Concomitant Impediments to the implementation of Smart Sustainable Practices in the Built Environment

Abstract

The paper examines the major barriers to the application of smart tools to enhance the implementation of sustainability practices in the built environment. The study collated 38 types of impediments from a comprehensive desktop review of the literature, and the data collected were further subjected to expert review via the use of empirical questionnaire surveys. The perceptions of 220 professional respondents from 21 countries were collated via the surveys for statistical analysis and classification purposes. The study findings revealed the significant impediments as related to inadequate knowledge and skills, the current market structure and inherent resistance to change in the built environment, and organizational challenges, among others. A comparative analysis of the perceptions of the diverse groups of survey participants was conducted and discussed. The adoption of the survey findings is envisaged to help the built environment in minimizing the impact of these barriers and can serve as a policy instrument and useful guidelines for government agencies, stakeholders, and others towards ensuring BIM can be used to deliver the full potential of sustainability practices in the construction industry. The study has provided effective practical strategies and recommendations for enhancing the implementation of smart sustainability practices in the built environment.

Keywords: BIM; barriers; built environment; construction stakeholders; sustainability practices; smart technologies.

1. Background of study

The construction industry has been a slow adopter of innovative and smart technology (such as BIM) and implementation of sustainability practices unlike other sectors such as the automobiles. Kim and Yu (2016) aligned with this viewpoint by revealing that 78% of current users of BIM are yet to utilize this innovative tool for green projects. Apart from the United Kingdom and the United States which have witnessed an improved adoption and implementation of BIM and sustainability, most other countries are still lagging in its execution (Jung and Lee, 2015; Olawumi and Chan, 2018d). Gu and London (2010), while expounding on the readiness and implementation level among countries as regards BIM and sustainability, reported that it varies significantly. Even countries considered to be the early adopters and initiators of these concepts experienced a disproportionate level of knowledge.

Meanwhile, according to Kummitha and Crutzen (2017) and Kim and Yu (2016), sustainable smart approaches have recently been gaining drastic momentum in the industry. However, due to several inherent challenges in the industry, there are several setbacks which need to be addressed (Olawumi et al., 2018). Sustainable smart practice or approach is a system whereby technological tools and software are employed and integrated to facilitate the implementation of sustainability objectives (environmental, social and economic) in building projects, infrastructures, and urban cities. These practices have improved the efficiency of operations and projects, improved quality of life, among others; and are measured using some established performance indicators.

Meanwhile, a desktop review of the extant literature (Ayegun et al., 2018; Kummitha and Crutzen, 2017; Olawumi and Ayegun, 2016) revealed a variety of forces and conflicting expectations due to the multi-stakeholders and layered structure of projects and organizations in the construction industry. Hence, this has made the execution of sustainable smart practices in projects more complex and tasking. More so, the initial cost of acquiring necessary Information and Communication Technology (ICTs) infrastructure which is regarded as the core of smart city initiative (Graham and Marvin, 2001); and central to its successful implementation, of which BIM is a key variety (Olawumi and Chan, 2018a, 2018b) is very high.

Although, Neirotti et al. (2014) reported that ICTs alone cannot help achieve the desired improvements in the built environment as regards improving the standard and quality of human lives, and fulfilling the required sustainability potential of buildings. Hence, the need for an evaluation of other concepts that can enhance the sustainability of buildings and cities. This study intends to assess the barriers affecting the adoption and implementation of sustainable smart practices in construction projects. Conversely, the existing literature has discussed some benefits obtainable by the adoption of sustainable smart practices in the built environment. For instance, Bakici et al. (2013) and Olawumi and Chan (2019a) highlighted some benefits of implementing smart, sustainable practices in the construction project which include improving the quality of life of urban dwellers of such cities, enhancing the ability of stakeholders to simulate building energy performance (Olawumi and Chan, 2018a). Moreover, Bradley et al. (2016) stressed the functional capacity of BIM technologies to address issues in other domain areas such as sustainability, project management of which it was not initially designed for its use.

1.1 Knowledge gaps, research objectives and values

Much criticism has been raised about the sole implementation of either smart initiative or sustainability practices in the built environment (Cugurullo, 2017) due to the difficulties and more problems caused by its adoption. Hence, Olawumi et al. (2018) advocated for the implementation of concepts of sustainable smart practices to facilitate a holistic sustainability development of the built environment. Meanwhile, there is still vagueness regarding what constitutes smart- and eco-initiatives (Angelidou, 2015; Olawumi and Chan, 2018c). Extant literature (*see* Olawumi et al., 2017; Olawumi & Chan, 2017, 2018b; Wong et al., 2014) have conducted reviews on the concepts of smart sustainable practices as it applies both industry practice and teaching.

Also, previous studies (Kivits and Furneaux, 2013; Olatunji et al., 2017b, 2016) illustrated several attempts by the construction industry to utilize BIM to implement sustainability practices in building projects. However, issues related to inadequate coordination in organization and collaboration among key stakeholders has been a bane of the built environment. Adamus (2013) and Ma et al. (2018) accentuated that a critical challenge with implementing sustainable practices in the industry is the need to balance the implementation of the three pillars of sustainable development (social, environmental and economic sustainability) in projects. More so, where there has been an implementation of sustainability practices in building projects, more emphasis has been on the environmental sustainability construct (Ali and Al Nsairat, 2009; Berardi, 2012).

More so, studies such as Chandel et al. (2016) and De Boeck et al. (2015) pointed out that there are still significant gaps in practice in the adoption of innovative tools such as BIM for the implementation of sustainability practices in the construction industry. Studies such as Hosseini et al. (2015) and Mao et al. (2016) emphasized that without sufficient knowledge on the status (such as its barriers etc.) of the implementation of these concepts in the construction industry; it would be difficult to improve track aspects of its implementation that is still lagging. Olawumi and Chan (2018a) highlighted some current application of BIM in implementing sustainability in building projects. Apart from these, there are several smart technologies and tools employed in the construction industry which include: (i) Building Information Modelling (BIM); (ii) virtual reality; (iii) semantic web technology or ontology; (iv) augmented reality; (v) sensors; (vi) Radio-frequency identification (RFID); and (vii) Point-cloud data extraction, among others (Olawumi et al., 2017). However, the current study will discuss one of these smart tools- BIM and the challenges of utilizing it to enable the implementation of sustainable practices in the built environment. Although the other smart devices are being used in the construction industry, BIM is still the most widely employed smart tool (Jung and Lee, 2015; Olawumi et al., 2017; Wong and Zhou, 2015). Virtually every project stakeholder can also utilize BIM, and it is also a multifunctional technology.

Although some previous research studies have highlighted the profound barriers relating to BIM in the construction industry – none is yet to appraise the impediments militating against adopting both BIM and sustainability practices on the same building project. Accordingly, this study reviewed the existing literature to gather solid evidence of the challenges faced by the built environment in the implementation of sustainable smart practices.

Given the above, the current study aims to provide answers to the following research questions:

1. What are the impediments to the use of smart technologies such as BIM and its implementation based on a review of the extant desktop literature?
2. What are the key barriers or impediments to the implementation of sustainable smart practices in the built environment?
3. How significant are the key barriers or impediments based on the respondents' professional disciplines and organizational setup; and how do their perceptions differ?
4. To which categories can the key barriers or impediments be classified?

Section 2 provides answers to research question 1, while Section 4.1 does justice to research question 2. Also, Sections 4.1 and 4.2 provide answers to research questions 2 and 3. More so, Section 4.3 does justice to research question 4. The current research is significant in the fact that although some previous studies have discussed the barriers of BIM in the built environment, none of the earlier studies had examined the impediments of BIM as it affects the implementation of sustainability practices. More so, the study aims to provide practical steps, strategies, and recommendations for policymakers, local authorities, construction firms, and other key stakeholders to enhance the implementation of smart, sustainable practices in the built environment.

The study will qualitatively and quantitatively evaluate the impediments and barriers to smart and sustainable practices in the built environment. The ranking of the critical barriers or impediments in this paper is intended to form a basis for the making of the practical and well-informed decision-making process by government departments and construction stakeholders. The research findings will contribute to the existing body of knowledge on issues regarding the implementation of sustainability and the use of smart technologies in the built environment by providing the key barriers and practical recommendation to the implementation of sustainable smart practices. The findings can be adopted as a policy instrument and useful guidelines for government agencies, stakeholders, and others towards ensuring BIM can be used to deliver the full potential of sustainability practices in the construction industry.

The paper's structure is as follows. Section 1 provides a background of the issues of BIM and sustainability practices' adoption in the construction industry and the research questions. Section 2 reviews the significant difficulties and challenges faced in the adoption of smart, sustainable practices in the construction industry, while Section 3 explains the research design and analytical tools adopted in analyzing the data. Section 4 provides highlights of the results of the data analyses carried out while Section 5 presents the discussions and implications of the study's findings. Section 6 provides the paper's summary and illustrates some recommendations for enhancing the implementation of smart, sustainable practices in the built environment; and highlights the limitations of the study.

2. Impediments of implementing smart sustainable practices: A desktop review

There has been a surge in recent years in the use of variants of BIM in construction process and previous studies such as Wang and Adeli (2014) and Olawumi et al. (2017) stressed the need to integrate smart techniques such as BIM with sustainability to achieve more energy savings, reduce carbon emissions, and promote green neighborhoods. However, as it is always the case when new techniques and concepts are introduced in the construction industry, the implementation of sustainable smart practices are facing some setbacks (Jalaei and Jrade, 2015; Nanajkar and Gao, 2014; Olawumi et al., 2018). One key aspect common to the implementation of smart, sustainable practices is the use of software to model and analysis the building model and associated performance parameters. According to Adamus (2013), there have been issues relating to data exchange between building design software and sustainability analysis software, mostly known as interoperability issues in the construction industry (Olawumi et al., 2017).

Technical impediments: Angelidou (2015) observed that technology-based product in the construction industry advanced faster and received more acceptance; although its implementation, according to Olawumi et al. (2018) can be much slower. However, the issues relating to sustainability and providing solutions to the construction industry's efficiency problems has lagged (Angelidou, 2015); hence, producing an imbalance and hindering the achievement of sustainable development in the built environment (Cugurullo, 2017). As noted by Kummitha and Crutzen (2017), there has been skepticism as smart cities and buildings such as how can is such planned, whose ideas make up the plan and what are the cost and benefits.

These issues according to Moser (2015) and Datta (2015) has heightened apprehensions among communities, its citizens and even among some stakeholders who may be the 'actual losers' due to the top-down approach of most innovative smart city initiative which has some negative implications for sustainable urban development (Calzada and Cobo, 2015). Also, according to Alsayyar and Jrade (2015), there is limited sustainability analysis software to support this initiative, and per Akinade et al. (2017), the sustainability parameters of building properties are difficult to access for performance analysis purposes.

Legal-related barriers: Kummitha and Crutzen (2017) reported how the government of India enacted some laws to fast-track the use of some specific cities as a platform to support the smart city initiative, however, per Bunnell (2015), the steps suffered some significant setbacks due to protest by marginalized communities who wanted the government to roll-back the scheme. BIM according to Aibinu and Venkatesh (2014) is not made mandatory by most clients for their projects, hence, if any contractor intends to adopt it in such projects, the contractor might likely bear the cost of the implementation. The above brings to the fore, the lack of awareness of this benefits to key stakeholders both in the construction industry and in the local communities (Gu and London, 2010; Hope and Alwan, 2012). Also, in the United Kingdom, it is mandatory for public projects exceeding five million pounds to implement BIM in such projects. Several other factors such as shown in Table 1 are some barriers which are evident in the literature and practice as hindering the implementation of smart, sustainable practices in the construction industry (Olawumi et al., 2018).

Education and knowledge-related barriers: Welter (2003) argued the need for citizenry participation in the design, building, and management of their buildings and cities in a bottom-top approach to city urbanization. However, currently reverse is the case in the built environment whereby only a few stakeholders are involved in building design and collaboration (Kummitha and Crutzen, 2017); amid the native non-collaborative culture of project stakeholders in the construction industry (Olatunji et al., 2016, 2017a). More so, Wang and Adeli (2014) argued for the necessity to promote sustainable building design among project stakeholders in order to ensure efficient material use and energy consumption (Lee et al., 2013; Pinto et al., 2013), reduce carbon emission and lifecycle costs (Hegazy et al., 2012).

Stakeholder's attitude: Abubakar et al. (2014) highlighted the resistance to change of construction organizations and key stakeholders in the built environment as a key impediment to the implementation of innovative concepts such as BIM and sustainability in building projects. Hence, per Gu and London (2010) and Redmond et al. (2012) this has led to the disproportionate level of implementation of sustainable smart practices in construction projects. Abubakar et al. (2014) classified this resistance to change into – societal and habitual resistance. Wu and Handziuk (2013) noted that the resistance to change had impacted negatively on the skills, knowledge, and the experience of project stakeholders as regards sustainable smart practices and its adoption in building projects. Hence, for the built environment to experience a full implementation of these concepts in every construction project; a significant change in stakeholders' attitude and perception to the uptake of innovative and revolutionary concepts such as BIM and sustainability practices.

Organizational and project-related barriers: Antón and Díaz (2014) regard the construction industry as a project-based sector which requires the coordination of various stakeholders from different organizations to collaborate to accomplish the project objectives. More so, per Olawumi et al. (2018) argued that for a successful implementation of BIM and sustainability practices, a considerable measure of physical human efforts and coordination is required. However, as reported by Boktor et al. (2014), the inadequacy of project team coordination, as well as the fragmented nature of the construction industry, have hindered the successful implementation of sustainable smart practices in building projects; especially in labor-intensive projects. These issues highlighted above impedes the delivery of construction projects and the application of innovative technologies and concepts.

The study will, in the subsequent sections, attempts to analyze the perception of various stakeholders from twenty-one countries on the barriers to the implementation of sustainable smart practices.

Table 1: Summary of identified barriers to the implementation of smart sustainable practices

Code	Barriers	Related sources of data
BA1	Varied market readiness across organizations and geographic locations.	Antón and Díaz (2014); Gu and London (2010); Kivits and Furneaux (2013); Redmond et al. (2012)
BA2	Industry's resistance to change from traditional working practices.	Abubakar et al. (2014); Gu and London (2010); Kivits and Furneaux (2013); Chan et al. (2019a, 2019b)
BA3	Lack of client demand and top management commitment	Aibinu and Venkatesh (2014); Boktor et al. (2014); Rogers et al. (2015)
BA4	Lack of support and involvement of the government	Abubakar et al. (2014); Bin Zakaria et al. (2013)
BA5	Low level of involvement of BIM users in green projects	Antón and Díaz (2014); Ma et al. (2018)
BA6	Societal reluctance to change from traditional values or culture	Aibinu and Venkatesh (2014); Kivits and Furneaux (2013); Redmond et al. (2012)
BA7	The lack of awareness and collaboration among project stakeholders	Antón and Díaz (2014); Bin Zakaria et al. (2013); Gu and London (2010); Hope and Alwan (2012)
BA8	Inadequacy of requisite experience, knowledge, and skills from the workforce	Abubakar et al. (2014); Aibinu and Venkatesh (2014); Chan (2014); Gu and London (2010); Kivits and Furneaux (2013); Nanajkar and Gao (2014)
BA9	Longer time in adapting to new technologies (steep learning curve)	Aibinu and Venkatesh (2014); Nanajkar and Gao (2014)
BA10	Lack of understanding of the processes and workflows required for BIM and sustainability	Aibinu and Venkatesh (2014)
BA11	Low level of research in the industry and academia	Aibinu and Venkatesh (2014); Antón and Díaz (2014); Redmond et al. (2012)
BA12	Inadequate in-depth expertise and know-how to operate sustainability-related analysis software programs	Ahn et al. (2014); Antón and Díaz (2014); Gu and London (2010)
BA13	Shortage of cross-field specialists in BIM and sustainability	Hope and Alwan (2012)
BA14	The high cost of BIM software, license, and associated applications	Aibinu and Venkatesh (2014); Kivits and Furneaux (2013); Nanajkar and Gao (2014)
BA15	The high initial investment in staff training costs	Aibinu and Venkatesh (2014); Kivits and Furneaux (2013)
BA16	Recurring need for additional and associated resources and high economic expenses	Aranda-Mena et al. (2009); Young et al. (2008)
BA17	Lack of initiative and hesitance on future investments	Gu and London (2010); Hanna et al. (2013)
BA18	Fragmented nature of the construction industry	Antón and Díaz (2014); Gu and London (2010); Kivits and Furneaux (2013); Redmond et al. (2012)
BA19	Organizational challenges, policy, and project strategy	Boktor et al. (2014); Dossick and Neff (2010)
BA20	Difficulty in assessing environmental parameters of building properties	Abolghasemzadeh (2013); Akinade et al. (2017)
BA21	Difficulty in accessing sustainability-related data (such as safety, health, and pollution index, etc.)	Adamus (2013); Antón and Díaz (2014); Olawumi and Chan (2019b, 2019c)
BA22	The risk of losing intellectual property and rights	Kivits and Furneaux (2013); Redmond et al. (2012)
BA23	Difficulty in allocating and sharing BIM-related risks	Kivits and Furneaux (2013)
BA24	Lack of legal framework and contract uncertainties	Aibinu and Venkatesh (2014); Redmond et al. (2012)
BA25	Increased risk and liability	Kivits and Furneaux (2013); Olawumi et al. (2018)
BA26	Lack of suitable procurement policy and contractual agreements	Aibinu and Venkatesh (2014); Sackey et al. (2015)
BA27	Non-uniformity of sustainability evaluation criteria and measures	Abolghasemzadeh (2013); Antón and Díaz (2014)
BA28	Lack of a comprehensive framework and implementation plan for sustainability	Azhar (2011); Redmond et al. (2012); Saxon (2013)
BA29	Absence or non-uniformity of industry standards for sustainability	Alsayyar and Jrade (2015); Boktor et al. (2014); Saxon (2013)
BA30	Inaccuracy and uncertainty in sustainability assessments for projects	Ahn et al. (2014); Alsayyar and Jrade (2015); Antón and Díaz (2014)
BA31	Incompatibility issues with different software packages	Antón and Díaz (2014); Kivits and Furneaux (2013); Nanajkar and Gao (2014); Rogers et al. (2015)
BA32	Absence of industry standards for BIM	Antón and Díaz (2014); Chan (2014); Redmond et al. (2012); Rogers et al. (2015); Saka et al. (2019)
BA33	Insufficient level of support from the BIM software developers	Redmond et al. (2012)
BA34	Inadequacy of BIM data schemas to semantically represent sustainability-based knowledge	Adamus (2013); Chan et al. (2019); Olawumi and Chan (2019d)

Code	Barriers	Related sources of data
BA35	Lack of supporting sustainability analysis tools	Akinade et al. (2015); Alsayyar and Jrade (2015)
BA36	Non-implementation of open source principles for software development	Hope and Alwan (2012)
BA37	Domination of the market by commercial assessment tools	Hope and Alwan (2012)
BA38	User-unfriendliness of BIM analysis software programs	Ahn et al. (2014); Aksamija (2012)

3. Research methodology

This study identified and assessed the barriers to the implementation of smart, sustainable practices in construction projects. The study adopted a quantitative research methodology via empirical questionnaire surveys to elicit the necessary data for the study. Moreover, the questionnaire items were gathered via the use of secondary data through a systematic review of desktop literature from journal papers, government gazettes, libraries, and web pages. According to Olatunji et al. (2017), the method of data collection is significant in establishing the aim of the study as well as in the composition of the questionnaire survey form.

A purposive sampling technique, together with a snowball sampling, was used in targeting relevant respondents for the study. The survey respondents are construction professionals with good knowledge of the concepts of smart, sustainable practices as it relates to the built environment. The respondents were given brief information on what smart sustainability practices is. Three modes were adopted in sending the questionnaire surveys to the respondents: (1) online survey forms; (2) fill-in PDF survey form; and (3) hand-delivered questionnaire. More so, personalized emails were sent to some potential respondents using with the attached fill-in PDF survey form as well as a link to the online survey form.

A total of 220 survey responses were received across 21 countries, and the data were analyzed in greater detail in later sections. One hundred sixty-one responses were collected via the online survey form, 14 via the fill-in PDF form and 45 via the hand-delivered method. There was a 100% response rate via the hand-delivery method of the questionnaire distribution. However, for the other two forms of distributions (fill-in PDF form and online surveys), it was difficult to determine the questionnaire return ratio as a snowball sampling technique was used for it. The questionnaire was pretested before distribution. The questionnaire survey collected some background information on the respondents as well as asked the respondents to rate the factors on a 5-point Likert scale: 1 = strongly disagree, 3 = neutral / no comment and 5 = strongly agree. The respondents have the option to tick ‘N/A’ if the factor is not applicable as a barrier to the implementation of smart, sustainable practices in construction projects. The respondents were given options to add to the factors listed for assessment. However, none of the 220 respondents added to the 38 factors listed on the survey form.

3.1 Statistical tools for data analysis

Several statistical tools and methods were employed in analyzing the data collected in the course of the study. These include: (1) Cronbach's alpha (α) reliability test; (2) Mean score ranking and standard deviation (SD); (3) Inferential statistical tests such as ANOVA, post-hoc Tukey tests, correlation analysis; and (4) Factor analysis and groupings. According to Field (2009), a reliability test is required to be undertaken before further analysis on a set of data. Cronbach alpha reliability test was used in this study to assess the questionnaire and its associated scale to ensure its measure the right construct (Field, 2009; Olatunji et al., 2017a).

The Cronbach's alpha is employed to test the internal consistency and reliability of a construct, and the range of its α coefficient ranges from 0 to 1. It implies that the larger the α-value, the better the reliability of the scale or the generated result (Chan et al., 2019b). The arithmetic mean is a measure of central tendency which indicates the average values of a set of figures (equation i) while SD is a quantitative measure of the differences of each value from the mean and it is a measure of variability (see equation ii). A low SD indicates that the values are close to the mean, whereas a high SD implies the data points are spread out over a large range of values. ANOVA (analysis of variance) is an inferential statistical tool used to determine whether any statistically significant differences exist between the means of two or more independent data groups. ANOVA requires typically distributed data points(Olatunji et al., 2017a). The post-hoc Tukey test is regarded as a posteriori test because it is only needed to confirm and reveal where the differences occurred between groups after an ANOVA analysis has identified the statistically significant different groups. Factor analysis is discussed in full details in section 4.3.

$$\bar{X} = \frac{\sum x}{n} - - - - equation\ (i)$$

$$SD = \sqrt{\frac{\sum (x - \bar{X})^2}{n - 1} - - - - \ equation\ (ii)}$$

Where $\bar{X}$ = mean score;

$\sum x$ = aggregate score of a set of values;

x = individual factor value;

n = number of values (that is, number of respondents in this study);

SD = Standard deviation.

The α-value for this study was 0.951, which is higher than the minimum threshold of 0.70 (Olawumi and Chan, 2018a) and implies good internal consistency and that the data are suitable for further statistical analysis. For the mean ranking, if two or more factors have the same mean value, the SD values are used to rank them; the factor with the lower SD value is ranked higher (Olatunji et al., 2017a; Olawumi and Chan, 2018c). However, if they have the same mean and SD value, they will have the same rank (Olawumi and Chan, 2018b).

3.2 Respondents' demographics

The section reveals vital information about the 220 respondents that participated in the survey (see Figure 1). The respondents were from 21 countries working under diverse organizational types with majority of them working in the academia (87, 39.5%), followed by public client participants (55, 25%), main contractors (35, 15.9%), project consultants (25, 11.4%), private clients (12, 5.5%), with the least number of participants coming from property management companies (6, 2.7%). Professional-wise, the findings a slight majority as quantity surveyors (25%), followed by academics (13.2%), architects (12.7%), project managers (12.3%), civil engineers (10.9%), builders and construction managers (8.6%), building services engineers (7.7%), urban planners (2.7%), BIM managers (2.3%), structural engineers (2.3%); and estate valuers and property managers (2.3%).

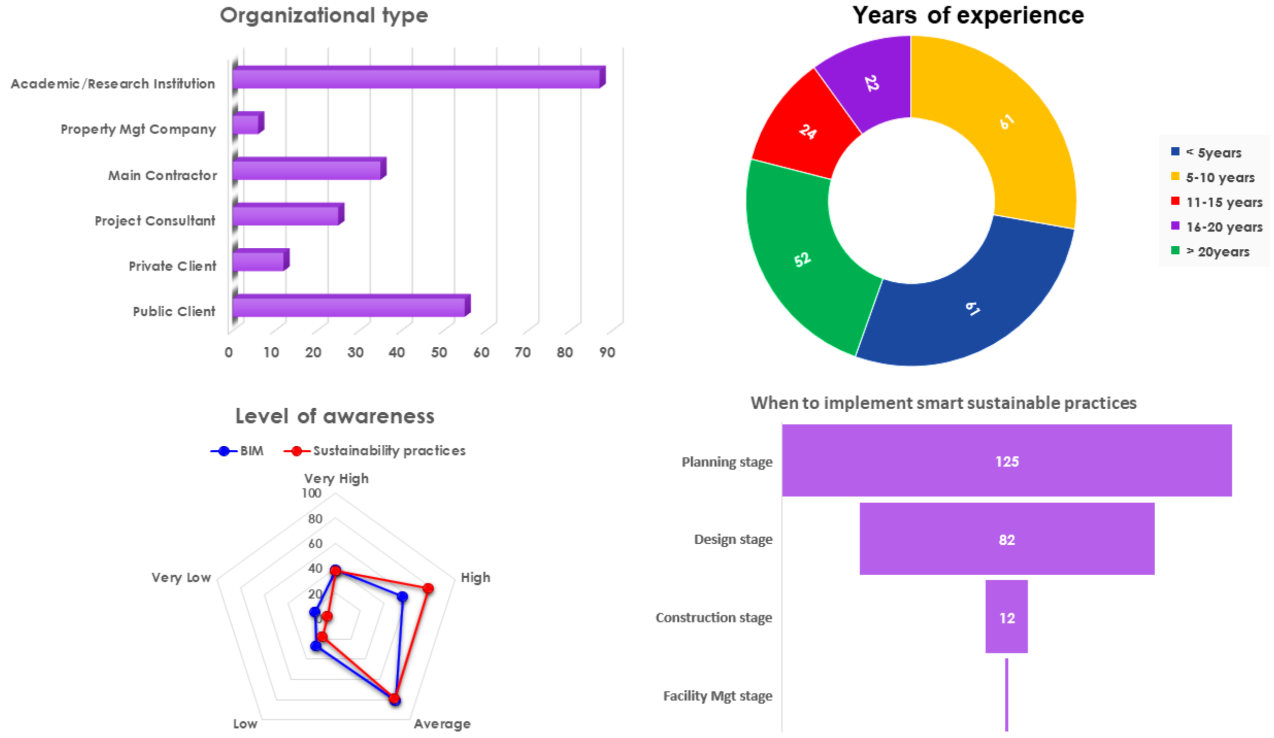


Figure 1: Respondents' demographics

Meanwhile, the respondents were asked about their level of awareness of the BIM concepts and processes. The findings revealed that a significant percentage of the respondents have at least a high level of awareness (95, 43.2%), while the eight-one of the respondents (36.8%) have an average level of awareness. Meanwhile, based on the respondents' level of awareness of the sustainability process, most of the respondents (116, 52.8%) have at least a high level of awareness. While about seventy-nine respondents (35.9%) have an average level of awareness of sustainability practices. The survey participants have considerable professional experience in the construction industry with 44.5% of the respondents (98) having at least 11 years working experience in the industry, and the next 27.7% of the respondents (61) have between five to ten years working experience in the construction industry. More so, majority of the respondents (125, 56.8%) argued for the implementation of smart, sustainable practices at the planning stage and another 37.3% of the respondents (82) noted that the design stage of project development is the best stage to implement the concepts while twelve respondents (5.5%) and one respondent preferred the construction and facility management stages respectively.

4. Results of statistical analyses

This section discusses the results of the data collected via the questionnaire surveys and the findings of the statistical tools employed in the study.

4.1 Descriptive statistical tests

For the 38 barriers identified, the mean values range from M= 3.32 (SD= 0.984) for "BA25 - *increased risk and liability*" to M=4.15 (SD= 0.860) for "*BA8 - the inadequacy of requisite experience, knowledge, and skills from the workforce*" at a variance of 0.83 (See Table 3). Moreover, based on similar benchmarks adopted by (Lu et al., 2008; Olatunji et al., 2017a) who utilized the mean value of 4 on a 5-point Likert scale to regard a factor as an important one; a total of five factors can be regarded as significant based on the mean score. These include "*BA8 - inadequacy of requisite experience, knowledge, and skills from the workforce*" (M=4.15, SD= 0.860), "*BA2- industry's resistance to change from traditional working practices*" (M=4.06, SD= 0.868), "*BA9- longer time in adapting to new technologies (steep learning curve)*" (M=4.02, SD= 0.876), "*BA10- lack of understanding of the processes and workflows required for BIM and sustainability*" (M=4.00, SD= 0.825), and "*BA15- high initial investment on staff training costs*" (M=4.00, SD= 0.934). From the research findings, it can be implied that low awareness and knowledge is still a significant hindrance to the implementation of smart, sustainable practices in the built environment along with the sustained archaic industry culture and the costs of investment.

The respondents from the public and private clients, project consultant, and the academics rated “BA8 - the inadequacy of requisite experience, knowledge, and skills from the workforce” (M=4.15, SD= 0.860) as the most significant barrier to the implementation of smart, sustainable practices in construction projects. However, the factor was rated by respondents from the main contractors as the second most significant factor who ranked “BA14- the high cost of BIM software, license, and associated applications” as the critical barrier. This findings from the various organizational set up show that the respondents from the main contractors perceived the cost of these concepts as significant because incorporating the cost of these software and its implementation in their work might increase their tender bid sum and put them in an unfavorable position against fellow competitive contractors. However, for the other set of respondents, the findings reveal there is still a lack of knowledge and expertise in both the private and public sectors of the construction industry. The civil engineers, project managers, and quantity surveyors agreed with this finding by ranking factor BA8 as the most significant barrier while the architects perceived “BA9- longer time in adapting to new technologies” (M=4.43, SD= 0.742) as the most critical barrier.

The academics regards “BA11 - low level of research in the industry and academia” as the least important barrier, this shows that there is a considerable increase in research publication in BIM (Olawumi et al., 2017) and sustainability (Olawumi and Chan, 2018d, 2017) in the literature. The private client’s respondents considered “BA25 - increased risk and liability” as the least significant factor, while to the public client’s respondents it is “BA22 - the risk of losing intellectual property and rights”. These findings are because the risks and liabilities in most construction projects are passed across to the contractors by both the private and public sectors clients. Hence, these factors have little impacts on their business interests.

4.2 Inferential statistical tests

In order to further investigate the differences in the perception from the diverse sets of respondents from differing organizational setups (private and public clients, project consultants, main contractors, and academics) and the professionals (architects, researchers, civil engineers, project managers, quantity surveyors, building service engineers, and construction managers). ANOVA was employed to analyze the 38 identified barriers which according to Olatunji et al. (2017) and Tsai et al. (2014) is a parametric statistical tool which is based on the mean of scores. More so, Olatunji et al. (2017) recommended that a post hoc Tukey’s test to be conducted on factors that are significant at p<0.05.

4.2.1 Statistical tests based on professional disciplines

The ANOVA analysis conducted on the data revealed a significant divergence in the opinions (at significance <5%) among the groups of respondents on six factors which are “BA11 - low level of research in the industry and academia” [$F(10,209) = 1.910$, $p = 0.045$]; “BA14 - high cost of BIM software, license, and associated applications” [$F(10,209) = 2.079$, $p = 0.027$]; “BA15 - high initial investment on staff training costs” [$F(10,209) = 2.532$, $p = 0.007$]; “BA16 - recurring need for additional and associated resources and high economic expenses” [$F(10,209) = 3.040$, $p = 0.001$]; “BA36 - non-implementation of open source principles for software development” [$F(10,209) = 3.002$, $p = 0.001$]; and “BA38 - user-unfriendliness of BIM analysis software programs” [$F(10,209) = 3.241$, $p = 0.001$].

A further analysis of the six significant barriers using the post hoc Tukey test revealed a very high significant difference (p = 0.001) on one factor “BA38 - user-unfriendliness of BIM analysis software programs”; with the architects (M=4.00, SD=1.054) perceiving it to be more significant than the construction managers (M=2.74, SD=0.991). The finding is consistent with the fact that architects use more software than an average construction manager; hence, if such software is user-unfriendly, it might hinder their use of the software.

4.2.2 Statistical tests based on organizational setups

The ANOVA analysis conducted on the results (at significant <5%) showed some significant differences in the opinions of respondents from diverse organizational setups on ten factors such as “BA4 - lack of support and involvement of the government” [$F(5,214) = 3.188$, $p = 0.008$]; “BA5 - low level of involvement of BIM users in green projects” [$F(5,214) = 3.599$, $p = 0.004$]; “BA7 - the lack of awareness and collaboration among project stakeholders” [$F(5,214) = 2.869$, $p = 0.016$]; “BA10 - lack of understanding of the processes and workflows required for BIM and sustainability” [$F(5,214) = 2.758$, $p = 0.019$]; “BA19 - organizational challenges, policy, and project strategy” [$F(5,214) = 2.673$, $p = 0.023$] among others (see Table 3). Moreover, based on the post hoc Tukey test evaluation of the ten significant barriers, eight barriers were found to be more important (p<0.05). These include “BA4 - lack of support and involvement of the government” with a moderate significance (p = 0.024) of which the respondents from the private clients (M= 4.33, SD= 0.651) perceived the barrier to be significant to their adoption of smart, sustainable practices than those from the public-sector clients. The finding is because private clients who are under less control of the governments might not receive funding or support from the government, unlike their public-sector counterparts who receive yearly or quarterly allocations for their operations.

More so, for “BA5 - low level of involvement of BIM users in green projects”, there is a high significance (p=0.016) between the public sector (M=3.36, SD=1.025) and private sector (M=4.33, SD=0.492) clients with the private sector identifying the factor to be of higher importance than their public counterparts. Similarly, at a significance of (p=0.023), the respondents from the main contractors (M=4.00, SD=0.804) perceived the factor to be of high importance than the public sector. The analysis is consistent with the findings of Olawumi et al. (2018), which revealed a higher level of involvement of BIM users in green projects in government establishments than in the private sector. See Table 2 for the results of the post hoc Tukey tests for the organizational setups.

Table 2: Post-hoc Tukey test for the organizational setups

Factors	Organizational setups	Significance	Factors	Organizational setups	Significance
BA4	Public clients vs Private clients*	0.024	BA20	Public clients vs Private clients* Public clients vs Academics* Main contractors* vs Public clients	0.006 0.003 0.017
BA5	Public clients vs Private clients* Public clients vs Main contractors*	0.016 0.023	BA21	Main contractors* vs Public clients Public clients vs Academics*	0.012 0.008
BA7	Public clients vs Private clients* Public clients vs Academics*	0.046 0.021	BA30	Main contractors* vs Public clients	0.023
BA19	Public clients vs Private clients*	0.021	BA37	Project consultants vs Main contractors*	0.019

*Note: *organizational setup considers the factor of higher significance than the other organizational setups*

Table 3: Barriers to smart sustainable practices in the built environment: inter-group comparisons

Barriers	Public clients		Private clients		Project consultants		Main contractors		Academics		Overall				
	Mean	Rk	Mean	Rk	Mean	Rk	Mean	Rk	Mean	Rk	Mean	SD	Rk	F	Sig.
BA1	3.98	4	4.17	17	3.88	10	3.91	11	4.01	4	3.97	0.805	7	0.452	0.811
BA2	3.95	5	4.42	2	3.96	6	3.89	18	4.18	2	4.06	0.868	2	1.326	0.254
BA3	3.62	16	4.00	28	3.92	9	3.97	8	4.01	6	3.90	0.933	9	1.347	0.246
BA4	3.24	35	4.33	10	3.96	7	3.83	23	3.55	24	3.61	1.127	25	3.188	**0.008**
BA5	3.36	30	4.33	9	3.72	18	4.00	5	3.56	22	3.64	0.963	21	3.599	**0.004**
BA6	3.56	19	4.08	24	3.76	16	3.86	22	3.49	28	3.63	1.009	23	1.313	0.260
BA7	3.49	25	4.33	13	3.88	11	3.91	12	3.99	7	3.86	0.928	10	2.869	**0.016**
BA8	4.05	1	4.50	1	4.12	1	4.09	2	4.23	1	4.15	0.860	1	1.110	0.356
BA9	3.98	3	4.42	2	3.92	8	4.00	6	4.01	5	4.02	0.876	3	0.612	0.691
BA10	3.78	9	4.33	10	4.04	2	3.94	9	4.16	3	4.00	0.825	4	2.758	**0.019**
BA11	3.25	34	3.67	34	3.64	23	3.63	35	3.22	38	3.38	1.051	35	1.554	0.174
BA12	3.85	8	4.25	16	3.80	14	3.97	7	3.71	16	3.84	0.937	12	0.965	0.440
BA13	3.93	6	4.42	2	3.96	5	4.06	3	3.93	9	3.97	0.967	8	0.900	0.482
BA14	3.87	7	4.33	12	4.00	4	4.11	1	3.93	10	3.99	0.981	6	0.768	0.573
BA15	4.00	2	4.42	7	4.00	3	4.00	4	3.91	11	4.00	0.934	5	0.795	0.555
BA16	3.71	11	4.42	7	3.60	29	3.91	10	3.79	14	3.80	0.851	13	1.824	0.109

Barriers	Public clients		Private clients		Project consultants		Main contractors		Academics		Overall				
	Mean	Rk	Mean	Rk	Mean	Rk	Mean	Rk	Mean	Rk	Mean	SD	Rk	F	Sig.
BA17	3.60	17	3.92	29	3.60	30	3.86	21	3.67	18	3.68	0.911	17	0.595	0.704
BA18	3.62	15	4.42	2	3.68	22	3.91	15	3.84	12	3.80	0.985	14	1.551	0.175
BA19	3.64	14	4.42	2	3.72	19	3.86	20	3.93	8	3.85	0.786	11	2.673	**0.023**
BA20	3.22	36	4.17	18	3.64	24	3.80	25	3.76	15	3.64	0.862	20	4.416	**0.001**
BA21	3.29	33	4.00	25	3.60	25	3.91	13	3.80	13	3.68	0.886	16	3.494	**0.005**
BA22	3.13	38	3.67	35	3.20	36	3.57	37	3.36	33	3.34	1.058	37	1.131	0.345
BA23	3.29	32	3.67	35	3.56	32	3.71	29	3.49	27	3.49	0.986	33	1.042	0.394
BA24	3.47	27	3.75	33	3.72	19	3.80	24	3.56	21	3.60	0.953	26	0.914	0.473
BA25	3.16	37	3.50	38	3.20	35	3.63	34	3.30	35	3.32	0.984	38	1.173	0.323
BA26	3.58	18	4.17	20	3.60	25	3.66	33	3.51	26	3.58	0.992	28	1.685	0.139
BA27	3.51	21	4.25	14	3.68	21	3.74	27	3.66	19	3.67	0.867	18	1.525	0.183
BA28	3.51	22	4.17	18	3.80	12	3.77	26	3.55	23	3.63	0.915	22	1.636	0.152
BA29	3.51	23	4.08	22	3.80	13	3.86	19	3.60	20	3.67	0.908	19	1.405	0.224
BA30	3.29	31	4.08	21	3.76	15	3.89	16	3.54	25	3.59	0.895	27	3.112	**0.010**
BA31	3.78	9	3.92	30	3.76	17	3.89	17	3.69	17	3.77	0.958	15	0.283	0.922
BA32	3.69	12	4.08	22	3.60	25	3.69	32	3.47	31	3.62	1.098	24	0.862	0.507
BA33	3.51	24	4.25	14	3.48	33	3.57	36	3.29	37	3.47	1.036	34	2.079	0.069
BA34	3.65	13	4.00	25	3.56	31	3.51	38	3.45	32	3.56	0.980	29	0.839	0.523
BA35	3.47	26	4.00	25	3.60	28	3.69	31	3.31	34	3.50	0.939	32	2.125	0.064
BA36	3.53	20	3.75	31	3.32	34	3.71	28	3.48	29	3.53	0.929	30	0.707	0.618
BA37	3.44	28	3.58	37	3.12	37	3.91	13	3.48	29	3.52	0.963	31	2.542	**0.029**
BA38	3.38	29	3.75	32	3.04	38	3.71	30	3.30	36	3.36	1.039	36	2.603	**0.026**

Note: Rk- Rank

4.3 Classification of the key barriers based on factor analysis

The study adopted factor analysis to reduce a large number of the barrier factors to a relatively set of variables by investigating the interrelationships between the variables (Hair et al., 2010; Xu et al., 2010). There are two types of factor analysis, principal component analysis (PCA) and Promax rotation method (Chan and Hung, 2015); the PCA was used in this study. According to Chan and Choi (2015), factor analysis (PCA) is a statistical technique used to identify the underlying clustered factors that define the relationships among sets of interrelated variables; and can be used to interpret ‘nonrelated clusters’ of factors (Fang et al., 2004), and explain complex concepts (Xu et al., 2010). Meanwhile, before subjecting the 38 factors to factor analysis, a Pearson correlation analysis was conducted as recommended by Xu et al. (2010), who noted that the statistical method helps to eliminate the existence of any multiplier effects among the variables. Hence, the correlations of these factors were assessed, and 30 factors which are not highly correlated with each other are used in subsequent analysis.

The PCA was conducted using varimax rotation method (an orthogonal rotation method) on the thirty non-correlated barriers factors from a sample of 220 responses. The results of the factor analysis are shown in Table 4, while the column 'factor loading' illustrates the total variance explained by each factor. Lingard and Rowlinson (2006), Chan and Choi (2015) and Chan (2019) recommended that the sample size must be considered sufficient in the ratio of 1:5 (number of variables: sample size) which the current study fulfilled. That is, 30 barrier factors multiplied by five samples required for each factor = at least 150 samples needed to proceed with the factor analysis. Kaiser-Meyer-Olkin (KMO) tests for sampling adequacy and Bartlett's test of sphericity (BTS) was used to examine the appropriateness of PCA for factor extraction (Field, 2009).

The KMO value for the study's factor analysis is 0.904, which shows an 'excellent' degree of common variance (Field, 2009) and above the acceptable threshold of 0.50 (Norusis, 1993). More so, according to Chan and Hung (2015), a KMO value close to 1 indicates that a compact pattern of correlations and that the PCA will generate distinct and reliable clusters. The BTS analyses revealed a substantial test statistic value (chi-square=3413.643) and a small significance value (p=0.000, df=435) which per Chan and Choi (2015) implies that the correlation matrix is not an identity matrix. Therefore, as the various requirements needed to proceed with a factor analysis has been met, the PCA can be applied in this study with for further investigation and discussion; this ensures the research can be conducted with better reliability and confidence.

Seven underlying factors were extracted using PCA which represent 65% of the total variance in responses (see Table 4) which is above the minimum threshold of 60% (Chan, 2019; Chan & Choi, 2015; Hair et al., 2010; Malhotra, 1996).

Table 4: Factor structure of the varimax rotation on the key barrier factors

Code	Barriers to implementing smart sustainability practices	Factor loading	Eigenvalue	Percentage of variance explained	Cumulative percentage of variance explained
Factor 1 – Technical-related barriers			10.763	35.877	35.877
BA35	Lack of supporting sustainability analysis tools	0.788			
BA36	Non-implementation of open source principles for software development	0.713			
BA34	Inadequacy of BIM data schemas to semantically represent sustainability-based knowledge	0.710			
BA32	Absence of industry standards for BIM	0.656			
BA38	User-unfriendliness of BIM analysis software programs	0.566			
BA31	Incompatibility issues with different software packages	0.502			
Factor 2 – Attitude-related barriers			2.191	7.302	43.179
BA4	Lack of support and involvement of the government	0.759			
BA5	Low level of involvement of BIM users in green projects	0.701			
BA6	Societal reluctance to change from traditional values or culture	0.627			
BA7	The lack of awareness and collaboration among project stakeholders	0.603			

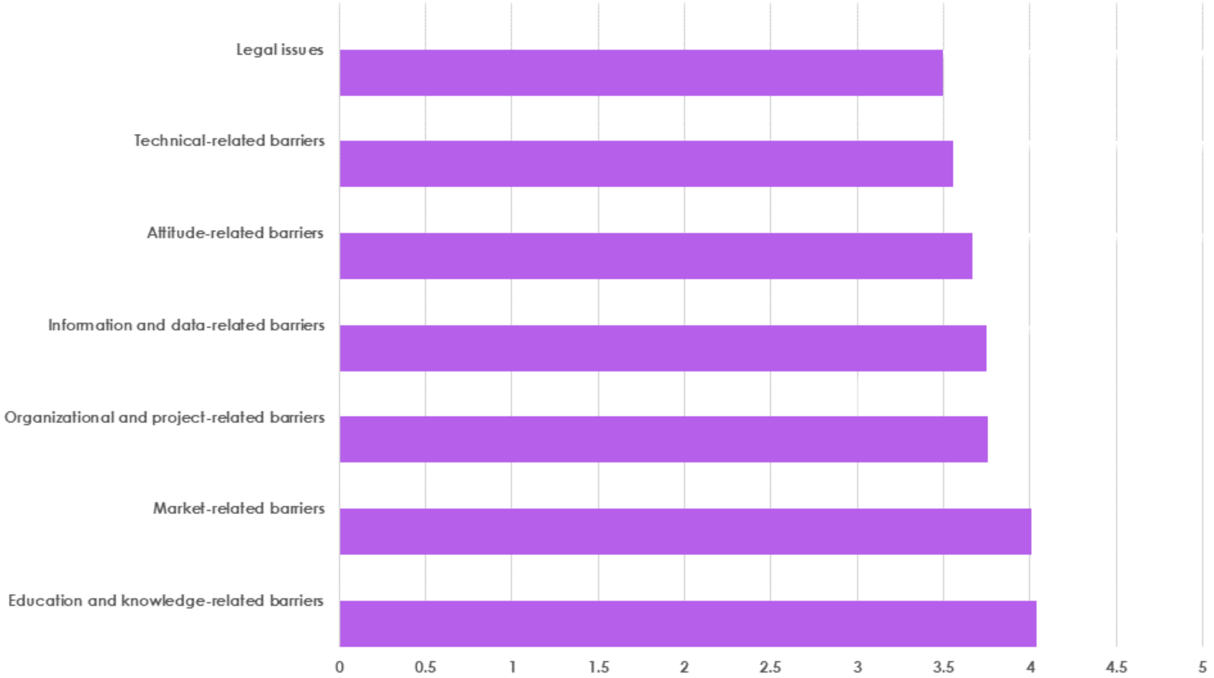
Code	Barriers to implementing smart sustainability practices	Factor loading	Eigenvalue	Percentage of variance explained	Cumulative percentage of variance explained
BA3	Lack of client demand and top management commitment	0.595			
BA11	Low level of research in the industry and academia	0.404			
Factor 3 – Education and knowledge-related barriers			1.642	5.473	48.652
BA8	Inadequacy of requisite experience, knowledge, and skills from the workforce	0.735			
BA9	Longer time in adapting to new technologies (steep learning curve)	0.726			
BA10	Lack of understanding of the processes and workflows required for BIM and sustainability	0.714			
BA13	Shortage of cross-field specialists in BIM and sustainability	0.668			
Factor 4 – Legal issues			1.446	4.822	53.473
BA25	Increased risk and liability	0.782			
BA24	Lack of legal framework and contract uncertainties	0.764			
BA26	Lack of suitable procurement policy and contractual agreements	0.756			
BA23	Difficulty in allocating and sharing BIM-related risks	0.633			
Factor 5 – Organizational and project-related barriers			1.251	4.170	57.643
BA17	Lack of initiative and hesitance on future investments	0.653			
BA19	Organizational challenges, policy, and project strategy	0.625			
BA18	Fragmented nature of the construction industry	0.614			
BA21	Difficulty in accessing sustainability-related data (such as safety, health, and pollution index, etc.)	0.533			
Factor 6 – Information and data-related barriers			1.207	4.024	61.667
BA30	Inaccuracy and uncertainty in sustainability assessments for projects	0.721			
BA29	Absence or non-uniformity of industry standards for sustainability	0.676			
BA14	The high cost of BIM software, license, and associated applications	0.596			
Factor 7 – Market-related barriers			1.006	3.353	65.021
BA1	Varied market readiness across organizations and geographic locations	0.648			
BA15	The high initial investment in staff training costs	0.515			
BA2	Industry's resistance to change from traditional working practices	0.504			

The 30 barrier factors are represented in one of the seven underlying grouped factors, and all the factor loadings of each barrier factors are close to 0.5 or higher as suggested by Chan and Hung (2015) and Chan and Choi (2015). According to Proverbs et al. (1997), the higher the value of the factor loading of an individual factor (which is maximum of 1.0), the higher the significance of the factor to the underlying cluster factor. The factor loading values also reflect how each factor contributes to its underlying grouped factor (Chan and Hung, 2015). The findings reveal a consistent and reliable factor loading and interpretation of the extracted individual factor.

5. Discussion of survey findings

5.1 Discussion of key cluster factors after factor analysis

The clustered factors are analyzed in Figure 2 in descending order of significance towards interpreting the individual factors linked to them. As suggested by Sato (2005), an identifiable and collective label is attached to each grouped factor of high correlation coefficients; which are themselves a cluster of individual factors. However, per Chan and Hung (2015), these labels are subjective, and each author may come up with different labels. The factor clusters are ranked using their factor scale rating as employed by Chong and Zin (2012) and Chan (2019). The factor scale rating is the ratio of the mean of individual factors within a cluster divided by the number of factors in the cluster (Chan and Hung, 2015; Chan, 2019). Discussion of the key factor clusters will focus on the top-four ranked factor clusters. Similarly, based on the precedent cases in the existing literature (Chan and Choi, 2015; Olawumi and Chan, 2019a; Xu et al., 2010), these studies only discussed top-three of the key cluster factors generated after factor analysis based on their factor scale ratings; and to converse space. Also, one of the purposes of employing the factor scale rating analysis is to highlight more significant cluster factors with relatively higher rating values for further discussion (Chan and Hung, 2015).



	Education and knowledge-related barriers	Market-related barriers	Organizational and project-related barriers	Information and data-related barriers	Attitude-related barriers	Technical-related barriers	Legal issues
Ranking	1	2	3	4	5	6	7
■ Factor scale rating	4.035	4.01	3.7525	3.75	3.67	3.5567	3.4975

Figure 2: Ranking results of the factor scale rating for the key cluster factors

5.1.1 Education and knowledge-related barriers

Factor 3, consisting of four barrier-related factors, is the highest-rated clustered factor with a factor scale rating of M=4.035. The cluster is related to experience and knowledge of construction organization staff, the steep learning curve, inadequate understanding of smart, sustainable practices processes, and the shortage of cross-field specialists in smart, sustainable practices. Gu and London (2010) observed through their study that little or no attention has been placed on the training of construction professionals to improve their understanding and skills in the adoption of new technologies. More so, Aibinu and Venkatesh (2014) noted that the rapid technological change has reduced the ability of the workforce to adapt and that despite the benefits of these concepts, the current skills shortage in the industry has reduced the potentiality of its positive impact on construction processes. Hence, as advised by Olawumi et al. (2018), professional bodies and construction firms should collaborate to improve the skillsets and capacity of their members and staff in smart, sustainable practices. Gu and London (2010) call for the training of students at an early stage on these concepts for them to appreciate it after their graduation from college. Moreover, the government can support this initiative by training its staff in construction-related departments and parastatals as well as providing financial subsidies to private firms in the training of their workforce.

5.1.2 Market-related barriers

The next significant clustered factor is factor 7 with three key factors and a factor scale rating of M=4.01. The cluster is concerned with the varied market readiness across construction firms and regions, the high investment cost of training, and the industry resistance to change from traditional working practices. Olawumi et al. (2018) accentuated that despite the benefits of these concepts, little progress has been achieved in implementing BIM and sustainability practices in several countries. Abubakar et al. (2014) pointed out the hesitance of construction stakeholders to new concepts and innovative technologies which has hindered developments in the industry when compared to other sectors of the economy. Kivits and Furneaux (2013) recommended firms to consider its workforce along with the adopted technology to close the gap in the interconnection of the sociotechnical system. Meanwhile, Olawumi et al. (2018) urge construction firms and project stakeholders to be proactive like their counterparts in other sectors in adopting innovative concepts and embrace dynamic and positive developments in the built environment.

5.1.3 Organizational and project-related barriers

Factor 5 comprises of four barriers with a factor scale rating of M= 3.7525, which are related to construction firms' hesitance to plan for future investments, challenges related to organizational policies and strategies, fragmented nature of the industry, and the difficulties in accessing sustainability-related data used for the sustainability assessments of buildings. Olawumi et al. (2018) argued that concepts such as smart, sustainable practices despite its revolutionary effects on the built environment still requires the integration of human efforts and strategies which when lacking can amplify its non-implementation in construction projects. Olawumi et al. (2018) revealed the lack of investment in most organizations, which has affected their adoption of smart, sustainable practices. Antón and Díaz (2014) described the construction industry as a project-based sector, and per Boktor et al. (2014) the uncollaborative environment nature of the industry and ineffective organization strategies has hindered the implementation of these concepts. Moreover, Adamus (2013) considered the availability of sustainability-related software and data as pivotal to the decision-making process of project stakeholders and the sustainability assessments of buildings; while, Olawumi et al. (2018) pointed out the need for the government and professional bodies to subsidize the cost of procuring related smart, sustainable practices software to aid its adoption. Overall, the need for the development of sound and effective strategies by construction firms and stakeholders towards the adoption of smart, sustainable practices cannot be overemphasized.

5.1.4 Information and data-related barriers

Factor 6 is composed of three key factors with a factor scale rating of M= 3.75, and it includes the uncertainty and inaccuracies in sustainability assessments of buildings, the absence or non-uniformity of industry standards for smart, sustainable practices, and the high cost of BIM software and its associated software. Adamus (2013) observed that computer-aided decision tools have the potential to improve the sustainability of the built environment. However, their effectiveness is being hindered by the interoperability between design and sustainability analysis software. Adamus (2013) revealed that some data schemas such as the gbXML lacks contextual information that can aid sustainability assessments of building models. Alsayyar and Jrade (2015) advocated the need for uniform sets of sustainability criteria and a central database to evaluate the sustainability potentials of a building at the design stage. Aibinu and Venkatesh (2014) highlighted the cost of implementation as a significant barrier to the adoption of BIM in Australia, and this includes the high initial cost of the BIM software, yearly licenses or upgrades, and associated applications. Hence, since smart, sustainable practices feed on data as inputs for its effective impacts on the built environment, project stakeholders must collaborate to improve access to relevant data and its exchange.

5.2 Practical implications of research findings

The current study has revealed salient issues militating against the implementation of BIM and sustainability practices in the built environment, which have a significant impact on the proper delivery of sustainable and smart building projects. As revealed in the research findings, the private sector clients lamented the lack of support and involvement by their respective governments to enable their implementation of sustainable smart practices in building projects. Chan et al. (2019b) reported the initiative of the Hong Kong government to introduce subsidies and credit facilities to private developers and clients to facilitate adopting BIM and sustainability practices in the Hong Kong built environment too much success. Such initiatives are recommended for adoption to governments in other climes to embrace and implement in their countries and regions. When and if this recommendation is accepted, the current disproportionate level of adoption and readiness will be ameliorated and put the built environment on a fast-track for the full implementation of sustainable smart practices.

Also, the involvement of BIM users in green projects and deployment of BIM technologies to facilitate the adoption of sustainability practices is relatively low in the built environment (Kim and Yu, 2016; Olawumi and Chan, 2019d). Also, there is a significant lack of awareness of these concepts by the critical stakeholders in the construction projects, and it has thus affected their ability to collaborate towards implementing sustainable smart practices in the built environment. Without addressing these significant barriers, the built environment might not be able to apply these innovative practices; hence, there is the need for construction organizations to empower their staff by ensuring they stay abreast of knowledge and practice regarding sustainable smart practices. More so, construction firms should strategize and restructure their company towards easing the implementation and deployment of BIM and sustainability practices in their organizations. Also, professional bodies such as the RICS, CIOB, etc. should encourage their members and prospective members to attend seminars and workshops that will aid their knowledge and technical know-how on these concepts.

Meanwhile, the research findings revealed there is currently uncertainty and inaccuracy in the assessments of projects using existing green rating systems. More so, there is a lack of uniformity in the sustainability criteria and priority given to each sustainability criteria by the existing rating tools, which are militating against the adoption of sustainable smart practices in these countries. These findings correspond with the previous studies such as Ali and Al Nsairat (2009) and Illankoon et al. (2017). These barriers are still very salient in the built environment, although some leading green rating system such as BREEAM and LEED are attempting to deploy their custom-made rating tool to other countries apart from the originating regions. However, most countries in South America, Asia-Pacific Region, Africa, and some parts of Europe are yet to have a building rating system suited to the local context of these countries. Hence, this study recommends for each country to establish their own custom-made rating systems tailored to their local context of their regions as well as establish their individual green building councils to monitor the progress of the implementation of sustainability practices in their building projects.

6. Conclusions and recommendations

This study identified and evaluated the key barriers to the implementation of smart, sustainable practices which was the primary research aim of this paper. A total of thirty-eight barrier factors were identified via a desktop literature review and the factors outlined in a questionnaire which was ranked by 220 respondents from 21 countries who participated in the international survey and have direct and extensive experience in smart, sustainable practices. The survey participants came from diverse professional disciplines and organizational backgrounds, which further lend credence to the data collected. The study meanwhile conducted a comparative assessment of the perceptions of the study participants based on their professional disciplines and organizational backgrounds towards establishing patterns of difference.

A significant finding of this study is that there is a relative level of agreement among most of the groups of respondents on factor BA8- "*inadequacy of requisite experience, knowledge, and skills from the workforce*" as a critical impediment to the implementation of smart, sustainable practices in the built environment. The research findings also revealed that the architects perceived the longer time required for them to learn and adapt to new technologies as the most significant barriers. Even, the academics disagreed with the perception of the practitioners that factor BA11- "*low level of research in the industry and academia*" is highly significant. On the other hand, the academics opined that there is a considerable increase in the level of research in these concepts in universities, and this perception is consistent with the recent findings in the literature. Another profound research finding, is the classification of the critical barriers or impediments via factor analysis of the thirty-eight barrier factors yielded seven clusters with a minimum of three factors in each cluster and a maximum of six factors; while each factor cluster was given an identifiable and collective label to represent its sub-set factors.

After examining the perceptions of the diverse groups of the survey respondents, some useful recommendations and effective strategies for mitigating or eliminating the barriers are suggested. These recommendations include: (1) Professional bodies and construction firms should engage more in the training of their members and staff through the mediums of training workshops and knowledge seminars; (2) Increase in funding support to aid the adoption of smart, sustainable practices; (3) Provision of government subsidy to ease the ‘financial stress’ of small and medium scale construction firms; (4) Incorporating smart, sustainable practices in the curriculum of construction-related colleges and departments; (5) The need for construction firms and stakeholders to be proactive in adopting new and innovative concepts; (6) The development of effective strategies and plans for fast-tracking the implementation of smart, sustainable practices by construction organizations; and (7) The need to ease the access to and exchange of relevant data among project stakeholders. An obvious limitation of this study is that only BIM out of the several smart technological tools was examined as it influenced sustainability practices. The justification for this has been provided in Section 1 for perusal.

The study has qualitatively and quantitatively evaluated the impediments and barriers to smart and sustainable practices in the built environment. The ranking of the key barriers or impediments can form a sound basis for developing the practical and well-informed decision-making process by government departments and construction stakeholders. The research findings have contributed to the existing body of knowledge on sustainability and the use of smart technologies to aid the implementation of concepts in the built environment by determining the key barriers to and providing practical recommendations for the implementation of smart, sustainable practices. The findings can be adopted as a policy instrument and useful guidelines for government agencies, stakeholders, and others towards ensuring BIM can be used to deliver the full potential of sustainability practices in the construction industry.

The implementation of the findings of this study is imperative as it will enhance the capacity of the built environment to maximize the perceived benefits of smart and sustainable practices in its everyday activities. Meanwhile, if policymakers and other key stakeholders consider these significant barriers as identified and classified in this study; it is hoped that these challenges can be overcome or eliminated. Collaborative efforts from policymakers, local authorities, practitioners, academics, and other key stakeholders can help to combat these challenges. It is envisaged that the research findings have stimulated multitudinous open debate for reference to the underlying problems besetting the built environment in each local context and internationally.

Acknowledgments

This research study was initially supported by the research funding of the Sustainable City Laboratory and subsequently supported by the full-time PhD research studentship under the auspice of the Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong. The authors appreciate the reviewers for their valuable comments and suggestions towards improving the initial draft of this paper.

References

Abolghasemzadeh, P., 2013. A comprehensive method for environmentally sensitive and behavioral microscopic egress analysis in case of fire in buildings. Safety Science 59, 1–9. https://doi.org/10.1016/j.ssci.2013.04.008

Abubakar, M., Ibrahim, Y.M., Kado, D., Bala, K., 2014. Contractors Perception of the Factors Affecting Building Information Modelling (BIM) Adoption in the Nigerian Construction Industry. Computing in Civil and Building Engineering ©ASCE 167–178.

Adamus, L.W., 2013. BIM: Interoperability for Sustainability Analysis in Construction, in: Central Europe towards Sustainable Building 2013: Integrated Building Design BIM. pp. 1–4.

Ahn, K.U., Kim, Y.J., Park, C.S., Kim, I., Lee, K., 2014. BIM interface for full vs. semi-automated building energy simulation. Energy and Buildings 68, 671–678. https://doi.org/10.1016/j.enbuild.2013.08.063

Aibinu, A., Venkatesh, S., 2014. Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia. Journal of Professional Issues in Engineering Education and Practice 140, 1–10. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000193.

Akinade, O.O., Oyedele, L.O., Ajayi, S.O., Bilal, M., Alaka, H.A., Owolabi, H.A., Bello, S.A., Jaiyeoba, B.E., Kadiri, K.O., 2017. Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills. Waste Management 60, 3–13. https://doi.org/10.1016/j.wasman.2016.08.017

Akinade, O.O., Oyedele, L.O., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., Bello, S.A., 2015. Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS). Resources, Conservation and Recycling 105, 167–176. https://doi.org/10.1016/j.resconrec.2015.10.018

Aksamija, A., 2012. BIM-Based Building Performance Analysis : Evaluation and Simulation of Design Decisions Integration of BIM-Based Performance Analysis with Design, in: ACEEE Summer Study on Energy Efficiency in Buildings. pp. 1–12.

Ali, H.H., Al Nsairat, S.F., 2009. Developing a green building assessment tool for developing countries - Case of Jordan. Building and Environment 44, 1053–1064. https://doi.org/10.1016/j.buildenv.2008.07.015

Alsayyar, B., Jrade, A., 2015. Integrating Building Information Modeling (BIM) With Sustainable Universal Design Strategies To Evaluate the Costs and Benefits of Building Projects, in: 5th International/11th Construction Specialty Conference. pp. 1–10.

Angelidou, M., 2015. Smart cities: A conjuncture of four forces. Cities 47, 95–106. https://doi.org/10.1016/j.cities.2015.05.004

Antón, L.Á., Díaz, J., 2014. Integration of LCA and BIM for Sustainable Construction. International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering 8, 1378–1382.

Aranda-Mena, G., Crawford, J., Chevez, A., Froese, T., 2009. Building Information Modelling Demystified: Does it make business sense to adopt BIM. International Journal of Managing Projects in Business 2, 419–434.

Ayegun, O.A., Abiola-falemu, J.O., Olawumi, T.O., 2018. Assessment of Clients' Perception and Satisfaction with Project Quality Delivery in Nigeria. Journal of Sustainable Construction Engineering and Project Management 1, 27–44.

Azhar, S., 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. Leadership and Management in Engineering 11, 241–252.

Bakici, T., Almirall, E., Wareham, J., 2013. A smart city initiative: The case of Barcelona. Journal of the Knowledge Economy 4, 135–148.

Berardi, U., 2012. Sustainability Assessment in the Construction Sector: Rating Systems and Rated Buildings. Sustainable Development 20, 411–424. https://doi.org/10.1002/sd.532

Bin Zakaria, Z., Mohamed Ali, N., Tarmizi Haron, A., Marshall-Ponting, A., Abd Hamid, Z., 2013. Exploring the adoption of Building Information Modelling (BIM) in the Malaysian construction industry: A qualitative approach. International Journal of Research in Engineering and Technology 2, 384–395.

Boktor, J., Hanna, A., Menassa, C.C., 2014. State of Practice of Building Information Modeling in the Mechanical Construction Industry. Journal of Management in Engineering 30, 78–85. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000176

Bradley, A., Li, H., Lark, R., Dunn, S., 2016. BIM for infrastructure: An overall review and constructor perspective. Automation in Construction 71, 139–152.

https://doi.org/10.1016/j.autcon.2016.08.019

Bunnell, T., 2015. Smart city returns. Dialogues in Human Geography 5, 45–48.

Calzada, I., Cobo, C., 2015. Unplugging: Deconstructing the smart city. Journal of Urban Technology 22, 23–43. https://doi.org/10.1080/10630732.2014.971535

Chan, C.T.W., 2014. Barriers of Implementing BIM in Construction Industry from the Designers' Perspective: A Hong Kong Experience. Journal of System and Management Sciences 4, 24–40.

Chan, D.W.M., 2019. Sustainable building maintenance for safer and healthier cities: effective strategies for implementing the Mandatory Building Inspection Scheme (MBIS) in Hong Kong. Journal of Building Engineering 24, Article Number 100737, 13 pages. https://doi.org/10.1016/j.jobe.2019.100737

Chan, D.W.M., Choi, T.N.Y., 2015. Difficulties in executing the Mandatory Building Inspection Scheme (MBIS) for existing private buildings in Hong Kong. Habitat International 48, 97–105. https://doi.org/10.1016/j.habitatint.2015.03.015

Chan, D.W.M., Hung, H.T.W., 2015. An empirical survey of the perceived benefits of implementing the Mandatory Building Inspection Scheme (MBIS) in Hong Kong. Facilities 33(5/6), 337–366. https://doi.org/10.1108/F-09-2013-0066

Chan, D.W.M., Olawumi, T.O., Ho, A.M.L., 2019a. Critical success factors for building information modelling (BIM) implementation in Hong Kong. Engineering, Construction and Architectural Management 26(9), 1838–1854. https://doi.org/10.1108/ecam-05-2018-0204

Chan, D.W.M., Olawumi, T.O., Ho, A.M.L., 2019b. Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong. Journal of Building Engineering 25, Article Number 100764, 10 pages. https://doi.org/10.1016/j.jobe.2019.100764

Chandel, S.S., Sharma, A., Marwaha, B., 2016. Review of energy efficiency initiatives and regulations for residential buildings in India. Renewable and Sustainable Energy Reviews 54, 13–58.

Chong, H.Y., Zin, R.M., 2012. Selection of dispute resolution methods: factor analysis approach. Engineering, Construction and Architectural Management 19, 428–443.

Cugurullo, F., 2017. Exposing smart cities and eco-cities: Frankenstein urbanism and the sustainability challenges of the experimental city. Environment and Planning 1–20. https://doi.org/10.1177/0308518X17738535

Datta, A., 2015. A 100 smart cities, a 100 utopias. Dialogue in Human Geography 5, 49–53.

De Boeck, L., Audenaert, A., De Mesmaeker, L., 2015. Improving the energy performance of residential buildings: a literature review. Renewable and Sustainable Energy Reviews 52, 960–75.

Dossick, C.S., Neff, G., 2010. Organizational Divisions in BIM-Enabled Commercial Construction. Journal of Construction Engineering and Management - ASCE 136, 459–467. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000109

Fang, D.P., Xie, F., Huang, X.Y., Li, H., 2004. Factor analysis-based studies on construction workplace safety management in China. International Journal of Project Management 22, 43–49.

Field, A., 2009. Discovering Statistics Using SPSS, Sage Publication. https://doi.org/10.1234/12345678

Graham, S., Marvin, S., 2001. Splintering urbanism: Networked infrastructures, technological Mobilities and the urban conditions. Routledge, London.

Gu, N., London, K., 2010. Understanding and facilitating BIM adoption in the AEC industry. Automation in Construction 19, 988–999. https://doi.org/10.1016/j.autcon.2010.09.002

Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 2010. Multivariate data analysis. Prentice-Hall Inc, pper Saddle, New Jersey, USA.

Hanna, A., Boodai, F., El Asmar, M., 2013. State of Practice of Building Information Modeling in Mechanical and Electrical Construction Industries. Journal of Construction Engineering and Management - ASCE 139, 1–8. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000747

Hegazy, T., Elhakeem, A., Ahluwalia, S.S., Attalla, M., 2012. MOST-FIT: Support techniques for inspection and life cycle optimization in building asset management. Computer-Aided Civil and Infrastructure Engineering 27, 130–142.

Hope, A., Alwan, Z., 2012. Building the Future : Integrating Building Information Modelling and Environmental Assessment Methodologies. Northumbria Research Link.

Hosseini, M.R., Azari, E., Tivendale, L., Chileshe, N., 2015. Barriers to Adoption of Building Information Modeling (BIM) in Iran : Preliminary Results, in: The 6th International Conference on Engineering, Project, and Production Management (EPPM2015). pp. 384–394.

Illankoon, I.M.C.S., Tam, V.W.Y., Le, K.N., Shen, L., 2017. Key credit criteria among international green building rating tools. Journal of Cleaner Production 164, 209–220.

https://doi.org/10.1016/j.jclepro.2017.06.206

Jalaei, F., Jrade, A., 2015. Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings. Sustainable Cities and Society 18, 95–107. https://doi.org/10.1016/j.scs.2015.06.007

Jung, W., Lee, G., 2015. The Status of BIM Adoption on Six Continents. International Journal of Civil, Structural, Construction and Architectural Engineering 9, 406–410.

Kim, K., Yu, J., 2016. BIM-based Building Energy Load Calculation System for Designers. KSCE Journal of Civil Engineering 20, 549–563. https://doi.org/10.1007/s12205-015-1625-0

Kivits, R.A., Furneaux, C., 2013. BIM: Enabling sustainability and asset management through knowledge management. The Scientific World Journal 2013. https://doi.org/10.1155/2013/983721

Kummitha, R.K.R., Crutzen, N., 2017. How do we understand smart cities? An evolutionary perspective. Cities 67, 43–52. https://doi.org/10.1016/j.cities.2017.04.010

Lee, S.H., Augenbroe, G.J.K., Zhao, F., 2013. A design methodology for energy infrastructures at the campus scale. Computer-Aided Civil and Infrastructure Engineering 28, 753–768.

Lingard, H., Rowlinson, S., 2006. Letter to the editor. Construction Management and Economics 22, 1107–1109.

Lu, W., Shen, L., Yam, M.C.H., 2008. Critical Success Factors for Competitiveness of Contractors : China Study. Journal of Construction Engineering and Management 134, 972–983. https://doi.org/10.1061/(ASCE)0733-9364(2008)134:12(972)

Ma, X., Xiong, F., Olawumi, T.O., Dong, N., Chan, A.P.C., 2018. Conceptual Framework and Roadmap Approach for Integrating BIM into Lifecycle Project Management. Journal of Management in Engineering 34, 1–10. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000647.

Malhotra, N.K., 1996. Marketing Research: An apply orientation, 2nd ed. Prentice-Hall, Upper Saddle River, NJ.

Mao, C., Xie, F., Hou, L., Wu, P., Wang, J., Wang, X., 2016. Cost analysis for sustainable off-site construction based on a multiple-case study in China. Habitat International 57, 215–222. https://doi.org/10.1016/j.habitatint.2016.08.002

Moser, S., 2015. New cities: Old wine in new bottles? Dialogue in Human Geography 5, 31–35.

Nanajkar, A., Gao, Z., 2014. BIM Implementation Practices at India's AEC Firms, in: International Conference on Construction and Real Estate Management. Kunming, China.

Neirotti, P., Marco, A.D., Cagliano, A.C., Mangano, G., Scorrano, F., 2014. Current trends in smart city initiatives: Some stylised facts. Cities 33, 25–36.

Norusis, M.J., 1993. SPSS for windows professional statistics release 6.0. SPSS Inc, Chicago, USA.

Olatunji, S.O., Olawumi, T.O., Aje, I.O., 2017a. Rethinking Partnering among Quantity-Surveying Firms in Nigeria. Journal of Construction Engineering and Management 143, 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001394

Olatunji, S.O., Olawumi, T.O., Awodele, O.A., 2017b. Achieving Value for Money (VFM) in Construction Projects. Journal of Civil and Environmental Research- The International Institute for Science, Technology and Education (IISTE) 9, 54–64.

Olatunji, S.O., Olawumi, T.O., Ogunsemi, D.R., 2016. Demystifying Issues Regarding Public Private Partnerships (PPP). Journal of Economics and Sustainable Development- The International Institute for Science, Technology and Education (IISTE) 7, 1–22.

Olawumi, T.O., Ayegun, O.A., 2016. Are Quantity Surveyors competent to value for Civil Engineering Works ? Evaluating QSs' competencies and militating factors. Journal of Education and Practice- The International Institute for Science, Technology and Education (IISTE).

Olawumi, T.O., Chan, D.W.M., 2019a. An empirical survey of the perceived benefits of executing BIM and sustainability practices in the built environment. Construction Innovation: Information, Process, Management 19(3), 321–342. https://doi.org/10.1108/CI-08-2018-0065

Olawumi, T.O., Chan, D.W.M., 2019b. Development of a benchmarking model for BIM implementation in developing countries. Benchmarking: An International Journal 26(4), 1210–1232. https://doi.org/10.1108/BIJ-05-2018-0138

Olawumi, T.O., Chan, D.W.M., 2019c. Building information modelling and project information management framework for construction projects. Journal of Civil Engineering and Management 25(1), 53–75. https://doi.org/10.3846/jcem.2019.7841

Olawumi, T.O., Chan, D.W.M., 2019d. Critical success factors for implementing building information modelling (BIM) and sustainability practices in construction projects: A Delphi survey. Sustainable Development 27(4), 587–602.

https://doi.org/10.1002/sd.1925

Olawumi, T.O., Chan, D.W.M., 2018a. Identifying and prioritizing the benefits of integrating BIM and sustainability practices in construction projects: A Delphi survey of international experts. Sustainable Cities and Society 40, 16–27. https://doi.org/10.1016/j.scs.2018.03.033

Olawumi, T.O., Chan, D.W.M., 2018b. Critical Success Factors (CSFs) for Amplifying the Integration of BIM and Sustainability Principles in Construction Projects: A Delphi Study, in: Proceedings of the RICS COBRA 2018, RICS, London, 23-25 April 2018., ISBN 978-1-78321-274-3, ISSN 2398-8614 (Paper #127 in electronic format).

Olawumi, T.O., Chan, D.W.M., 2018c. Beneficial Factors of Integrating Building Information Modelling (BIM) and Sustainability Practices in Construction Projects, in: Proceedings of the Hong Kong International Conference on Engineering and Applied Science (HKICEAS) 2018. Higher Education Forum, Hong Kong, 24-26 January 2018, pp. 141–152, ISBN 978-986-87417-4-4 (in electronic format).

Olawumi, T.O., Chan, D.W.M., 2018d. A scientometric review of global research on sustainability and sustainable development. Journal of Cleaner Production 183, 231–250. https://doi.org/10.1016/j.jclepro.2018.02.162

Olawumi, T.O., Chan, D.W.M., 2017. Geospatial Map of the Global Research on Sustainability and Sustainable Development: Generating and converting KML files to Map. Mendeley Data 1. https://doi.org/10.17632/sv23pvr252.1

Olawumi, T.O., Chan, D.W.M., Wong, J.K.W., 2017. Evolution in the intellectual structure of BIM research: A bibliometric analysis. Journal of Civil Engineering and Management 23(8), 1060–1081. https://doi.org/10.3846/13923730.2017.1374301

Olawumi, T.O., Chan, D.W.M., Wong, J.K.W., Chan, A.P.C., 2018. Barriers to the integration of BIM and sustainability practices in construction projects: A Delphi survey of international experts. Journal of Building Engineering 20, 60–71. https://doi.org/10.1016/j.jobe.2018.06.017

Pinto, T., Praça, I., Vale, Z., Morais, H., Sousa, T.M., 2013. Strategic bidding in electricity markets: an agent-based simulator with game theory for scenario analysis. Integrated Computer-Aided Engineering 20, 335–346.

Proverbs, D.G., Holt, G.D., Olomolaiye, P.O., 1997. Factor influencing the choice of concrete supply methods. Building Research and Information1 25, 176–184.

Redmond, A., Hore, A., Alshawi, M., West, R., 2012. Exploring how information exchanges can be enhanced through Cloud BIM. Automation in Construction 24, 175–183. https://doi.org/10.1016/j.autcon.2012.02.003

Rogers, J., Chong, H.-Y., Preece, C., 2015. Adoption of Building Information Modelling technology (BIM) Perspectives from Malaysian engineering consulting services firms. Engineering , Construction and Architectural Management 22, 424–445. https://doi.org/10.1108/ECAM-05-2014-0067

Sackey, E., Tuuli, M., Dainty, A., 2015. Sociotechnical Systems Approach to BIM Implementation in a Multidisciplinary Construction Context. Journal of Management in Engineering 31, 1–11. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000303

Saka, A.B., Chan, D.W.M., Olawumi, T.O., 2019. A Systematic Literature Review of Building Information Modelling (BIM) in the Architecture, Engineering and Construction (AEC) Industry - The Case of Nigeria, in: Proceedings of the Environmental Design & Management International Conference (EDMIC) 2019 on Drivers and Dynamics of Change in the Built Environment. EDMIC, 20-22 May 2019, Ile-Ife, Nigeria, pp. 728–738, ISSN 2682-6488.

Sato, T., 2005. Factor analysis in personality psychology [WWW Document].

Saxon, R.G., 2013. Growth through BIM. Construction Industry Council.

Tsai, M.-H., Mom, M., Hsieh, S.-H., 2014. Developing critical success factors for the assessment of BIM technology adoption: part I. Methodology and survey. Journal of the Chinese Institute of Engineers 37, 845–858. https://doi.org/10.1080/02533839.2014.888811

Wang, N., Adeli, H., 2014. Sustainable building design. Journal of Civil Engineering and Management 20, 1–10. https://doi.org/10.3846/13923730.2013.871330

Welter, V.W., 2003. Biopolis: Patrick geddes and the city of life. MIT Press, Cambridge, MA.

Wong, J., Wang, X., Li, Heng, Chan, G., Li, Haijiang, 2014. A review of cloud-based bim technology in the construction sector. Journal of Information Technology in Construction 19, 281–291.

Wong, J.K.W., Zhou, J., 2015. Enhancing environmental sustainability over building life cycles through green BIM: A review. Automation in Construction 57, 156–165. https://doi.org/10.1016/j.autcon.2015.06.003

Wu, W., Handziuk, E., 2013. Use of Building Information Modeling in Aging-in-Place Projects: A Proof of Concept. Computing in Civil Engineering 443–450.

Xu, Y., Yeung, J.F.Y., Chan, A.P.C., Chan, D.W.M., Wang, S.Q., Ke, Y., 2010. Developing a risk assessment model for PPP projects in China-A fuzzy synthetic evaluation approach. Automation in Construction 19, 929–943. https://doi.org/10.1016/j.autcon.2010.06.006

Young, N.W., Jones, S.A., Bernstein, H.M., 2008. Building Information Modeling (BIM) - Transforming Design and Construction to Achieve Greater Industry Productivity, in: SmartMarket Report. New York, p. 48.