. The findings of the rank agreement analysis show a high degree of consensus among experts in Nigeria and Hong Kong on the project productivity and efficiency BT group (100%) and a marginal consensus on the green initiative and sustainable products (57%).

The study's findings and deliverables, such as the impact evaluation models (IEM), have bridged the gap in knowledge and practice regarding the beneficial outcomes of SSP in the built environment, whether in developed or developing countries. It has provided objective means and metrics to predict and assess the potential impact of deploying SSP initiatives, including green-tech in building and infrastructure projects. It also provides clients, contractors, policymakers, and practitioners with areas to focus on and understand to improve the delivery of smart, sustainable projects. The IEM is also a basis for practitioners to compare and benchmark their projects. It is recommended that these key stakeholders promote and invest in SSP initiatives in the construction sector to ensure the impacts of these benefits can be felt and maximised. This study underscores the importance of context and would be important in the transferability of best practices among countries. Also, one of the key implications of this study is the need to provide more related education and training as a long-term effective strategy to drive SSP execution and ensure the reaping of its perceived benefits in the construction industry. Policymakers can use the study results to facilitate and advance the smart, sustainable, and liveable buildings and cities with minimal to zero environmental impact. As revealed in this study, the key benefits of SSP in the built environment (BE) of Hong Kong and Nigeria should be used to promote and maximise its implementation. Adequate awareness and understanding of these perceived benefits and resulting impacts amongst BE stakeholders will ensure the widespread of the pertinent and imperative SSP.

There are some limitations that provide fertile ground for future studies. Firstly, although the study was conducted in Nigeria and Hong Kong, these countries were selected based on their contrasting context (developed/developing economies & proliferation of digital construction). Future studies could compare other contexts or building types, such as heritage buildings. Secondly, emphasis was placed on the quality of responses rather than quantity and only experts were involved in the survey. Future studies could launch a general survey covering various experience levels of industrial practitioners and compare perceptions of the respondents based on their professions. Thirdly, the evaluated SSP deal with the nexus between BIM and sustainable practices and subsequent studies could consider the benefits of leveraging other technologies, such as Artificial Intelligence, for sustainable practices. Lastly, the case study application of the developed IEM in relevant projects is proposed for further validation and execution in future.

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