Key Drivers of Implementing Smart and Sustainable Practices in the Built Environment

Abstract

Purpose – The construction industry has been evolving in recent years through the adoption of smart tools such as BIM to reduce the complexity in the construction process and optimize the project's goals. This paper aims to identify and assess the key drivers for the implementation of smart sustainable practices in the construction industry.

Design/methodology/approach – Inferential and descriptive statistical techniques were employed in analyzing the data collected via an international empirical questionnaire survey deployed in soliciting the perceptions of 220 construction professionals across 21 countries. Factor analysis was used to categorize the identified key drivers into their underlying clusters for further discussion. Also, the data were analyzed based on the various groups and regions of the study's respondents.

Findings – The key drivers (KDs) are related to the technical competence of staff, as well as knowledge and awareness level within the industry; issues related to organizational and project's strategy and policies; availability of financial resources, and development of relevant standards and policies to aid its execution among others. A comparative analysis of the perceptions of the different respondents' groups was undertaken and discussed.

Practical implications – The analysis of the key drivers for the implementation of smart and sustainable practices in the construction industry is expected to aid the decision-making of the relevant stakeholders as well as serve as a consultation instrument for government agencies in their design of localized policies and guidelines to aid smart and sustainable urbanization. The findings revealed the gaps in the implementation of smart and sustainable practices in various climes and organization setups and provided useful and practical strategies for addressing the current hindrances during implementation.

Originality/value – The study has generated valuable insights into the significant drivers that can enhance the implementation of smart and sustainable practices across regions. It is evident that synergy among the relevant stakeholders in the built environment will help accelerate the implementation of smart sustainable practices in the construction industry. The study findings have provided profound contributions to theory and research as well as to industry practice.

Keywords: Construction industry; BIM; drivers; stakeholders; sustainability; smart sustainable practices.

1. Introduction

In recent years, the construction industry has been trying to adopt smart tools which are based on information and communication technologies (ICT) such as Building Information Modelling (BIM), virtual reality, augmented reality systems, and cloud technologies among others to aid construction process and facilitate the integration of other domain knowledge like sustainability (Adamus, 2013), project management (Ahankoob et al., 2018; Ajam et al., 2010), cost control (Ahn et al., 2016), safety management (Zhang et al., 2015), etc. Bibri and Krogstie (2017) argued the importance of these smart tools to enhance and support theoretical concepts such as sustainability, which according to Olawumi and Chan (2018a), has been gaining immense interest from academics, industry professional, and the government. The definition and concept of sustainability has been discussed in previous studies (Olawumi & Chan, 2018a; WCED, 1987; Wong & Zhou, 2015); while the concept of smart tools and buildings have been defined and discussed in Cugurullo (2017),

Furthermore, a review of these smart tools shows that BIM has found more use and received the most widespread implementation in the built environment (Bradley et al., 2016; Jung & Lee, 2015; Ma et al., 2018). Hence, this study will focus solely on BIM as a smart tool to aid the sustainability of the built environment, with peculiar emphasis on the construction sector. The process of integrating these smart tools such as BIM to facilitate the implementation of sustainability practices is regarded as smart sustainable practices in this study. Olawumi et al. (2017) highlighted some BIM tools, processes, and software that has found applications in the building design analysis and simulation towards aiding the relevant stakeholders to make sound sustainability-related decisions. Another application of BIM to aid sustainability practices in the literature includes – the use of plugins in BIM software to assess some sustainability parameters in buildings by (Oti et al., 2016). Also, Tah and Abanda (2011) utilize semantic web tools to evaluate the sustainability performance of projects and energy simulation. However, despite the robustness of BIM, its interoperability and proprietary issues have limited its application to sustainability issues (Olawumi et al., 2017).

Some key attributes of BIM that can be exploited for sustainability issues to enhance smart and sustainable practices in construction projects based on the extant literature includes 1) As a decision-making tool (Hope & Alwan, 2012); 2) Energy simulation or daylighting simulation (Olawumi et al., 2017); 3) Evaluation of the embodied CO_2 over the lifecycle of a building (Capper et al., 2012); 4) Validation of compliance with sustainability criteria (Sheth et al., 2010). Others include – 5) Storage of big data of building information that can be extracted to rating using any available green building rating systems like LEED or BREEAM (Hope & Alwan, 2012); 6) Visualization and walkthroughs for project teams especially as it relates to energy systems in buildings (Olawumi et al., 2017; Sheth et al., 2010); and 7) Improved communication and coordination of construction processes from planning to commissioning (Olawumi & Chan, 2019e).

1.1 Knowledge gaps, research scope, and objectives

A plethora of published literature (*see* Ali & Al Nsairat, 2009; Anthopoulos, 2017; Ilhan & Yaman, 2016; Olawumi & Chan, 2018d; Shi et al., 2013) have provided holistic reviews and undertook empirical studies to discuss and shows the different application and the use of smart tools to aid sustainability issues. However, no study has examined the drivers of implementing smart and sustainable practices across regions as undertaken in this study. Also, as seen in the previous section and extant literature (Jung & Lee, 2015; Malleson, 2012; Olawumi & Chan, 2018a), among others, there has been a varied adoption, implementation, and application of BIM and sustainability practices in the construction industry.

The construction industry is given more focus in this study as part of the built environment because, according to previous studies (Abanda & Byers, 2016; Bynum et al., 2013), buildings account for one-third of the global energy use and one-fifth of the greenhouse gases emission. Furthermore, according to Gourlis and Kovacic (2017) and (Olawumi & Chan, 2019c), BIM has offered encouraging promises to optimize energy consumption and reduce the carbon footprints of the building facilities. The scope of the study is delimited to construction projects (as a subset of the built environment), BIM (a type of smart tools), and sustainability practices as it relates to the whole lifecycle of buildings. Moreover, this formed the basis for the literature search for the key drivers for this study (see Table 1).

Several attempts have been made in the extant literature to address issues related to smart and sustainable practices in the construction industry. For instance, a study by Abanda and Byers (2016) utilized BIM tools to simulate the energy performance of buildings. Although the findings are of significant value, the focus on the 'energy' criterion limits its ability to influence building sustainability. Similar studies by Tsai et al. (2014b) and Oti et al. (2016) demonstrated the use of BIM plugins to embed some sustainability criteria to assess the greenness of building projects. However, these studies place emphasis on a single construct of sustainable development and fail to provide ample ways to enhance its adoption and implementation.

Meanwhile, a few research studies have attempted to investigate the drivers to BIM adoption, such as Tsai et al. (2014a) and Chan et al. (2019a) who examine BIM adoption in Taiwan and Hong Kong, respectively. These studies fail to consider how BIM can help improve sustainability practices in the construction industry. Similar studies by Olawumi and

Chan (2018d, 2019c) have examined the benefits and barriers to the implementation of BIM and sustainability practices; hence, there is a salient need to examine the critical success factors that can drive its implementation. Furthermore, a desktop review of the previous studies (*see* Jung & Lee, 2015; Olawumi et al., 2017; Olawumi & Chan, 2018a) manifested an uneven rate of adoption of BIM and sustainability across the various regions in the world.

These relevant knowledge gaps in the extant literature and practice will be bridged and addressed in this study. Also, the need for enhancing the sustainability potential of the built environment and building projects as outlined in the sustainable development goals of the United Nations has motivated and necessitated this study.

Given the above, this study aims to assess the key drivers (KDs) that aid the implementation of smart and sustainable practices in the construction industry and projects. The following research questions will be answered in towards achieving the aim of the study:

i. What are the significant drivers that can aid the implementation of smart and sustainable practices in construction projects?
ii. How do the perceptions of the study's respondents differ based on their professions, organizational setups, and regions?
iii. What are the practical implications of the study's findings on the implementation of smart and sustainable practices in the built environment?

The current study will further bridge the gap by identifying key drivers that can aid the joint implementation of BIM and sustainability practices in construction projects. The comparative evaluation of the perceptions of the respondents based on their professions, organizational setup, and regions is expected to shed more insight and perspectives on the implementation of smart and sustainable practices in construction projects, firms, and regions. The findings are also expected to enhance the capacity of project stakeholders, professional bodies, government agencies to implement BIM and sustainability practices in their projects, and locality. The current study reiterated the need for the application of BIM and sustainability practices in construction projects as against the singularity of the adoption of either BIM or sustainability practices initiatives.

The paper is structured as follows. Section 1 provides backgrounds to the study and highlights the knowledge gaps, scope, and research objectives. Section 2 explores the salient issues as regards smart sustainable practices in the built environment, while Section 3 encapsulates the research design, methods, and various statistical techniques adopted in the study. Section 4 provides the result of the data analysis and compares the different viewpoints of the different respondents' groups. Section 5 discusses the findings of the study, provides insight on the significant KDs for each region, and outlines the practical implementation of the research findings. Finally, Section 6 concludes the paper and highlights the possible strategies to aid the adoption of smart sustainable practices in the construction industry.

2. Smart and sustainable practices: Salient issues in the built environment

The built environment has witnessed an increased knowledge and adoption of innovative concepts and processes which were intended to enhance the overall construction process, improve productivity, among others. Some of these concepts include sustainability (Lozano, 2008; Olawumi & Chan, 2018a); risk management (Xu et al., 2010), safety management (Zhang et al., 2015); BIM (Qi et al., 2014) among others. According to Albino et al. (2015) and Olawumi and Chan (2018a), the concept of smart buildings and sustainability has gained enormous recognition in the literature, government circles, and from international organizations. The nexus between BIM and sustainability issues which gave rise to the concept of smart sustainable practices as discussed in section 1 is found in the capacity of BIM system to embed a large amount of data for storage, document management, communication among stakeholders, visualize sustainability analyses results, etc. (Gu & London, 2010; Olawumi et al., 2017).

However, despite the increasing adoption of BIM in the construction projects, Kassem et al. (2012) and Olatunji et al. (2017b) stressed that the difficulty in evaluating the business value of smart tools like BIM in terms of return on investment (ROI) has hindered its implementation in construction projects especially in small and medium scale projects (capital-wise). Hence, per Alsayyar and Jrade (2015), to improve its implementation, it is important to provide anecdotal evidence of profitable deployment of BIM in construction projects to the prospective clients to increase their satisfaction and confidence. BIM is described as a system that consists of its product and processes (Olawumi & Chan, 2019e, 2019b). The incorporation of smart tools such as BIM in sustainability issues is aimed to serve as a decision-making tool when integrated with the existing building rating systems to evaluate the level of achievement of some sustainability criteria by buildings (Ahvenniemi et al., 2017).

Previous studies have examined the application of BIM for improving building sustainability. For instance, Lu et al. (2017) reviewed the uses of BIM in green buildings and their capacity to support the building lifecycle stages. Also, Lu et al. (2017) and Olawumi et al. (2017) highlighted some BIM functionalities in enhancing building sustainability, such as design analysis to evaluate energy performance and carbon emission analyses, daylighting analysis, sustainable material selection among others. Akinade et al. (2015) and Olawumi and Chan (2018d) also discussed some benefits of integrating smart and sustainable practices in construction projects to include – (1) enhancing the productivity and efficiency of construction projects (Gu & London, 2010); (2) real-time sustainable design analysis and simulation (Kivits & Furneaux, 2013); (3) minimize carbon emission and footprints (Hope & Alwan, 2012); and (4) improving building energy efficiency (Boktor et al., 2014; Harding et al., 2014) among others. However, despite all these benefits derivable from implementing smart sustainable practices in construction projects; Marsal-Llacuna et al. (2015) revealed that project stakeholders tend towards the sole adoption of BIM more than implementing the two innovations.

Meanwhile, to boost the adoption of smart and sustainable practices in construction projects, Aibinu and Venkatesh (2014) and Nanajkar and Gao (2014) recommended for developers of BIM tools to focus more on suitable cloud-based technology and open-source software. In a similar vein, Ahvenniemi et al. (2017) stressed the importance of smart tools to be cost and resource-efficient. Meanwhile, Becerik-gerber and Kensek (2010), Olawumi and Chan (2019d), and Sackey et al. (2015) observed that the involvement of project teams in the early stages of the construction project could enhance its adoption in such construction projects. Project complexity in terms of its shape and system can also pose challenges to the adoption of smart and sustainable practices due to instances of incomplete and unreliable information in building models (Aksamija, 2012; Olawumi et al., 2017; Peansupap & Walker, 2005). Also, Rogers et al. (2015) argued that the lack of industry standard for BIM and sustainability assessment is one of the banes for the slow progress in the adoption of smart sustainable practices in some countries.

Also, the existing green building rating tools, according to Berardi (2013) and Robinson and Cole (2015), places greater consideration on the environmental aspect of sustainable development instead of a holistic consideration of the three sustainability pillars. Towards ameliorating this significant gap in the literature, Olawumi et al. (2018) recommended for these green rating tools to embed other aspects of sustainability- economic and social pillars in their evaluation of building sustainability. Also, Huang et al. (2009) reported that some of the sustainability criteria used in evaluating building sustainability do not reflect its actual interaction with the urban system nor provide indications on the strategies to deploy to achieve these criteria. Another salient issue regarding the implementation of smart and sustainable practices in the built environment is the legal issues regarding their use and ownership. Aranda-Mena et al. (2009) and Azhar (2011) advocated for the development of a uniform legal framework and practice to resolve the problem of proprietary ownership of BIM models, simulation results and, contractual issues, and project uncertainties among others. Therefore, to ensure an industry-wide implementation of smart and sustainable practices in the built environment, Aibinu and Venkatesh (2014) and Redmond et al. (2012)

recommended for local authorities and government agencies to set out policies and legislation for its deployment and enforcement of relevant guiding laws and statues.

The establishment of good working practice and strategy to aid the implementation of smart sustainable practices cannot be over-emphasized (Azhar, 2010). Jung and Joo (2011) recommended the development of standards that can enhance the effectiveness of the adoption of BIM (Jung & Joo, 2011; Olawumi & Chan, 2019b, 2019e) and sustainability practices (Olawumi & Chan, 2018a) in the built environment. Meanwhile, vital support of construction firms' top management is critical to the continuous and successful implementation of these innovative concepts in the construction industry (Boktor et al., 2014; Saxon, 2013). Also, the firm's leadership support can be in diverse forms- such as financial supports, redesign of the firm's structure and policy to suit the new concept, and training supports, among others (Chan et al., 2019a). Cugurullo (2017) acknowledged the quest by some cities such as Masdar City in Abu Dhabi to be an eco-city project and Hong Kong as a smart city, among others. However, it resulted in an uneven pattern of urban development because of the singularity of the adoption of either smart tools or sustainable practices. Hence, it is important to consider both concepts – BIM and sustainable practices; and one of the ways to achieve this is to investigate the key drivers that can enhance the adoption of smart and sustainable practices in construction projects.

Given the above, Table 1 shows the summary of the KDs that can enhance the execution of smart sustainable practices as identified via a review of extant literature and through pilot studies. The 30 KDs highlighted in Table are sourced based on the scope definition of this study, as discussed in section 1.1. Subsequent sections of this paper will define the adopted research methodology adopted and examine the perceptions of over 200 survey respondents whose perceptions formed the basis of the identification of the significant KDs of implementing smart and sustainable practices in the built environment.

[Insert Table 1]

3. Research Methodology

The study identified and assessed the key drivers that aid the key construction stakeholders in their execution of smart sustainable practices in the construction study. A quantitative research method was adopted in this study using an empirical questionnaire survey and secondary means of data such as the desktop review of relevant journal articles, online materials, textbooks, official gazettes, and building standards, etc. As pointed out by Olatunji et al. (2017), the means and instruments of data collection are essential to the achievement of the study's aim and reliability of the collated data. Hence, the use of the empirical questionnaire survey in this study helps to aggregate the opinions of stakeholders in the built environment as regards the 30 KDs. Although opinions of respondents might be subjective based on their experience, locations, etc. the use of several statistical methods helps to minimize these biases.

The targeted survey respondents for the questionnaire were sampled via using both purposive and snowball sampling techniques, and they have requisite direct hands-on experience in smart digital technologies like BIM and the process of achieving sustainability in building projects. Three delivery modes were used in the questionnaire distribution, which is yielded 220 responses from 21 countries as follows: (1) online survey (161 responses), (2) fill-in PDF questionnaires (14 responses), and (3) hand-delivered questionnaires (45 responses). Some of the respondents were sent both the online survey link and an attached PDF survey form. Also, before the survey form distribution, the survey form was pretested. The weblinks to the online survey form and the fill-in PDF survey was posted on relevant LinkedIn groups of different professionals in the built environment, ResearchGate, network groups, email addresses culled from webpages of universities, professional bodies, construction companies, etc., among others social media means. The respondents were told to input their contact details if they are interested in the final result of the survey, which is intended to serve as a motivation for the respondents to participate in the survey exercise. Although the survey exercise yielded responses from 21 countries, no countries, in particular, were targeted. The main goal of the questionnaire distribution is to secure a good representative number of responses from each region of Europe, Asia, Africa, and North & South America. The respondents were also encouraged to share the questionnaire survey link to their colleagues with requisite knowledge of the subject matter.

The first section of the survey form solicited basic information about each survey participant (such as their profession, years of experience in the construction industry, their organization type, location, and awareness of BIM and sustainability concepts) and the other sections request the respondent to rate the KDs on a 5-point Likert scale (*1 = strongly disagree, 3 = neutral and 5 = strongly agree*). If a factor is not perceived to be applicable as a CSF, the respondent has the option to tick an 'N/A' box. The gleaned data were analyzed using various statistical methods, as explained in the next sub-section and the findings discussed in subsequent sections of this paper.

3.1 Statistical methods and reliability tests

Inferential and descriptive statistical tools were adopted to evaluate the set of data collated from the study's respondents. These tools included: (1) Reliability using the Cronbach's alpha (α) reliability test; (2) Ranking via mean scores (M) and standard deviations (SD); (3) Analysis of variance (ANOVA), post-hoc Tukey tests, correlation analysis; and (4) Factor analysis and clustering. According to Field (2009), Olawumi et al. (2018), and Olawumi and Chan (2018d), a set of data must undergo reliability testing to evaluate whether the data instruments are measuring the right construct (Olatunji et al., 2017a; Olawumi, 2016).

The Cronbach alpha (α) is useful to measure whether the questionnaire and its associated Likert scale measures the right construct and maintains an internal consistency (Field, 2009; Saka et al., 2019) value for the study was 0.966 which is significantly higher than 0.70, the minimum threshold for a reliable dataset (Olawumi & Chan, 2019d). This implies that the dataset has good internal consistency, reliable, and suitable for further statistical analysis (Chan et al., 2010; Chan & Choi, 2015). Therefore, for the KD's factor ranking, if there is a case of more than one factor having the same mean value, their SD values will be utilized in ranking them, such that those with lower SD values are ranked higher (Olatunji et al., 2017a). However, in the case of the factors having the same mean score and SD value, they will be accorded the same factor ranking (Olawumi et al., 2018).

3.2 Respondents' demographics

A diverse group of 220 survey participants across 21 countries participated in the study (see Figure 1). The respondents are from six varied set of organizational setups as classified in this as follows – academics (40%), public sector clients (25%), main contractors (16%), project consultants (11%), private sector clients (5%), and property managers (3%). It must be noted that personal information, such as the names of their organization or firm, were not solicited from the respondents in the survey form. Hence, the respondents could not be grouped by such means. The respondents were also classified based on their profession, and the results revealed that the quantity surveyors, architects, and project managers were more represented in the study's respondent population with a percentage of 25, 12.7, and 12.3, respectively. The civil engineers (11%) and building services engineers (8%) followed closely. The distribution of the respondents (see Figure 1) based on their regions are Asia (56.4%), Africa (29.1%), Europe (9.1%), and America (5.5%). The key countries based on the number of participating respondents in the Asia region are China, Singapore, and Australia; in Africa, we have Nigeria, South Africa, and Egypt. For the European continent, we have the United Kingdom and Germany; and in the American regions (South and North America), we have the United States and Canada.

The respondents have a high level of knowledge and awareness of BIM and sustainability practices with 43% and 53%, respectively; while about 37% and 36% of the respondents reported an average level of understanding of BIM and sustainability respectively. Further analysis of the level of awareness of the respondents based on their knowledge of BIM revealed that Europe (70%) and the America regions (67%) have more than two-thirds of their respective respondents' population with at least a high level of awareness of the BIM process. Meanwhile, Africa and Asia have 47% and 35% respectively with at least a high level of BIM awareness. The findings correspond with the extant literature (Jung & Lee, 2015; Olawumi et al., 2017) which examines the adoption of BIM across various regions. For the sustainability practices awareness, regions such as Africa (67.2%), America (66.7%), and Europe (60%) have more than two-thirds of their respective respondents' population with at least a high level of awareness of the sustainability practices. The respondents from the Asia region have 42.7% with at least a high level of awareness of sustainability practices. This analysis corresponds with the extant literature (Olawumi & Chan, 2018a) which discusses the trend and implementation of sustainability in different regions and countries.

[Insert Figure 1]

The demographics of the respondent (Figure 1) based on their level of experience was also evaluated. On average, 44.5% of the respondents have at least 11 years of working experience in the construction industry, of which about 23.6 percent have more than 20 years of working experience. The opinions of the respondents were also solicited on which stage of the project development to implement smart sustainable practices; 57% and 37% of the respondent considers the planning and design stages respectively; while only 6% preferred the construction phase. The result of the statistical analysis of the respondents' demographics revealed that the professionals which supplied the necessary data upon which the study's findings are based have a mixture of both practical experience and theoretical knowledge in the subject matter. Hence, this lends further credence to the data collected and subsequent analysis in this study.

4. Results of statistical analyses

This section expatiated on the results of the gleaned data via the survey forms and analyzed using various statistical methods and discusses the survey findings.

4.1 Descriptive statistical tests

In ranking the key drivers based on the data collected from the study's respondents, the mean score "M" and standard deviation "SD" was employed. In situations where two or more KDs have the same mean value, their SD values are considered in the ranking as highlighted in Olatunji et al. (2017a) and Olawumi and Chan (2018d) The mean scores for the 30 identified individual KDs range from M= 3.79 (SD= 0.919) for "*C25 - availability and affordability of cloud-based technology*" to M= 4.34 (SD= 0.780) for "*C1 - technical competence of staff*" at a variance of 0.55 (see Table 2). A benchmark score of 4 out of 5 on a 5-point Likert scale was used in the study to identify the highly significant KDs of smart sustainable practices in the construction industry. Using this approach, the study pinpointed top-five KDs, which include: "*C1 - technical competence of staff*" (M= 4.34, SD= 0.780), "*C3 - more training programs for cross-field specialists in BIM and Sustainability*" (M= 4.27, SD= 0.738). "*C21 - early involvement of project teams*" (M= 4.24, SD= 0.821), "*C2 - greater awareness and experience level within the firm*" (M=4.22, SD= 0.728), and "*C9 - effective collaboration and coordination among project participants*" (M= 4.17, SD= 0.784). The findings revealed that to enhance the execution of smart sustainable practices in the construction industry, it rests on the technical competency and knowledge of the project stakeholders on BIM and sustainability. Also, proper coordination and early involvement of project team members are very significant (Antón & Díaz, 2014; Olawumi & Chan, 2018c). Hence, policymakers, local authorities, and other key stakeholders need to prioritize human capital development in their drive for the adoption of smart technologies and the implementation of green buildings.

There is a considerable agreement among all the respondents' groups on factor "C3 - more training programs for cross-field specialists in BIM and sustainability" (Olawumi et al., 2018; Wong & Fan, 2013); which was ranked as a key factor and rated among the top five most important factor by all the groups. The finding reveals that when stakeholders in the construction industry have considerable knowledge and skillset in smart sustainable practices, it will ease its execution in the built environment. Also, for factor "C1- technical competence of staff" (Aibinu & Venkatesh, 2014); which was ranked the most significant driver for the execution of smart sustainable practices; the factor was ranked among the top-five key factors by all the respondent's groups except the private clients and academics' groups who both gave it the 7th rank. The result aligns with the findings of Olawumi and Chan (2018c) who recommended to the government and professional bodies in the construction industry to organize regular training workshops and seminars to keep their staff and members abreast of the current trend in the industry and equip them with necessary technical skills as required. The differing rank by the academics and private clients is consistent with the fact that academics are the knowledge of the industry and the private clients generally have the resources to train their staff, although their rankings are still relatively above the average.

Meanwhile, for the factor "C21- early involvement of project teams" (Goedert & Meadati, 2008), the perception of the project consultants and respondents from the main contractors differs significantly from other survey participants from other organization-based respondents. The two respondent groups ranked the factor as 10th rank as against the top-five rankings achieved by the factor in other respondents' groups. The findings reveal an average recognition of the fact that the early introduction of key stakeholders at the planning stage of a project could influence the achievement of smart sustainable practices in the project. This is because most consultants to the project are primarily involved in the project from its start. However, several issues which vary from poor coordination and collaboration, and difficulty in analysis the sustainability credentials of building plans at the early phase of project development has contributed in a way to hinder the smooth execution of such innovative strategy.

[Insert Table 2]

4.2 Inferential statistical tests

Parametric statistical methods such as ANOVA test were applied to the collated data to investigate any discrepancies in the perceptions of the different groups of survey participants such as organizational setups (e.g., public and private clients, project consultants, main contractors, etc.) and those categorized based on their professional disciplines (e.g., architects, civil engineers, project managers, etc.). ANOVA test is a parametric tool which measures variance using the mean of scores (Olawumi & Chan, 2019d; Tsai et al., 2014a); and according to Mom et al. (2014) and Olatunji et al. (2017), if a factor is significant ($p<0.05$); a post-hoc Tukey test will be conducted. Moreover, before an ANOVA test can be performed on a set of data, the assumption of homogeneity of the sample data must be satisfied (i.e., $p>0.05$) which states that that the variance across groups is equal. Levene's test for homogeneity of variances was employed, and the significance level (p-value) for the KDs was greater than $p > 0.05$, which implies the group variances are equal. Hence, parametric tests (such as ANOVA) will be useful for further analysis of the data.

4.2.1 Statistical tests based on organizational setups

The ANOVA test employed on the data (at a significance level <5%) showed no divergence in the perceptions among the groups of respondents based on the organization setups identified in the study. These organizational setups include respondents from the main contractors, academics, public clients, private clients, and project consultants. The findings are consistent with the fact that a good number of the respondents might have been engaged in two or more of these organizational setups in the course of their professional jobs. Also, even those in academics often have a partnership with colleagues practicing in the industry (Olatunji et al., 2017a), and they do share both theoretical and practical experiences. Furthermore, since the concept of smart sustainable practices is an interdisciplinary discipline, there exists a thin line in the workings of several organizations in the construction industry.

4.2.2 Statistical tests based on professional disciplines

The ANOVA statistical method conducted on the survey data revealed some significant differences (at a significance level <5%) in the opinions among the survey participants on three KDs (see Table 2). These drivers include two factors with significant differences "C4- increased research in the industry and academia" [$F(10,209)= 2.491$, $p=0.008$]; and "C28- technical support from software vendors" [$F(10,209)= 2.664$, $p=0.004$]. The other factor "C16- appropriate legislation and governmental enforcement & credit for innovative performance" [$F(10,209)= 2.035$, $p=0.031$] has a moderate significant difference. However, a further test of the three significant factors via a post-hoc Tukey test revealed a moderate divergence (p=0.036) in only one factor "C16- appropriate legislation and governmental enforcement & credit for innovative performance"; with the architects (M= 4.39, SD= 0.685) perceiving it to be of greater importance than the construction managers (M= 3.58, SD= 0.692).

The architects, according to Olawumi and Chan (2019a), are involved early in the construction process when issues relating to smart sustainable practices execution and other concepts are integrated into construction projects. Also, project consultants, which include the architects, work in conjunction with the clients to ensure the construction project complies with relevant statutory and legal frameworks and standards, which mostly must be adhered to at the planning and design stage of the project. This unique relationship between the client and architect and the fact they are more involved in the early stage of construction projects than their construction managers counterparts; which makes their perception of this factor to be worthy of note. Furthermore, according to Brinkerink et al. (2019), the relevant stakeholders must acquire a good understanding of the applicable legislation which will enable them to develop appropriate plans and strategies to benefit from government subsidies, tax reliefs or other credits for innovation.

4.3 Classification of the key drivers based on factor analysis

The basic concept of factor analysis is to identify a few numbers of factors that best represent the structure of relationships among a larger set of variables (Olawumi & Chan, 2019a) and aids the illustration of a complex phenomenon (Xu et al., 2010). In the extant literature, two types of factor analysis are prominent, and these include principal component analysis (PCA) and the Promax rotation method (Chan, 2019; Chan & Hung, 2015). The Promax rotation method allows for the underlying factors to be correlated, that is, in a case when the factors are not independent of each other (Chan & Choi, 2015; Chan & Hung, 2015). However, this study adopted the PCA approach as the factors are expected to be independent and also for the unique data-reduction capacity and simplicity of the PCA method (Olawumi & Chan, 2019a). A Pearson correlation analysis was carried out on the 30 KDs and none of the factors correlated to another, thus, satisfying the use of the PCA method. Varimax rotation, an orthogonal factor rotation method, was employed in rotating the 30 underlying factors.

Chan and Choi (2015), and Lingard and Rowlinson (2006) posited a provisional requirement that a set of data must meet before it is suitable for factor analysis. An essential requirement is that the sample size of the data and the number of factors must comply with a ratio of 5:1, which was met by this study. This study has 220 responses, which are higher than the minimum 150 sample size necessary for factor analysis to be undertaken. Meanwhile, two further tests- Kaiser-Meyer-Olkin (KMO) value and Bartlett's test of sphericity (BTS) were carried out to test the appropriateness of the dataset for factor analysis. KMO values range from 0 to 1 and measure the relative compactness of correlations among the factors. The KMO value for the study is 0.948 which indicates the PCA generated a reliable and distinct cluster (Chan & Choi, 2015; Xu et al., 2010). The BTS examines the correlation among the underlying factors, and the BTS analysis revealed a chi-square test value of 4,926.376 at a very small significance level (p=0.000, df= 435) which implies that the correlation matrix is not an identity matrix (Xu et al., 2010). As the key pre-requirements of factor analysis has been met, PCA can be applied to the dataset, and it also ensures consistent and reliable results.

Five clustered factors were generated from the PCA analysis (see Table 3), which represents 68% of the total variance explained which is higher than the minimum eigenvalues of 60% (Chan, 2019; Chan & Choi, 2015; Chan & Hung, 2015; Malhotra, 1996). Also, the underlying factors have a factor loading which ranges from 0.459 to 0.797, and the classification of the underlying factors under each cluster is reasonable and sufficient.

[Insert Table 3]

5. Discussion of survey findings

This section will discuss the findings of this study in three aspects: (i) discussion of the clustered key drivers; (ii) discussion of the perspectives of the respondents on the KDs based on their regions; and (iii) the practical implications of the research findings.

5.1 Discussion of the clustered KDs

The factor clusters representing the relationship among the underlying factors are designated with an identifiable and collective label (Sato, 2005), to aid its description (Olawumi & Chan, 2019a). The labels are based on the researcher's perception, and hence are subjective (Chan & Hung, 2015). A metric known as factor scale rating was employed to rank the factor clusters in descending order of relevance (Chan, 2019; Chan & Hung, 2015). The factor scale rating adds up the mean scores of each underlying factor of each cluster and divides the total mean score by the number of the underlying factor (Olawumi & Chan, 2019a). This section discusses the top-three factor clusters to conserve space and provided some recommendations to enhance smart and sustainable practices in construction projects.

[Insert Table 4]

5.1.1 Knowledge & industry-related drivers

Factor cluster 1 consists of nine underlying factors with a factor loading of more than 0.5 and has the highest factor scale rating of M=4.1456. The cluster focuses on issues related to the technical competence of staff, training scheme for specialists in smart sustainable practices, efficiency in the coordination of project stakeholders, firm's awareness, and experience level, among others. Gu and London (2010) and Ma et al. (2018) accentuated that staff of construction firms and government agencies required requisite training on both the technical and non-technical aspects of BIM to ease the implementation of smart sustainable practices in construction projects. Accordingly, they further argued that such training should be continuous because of the new roles and responsibilities emerging each day in the adoption of BIM and the implementation of sustainability practices in the construction industry. Meanwhile, Antón and Díaz (2014) and Olawumi and Chan (2018b) emphasized the need for the development and availability of an in-house database to keep track of past and current projects' data and its organization.

The development of the database, as argued by Gu and London (2010), should align with the project management structure and organization of the firm, as well as suitable to meet the industry needs. However, such a database and its platform must be user-friendly and provide adequate data security. Abanda et al. (2015) advocated for the creation of action learning centers as a practical, knowledge-sharing, and problem-solving environment in which project stakeholders can share their experience, provide technical supports, and learn from each other. Also, an increased level in research and development (R&D) in the academics and industry improved the level of adoption of smart sustainable practices in the construction industry (Aibinu & Venkatesh, 2014; Wong & Fan, 2013).

5.1.2 Organizational & project-related drivers

The second most significant factor cluster is factor 3, which comprises of five key factors with a minimum factor loading of at least 0.5 and a factor scale rating of M= 4.01. The factor is concerned with project complexity in terms of its shape and system, client satisfaction level, the early involvement of project stakeholders, data compatibility and interoperability, and availability of affordable cloud-based technology. Ahn et al. (2014) reported that the current industry foundation class (IFC) schema used in the BIM system is inadequate for the integration of relevant information to aid building design simulation and energy modeling. Accordingly, to enhance the execution of smart sustainable practices in the built environment, more efforts need to be deployed by key project stakeholders in ensuring interoperability and data compatibility (Adamus, 2013; Ahn et al., 2014; Olawumi et al., 2018). Meanwhile, Hope and Alwan (2012) and Olawumi et al. (2017) reiterated the need for a clear understanding and evaluation of sustainability criteria in construction projects. there is a need to integrate BIM with sustainability assessment methods. Therefore, it is recommended for project stakeholders, organizations, professional bodies, and the various local authorities to work in sync to enhance the project and organization-related drivers towards improving the adopting of smart and sustainable practices in construction projects.

5.1.3 Financial, legal & statutory drivers

Factor cluster 2 consisting of seven key underlying factors and a factor rating of M= 3.9857. The factor is related to the ease of securing funding for the acquisition of BIM software and its associated licenses, government support in the form of start-up funding for construction firms, development of an appropriate legal framework to guide its deployment in projects, the security of intellectual property and rights among others. Nanajkar and Gao (2014) acknowledged the hindrances posed by the high initial cost of procuring BIM software. Hence, to enhance the implementation of smart sustainable practices in construction projects, there must be a conscious effort and commitment by the relevant stakeholders to make the necessary funding available to aid the smooth implementation of smart and sustainable practices in construction projects (Kivits & Furneaux, 2013; Olawumi & Chan, 2018d). Also, top management of construction firms should avoid being hesitant on making long-term future investments and commitment as regards the execution of BIM and sustainability practices in their projects (Gu & London, 2010; Hanna et al., 2013) towards making long-term impacts. The government should endeavor to support small and medium-scale construction firms with funding supports and incentives to aid their adoption of smart sustainable practices in-house and in their construction projects (Bin Zakaria et al., 2013; Olawumi & Chan, 2019d).

5.2 Comparative assessment of the KDs based on respondents' regions

It is imperative to examine the significance of the key drivers based on different regions or continents as these regions differ in the level of adoption and implementation of BIM (Jung & Lee, 2015; Olawumi et al., 2017) and sustainability (Olawumi & Chan, 2018a). Also, further analysis of the KDs for each region provides insights into the current state of the implementation of smart and sustainable practices and how the relevant stakeholders can team up to address the identified shortcomings. More so, the comparative assessment of the KDs per region will help avoid the problem of generalization of the research findings as well as provide the similarities. Table 5 shows the top-five significant drivers and bottom-three less significant drivers of implementing smart and sustainable practices for each region of the study's respondents. These regions include Africa, Asia, Europe, and America in no particular order.

[Insert Table 5]

The findings of the analysis for the key drivers for each region reveal some similarities. As shown in Table 5, the five most significant for all respondents are drivers C1, C3, C21, C2, and C9. Driver C1, which is concerned with the "technical competence of staff" and C2 – "greater awareness and experience level within the firm," is rated as one of the top-five significant drivers in Asia, Africa, and America regions but not in the European region. Also, factor C3- "training programs for cross-field specialists in BIM and sustainability" is ranked as a top-five driver in the built environment of Africa, Asia, and European regions; similarly, for drivers C9- "effective collaboration and coordination among project participants" and C21- "early involvement of project teams" which are critical KDs for the European, African, and America construction sectors See Table 5). The results provided evidence that despite the significant progress made by some countries in Europe and America as regards the adoption of BIM and sustainability (Bernstein et al., 2012; Malleson, 2012; Olawumi & Chan, 2017) such as the United Kingdom, the United States, Canada among others (which are well represented among the study's respondents) issues such as those represented by drivers C1, C2, C3, C9, and C21 are still salient in the construction sectors of these countries. Hence, to enhance the implementation of smart and sustainable practices, stakeholders in these regions must give considerable attention to these drivers.

Also, in the Asia region, drivers C27 and C15, which is concerned with the standardization of BIM and sustainability assessment tools, is regarded as an important factor in enhancing smart and sustainable practices in this region. Although, there have been some efforts in this regard, such as the development of BIM standards in Hong Kong (Chan et al., 2019a, 2019b), and development of green rating tools in Hong Kong (HKGBC, 2018), South Korea (IBEC, 2008), and Singapore (BCA, 2015). However, these standards are still insufficient to address some key issues of smart sustainable practices (Illankoon et al., 2017). Respondents from Europe highlighted drivers C26 and C12 as the salient drivers necessary for its adoption in this region. However, respondents from America and the African region gave less importance to driver C30 which implies the availability of open-source software will make little or no significant improvement to the implementation of smart and sustainable practices in these regions. Similarly, in the construction sectors of Europe and Africa, driver C6 is considered as less significant to the adoption of smart and sustainable practices. Meanwhile, in Asia, drivers C13 and C14 are given less consideration in these regions.

The comparative evaluation of the perceptions of the respondents based on their regions, as discussed in this section, has shed more insight and perspectives on the trends and issues relating to the implementation of smart and sustainable practices in the construction industry of these regions.

5.3 Practical implementation of research findings

The current study has identified the key drivers that can enhance the implementation of smart and sustainable practices in the construction industry. Also, the research has provided a purview of the significant KDs based on the different regions such as Europe, Asia, Africa, and America as well as based on the respondents' professional and organization setups. The motivation behind the study and the findings of the study aligns with previous studies such as Ahvenniemi et al. (2017) and Allwinkle and Cruickshank (2011) who argued that in the considering buildings or cities as being smart; the evaluation should not be only on the use of smart tools in its design, construction, and operations but only the implementation of sustainability practices. These findings provided valuable contributions to theory and research as well as to industry practice.

In curating the 30 key drivers for the implementation of smart and sustainable practices in the construction industry; the current study has provided an organized list of factors to aid the decision making of relevant stakeholders in the construction industry such as the government agencies, construction organizations, professional bodies, academics, etc. It is advised that more in-depth analysis can be done on these 30 KDs, as to how it can influence the adoption of smart and sustainable practices in each clime, construction projects, and firms. As discussed, these key drivers can form a basis for further discussion by the relevant construction stakeholders.

The KDs and the findings based on the analysis of the different professions and organization setup, as well as regions of the respondents, can form part of a consultation instrument by relevant government agencies in charge of smart cities and sustainable development in designing localized policies and guidelines to aid the implementation of smart and sustainable practices. As revealed in the comparative analysis of the significant KDs for each region; it is imperative for top management of construction firms and professional bodies to place more emphasis on the training of their staff as well as increasing their knowledge and awareness of BIM and sustainability practices through the organization of seminars, workshops, conferences, among others.

The findings across the regions revealed the importance of collaboration and coordination among project stakeholders as well as their early involvement in construction projects. Hence, there is a need for the construction industry to avoid the use of traditional procurement methods and incorporate procurement methods and project management techniques that ensure the critical project stakeholders are involved in the early stages of the planning and design of such projects. However, despite the advantages and preeminence of open-source software development in other fields, the study respondents opined that it might not give construction stakeholders and firms the required leverage in the implementation of smart and sustainable practices in the built environment.

5.4 Limitation of the study and future research

A major limitation of the study is the relatively small sample size for regions such as Europe (20) and America (12), both in the number of respondents and countries involved. However, the level of experience of the respondents from these two regions helps to minimize this limitation.

It is recommended for future studies to examine the key drivers highlighted in this study based on an in-depth case study investigation of various construction projects, organizations, and countries and ways of maximizing each stakeholder's inputs towards enhancing the adoption and implementation of smart and sustainability practices in the construction industry. This kind of future research can help verify and evaluate the feasibility and effectiveness of those identified key drivers in promoting and achieving smart sustainable practices in the built environment.

6. Conclusions

The study investigated the concepts of smart and sustainable practices based on the extant literature towards identifying the key drivers (KDs) for the implementation of smart sustainable practices in the built environment. The different research approaches helped revealed the different implementation strategies, policies, and meaning of smart sustainable practices – as some countries focus more on the use of smart tools such as BIM, others on eco-issues, and some others tried to create a balance between the two concepts. The review of extant literature also revealed the deep-seated variance in the adoption, trend, and application of BIM and sustainability practices across the various regions, organization setups, and professional disciplines and noted the shortcomings of the existing green rating tools that place more consideration on the environmental sustainability. The key drivers of smart and sustainable practices in the construction industry have opined by the respondents included – the need to organize training programs and workshops for the training of cross-field specialists. Also, featured among the significant drivers is the technical competence of construction organizations' staff; and early involvement and integration of key project personnel in the project.

A factor analysis of the key drivers yielded five-factor clusters. Therefore, based on the findings of the current study, the following recommendations and practical strategies are outlined for the relevant stakeholders in the construction industry towards enhancing the adoption of smart and sustainability practices in the built environment. These include:

- There is a salient need for key project stakeholders, and government agencies to accord higher priority to the human capital development of their staff towards equipping and re-training them to meet up with the current trend of innovation in the industry.
- Government agencies, as well as professional bodies, should provide synergy towards providing adequate and applicable subsidies or financial incentives to small and medium-scale construction firms to aid their adoption of smart sustainable practices in their construction projects.
- Government regulatory agencies and professional bodies should work synchronously towards developing relevant policies and standards to aid the adoption of these concepts within the local context.
- Construction firms should develop their in-house database platforms, which can help such firms in their implementation of smart sustainable practices as well as keep track of their projects' data and information.
- Top management of firms should prioritize the development and establishment of a good working strategy or model to implement smart sustainable practices.
- Academic researchers and industrial practitioners are recommended to synergize their resources, experiences, and skills towards addressing some limitations found in existing smart sustainability tools and the structure of sustainability criteria, as well as providing technical support.
- The development of open-source or affordable cloud-based technologies should be accelerated to mitigate against the potential barriers posed by the cost of purchasing the commercial desktop-based software.

The study has examined the factors influencing the adoption of smart and sustainable practices based on the literature and the perceptions of the respondents, and it is revealed that the construction industry still lags in its adoption and implementation of smart and sustainable practices in the construction industry. The study has attempted to recommend the possible practical ways to overcome the current deficiencies and determined the key drivers that could accelerate its implementation. Nevertheless, for these drivers and practical recommendations to achieve the preconceived goals, there must be synergy among all relevant construction stakeholders, firms, and government agencies towards achieving smart sustainable practices in the built environment.

References

Abanda, F. H., & Byers, L. (2016). An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling). *Energy*, *97*, 517–527. https://doi.org/10.1016/j.energy.2015.12.135

Abanda, F. H., Vidalakis, C., Oti, A. H., & Tah, J. H. M. (2015). A critical analysis of Building Information Modelling systems used in construction projects. *Advances in Engineering Software*, *90*, 183–201. https://doi.org/10.1016/j.advengsoft.2015.08.009

Abdirad, H. (2016). Metric-based BIM Implementation Assessment : A Review of Research and Practice. *Journal of Architectural Engineering and Design Management*, 1–27. https://doi.org/10.1080/17452007.2016.1183474

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).

Ahankoob, A., Manley, K., Hon, C., & Drogemuller, R. (2018). The impact of building information modelling (BIM) maturity and experience on contractor absorptive capacity. *Architectural Engineering and Design Management*, *0*(0), 1–18. https://doi.org/10.1080/17452007.2018.1467828

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*(PART B), 671–678. https://doi.org/10.1016/j.enbuild.2013.08.063

Ahn, Y. H., Kwak, Y. H., & Suk, S. J. (2016). Contractors' Transformation Strategies for Adopting Building Information Modeling. *Journal of Management in Engineering*, *32*(1), 1–13. https://doi.org/http://dx.doi.org/10.1061/(ASCE)ME.1943-5479.0000390

Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., & Airaksinen, M. (2017). What are the differences between sustainable and smart cities? *Cities*, *60*, 234–245. https://doi.org/10.1016/j.cities.2016.09.009

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 Practice*, *140*(Autodesk 2011), 1–10. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000193.

Ajam, M., Alshawi, M., & Mezher, T. (2010). Augmented process model for e-tendering: Towards integrating object models with document management systems. *Automation in Construction*, *19*(6), 762–778. https://doi.org/10.1016/j.autcon.2010.04.001

Akinade, O. O., Oyedele, L. O., Ajayi, S. O., Bilal, M., Alaka, H. A., Owolabi, H. A., … 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).

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*, *22*(1), 1–19. https://doi.org/10.1080/10630732.2014.942092

Ali, H. H., & Al Nsairat, S. F. (2009). Developing a green building assessment tool for developing countries - Case of Jordan. *Building and Environment*, *44*(5), 1053–1064. https://doi.org/10.1016/j.buildenv.2008.07.015

Allwinkle, S., & Cruickshank, P. (2011). Creating smart-er cities: An overview. *Journal of Urban Technology*, *18*(2), 1–16. https://doi.org/10.1080/10630732.2011.601103

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).

Anthopoulos, L. (2017). Smart utopia VS smart reality: Learning by experience from 10 smart city cases. *Cities*, *63*, 128–148. https://doi.org/10.1016/j.cities.2016.10.005

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*(5), 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*(3), 419–434.

Azhar, S. (2010). BIM for sustainable design: results of an industry survey. *Journal of Building Information Modeling*, *4*(1), 27–28.

Azhar, S. (2011). Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering*, *11*(3), 241–252.

BCA. (2015). *Green Mark for Residential Buildings: including Hawker Centers, Healthcare Facilities, Laboratory Buildings and Schools*. Singapore: Building and Construction Authority. Retrieved from http://bit.ly/2X3MTQL

Becerik-gerber, B., & Kensek, K. (2010). Building Information Modeling in Architecture, Engineering, and Construction: Emerging Research Directions and Trends. *Journal of Professional Issues in Engineering Education and Practice*, *136*(3), 139–147. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000023

Berardi, U. (2013). Sustainability assessment of urban communities through rating systems. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-013-9462-0

Bernstein, H. M., Jones, S., & Russo, M. (2012). *The business value of BIM in North America: multi-year trend analysis and user rating (2007–2012)*. *SmartMark Rep*.

Bibri, S. E., & Krogstie, J. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society*, *31*, 183–212. https://doi.org/10.1016/j.scs.2017.02.016

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*(8), 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*(1), 78–85. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000176

Bolgani, M. (2013). The Implementation of BIM within the public procurement: A model-based approach for the construction industry. *VTT Technology, Finland*, 130.

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

Brinkerink, J., Chegut, A., & Letterie, W. (2019). Energy performance and capital expenditures in manufacturing industries. *Energy Efficiency*. https://doi.org/10.1007/s12053-019-09779-x

Bynum, P., Issa, R. R. A., & Olbina, S. (2013). Building Information Modeling in Support of Sustainable Design and Construction. *Journal of Construction Engineering and Management - ASCE*, *139*(1), 24–34. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000560

Capper, G., Matthews, J., & Lockley, S. (2012). In corporating embodied energy in the BIM process. In *CIBSE ASHRAE Technical Symposium*. London, UK: Imperial College.

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*(2), 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*(100737), 13 pages. https://doi.org/https://doi.org/10.1016/j.jobe.2019.100737

Chan, D. W. M., Chan, A. P. C., & Choi, T. N. Y. (2010). An empirical survey of the benefits of implementing pay for safety scheme (PFSS) in the Hong Kong construction industry. *Journal of Safety Research*, *41*(5), 433–443. https://doi.org/10.1016/j.jsr.2010.07.001

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*(100764), 10 pages. https://doi.org/10.1016/j.jobe.2019.100764

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

Deutsch, R. (2011). *BIM and Integrated Design: Strategies for Architectural Practice*. Hoboken: John Wiley & Sons.

Field, A. (2009). *Discovering Statistics Using SPSS*. *Sage Publication* (Vol. 58). https://doi.org/10.1234/12345678

Goedert, J. D., & Meadati, P. (2008). Integrating Construction Process Documentation into Building Information Modeling. *Journal of Construction Engineering and Management*, *134*(7), 509–516.

Gourlis, G., & Kovacic, I. (2017). Building Information Modelling for analysis of energy efficient industrial buildings – A case study. *Renewable and Sustainable Energy Reviews*, *68*, 953–963. https://doi.org/10.1016/j.rser.2016.02.009

Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, *19*(8), 988–999. https://doi.org/10.1016/j.autcon.2010.09.002

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*(10), 1–8. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000747

Hanna, A. S., Yeutter, M., & Aoun, D. G. (2014). State of Practice of Building Information Modeling in the Electrical Construction Industry. *Journal of Construction Engineering and Management - ASCE*, *140*(12). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000893

Harding, J., Suresh, S., Renukappa, S., & Mushatat, S. (2014). Design Teams in Achieving BREEAM Accreditation ? *Journal of Construction Engineering*. https://doi.org/http://dx.doi.org/10.1155/2014/390158

HKGBC. (2018). *BEAM Plus New Buildings V2.0* (2.0 (Beta)). Hong Kong: Hong Kong

Green Building Council. Retrieved from http://bit.ly/2HAifcj

Hope, A., & Alwan, Z. (2012). Building the Future : Integrating Building Information Modelling and Environmental Assessment Methodologies. *Northumbria Research Link*. Retrieved from https://core.ac.uk/download/pdf/8790178.pdf

Huang, S. L., Yeh, C. T., Budd, W. W., & Chen, L. L. (2009). A Sensitivity Model (SM) approach to analyze urban development in Taiwan based on sustainability indicators. *Environmental Impact Assessment Review*. https://doi.org/10.1016/j.eiar.2008.03.003

IBEC. (2008). *CASBEE for New Construction: Comprehensive Assessment System for Building Environmental Efficiency Technical Manual*. (J. G. B. Council, Ed.). Japan: Institute for Building Environment and Energy Conservation.

Ilhan, B., & Yaman, H. (2016). Green building assessment tool (GBAT) for integrated BIM-based design decisions. *Automation in Construction*, *70*, 26–37. https://doi.org/10.1016/j.autcon.2016.05.001

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. (2014). Integrating Building Information Modeling (BIM) and Energy Analysis Tools with Green Building Certification System to Conceptually Design Sustainable Buildings. *Journal of Information Technology in Construction*, *19*, 494–519.

Jung, W., & Lee, G. (2015). The Status of BIM Adoption on Six Continents. *International Journal of Civil, Structural, Construction and Architectural Engineering*, *9*(5), 406–410.

Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation. *Automation in Construction*, *20*(2), 126–133. https://doi.org/10.1016/j.autcon.2010.09.010

Kassem, M., Brogden, T., & Dawood, N. (2012). BIM and 4D planning: a holistic study of the barriers and drivers to widespread adoption. *Journal of Construction Engineering and Project Management*, *2*(4), 1–10.

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

Lingard, H., & Rowlinson, S. (2006). Letter to the editor. *Construction Management and Economics*, *22*(11), 1107–1109.

Lozano, R. (2008). Envisioning sustainability three-dimensionally. *Journal of Cleaner*

Production, *16*(17), 1838–1846. https://doi.org/10.1016/j.jclepro.2008.02.008

Lu, Y., Wu, Z., Chang, R., & Li, Y. (2017). Building Information Modeling (BIM) for green buildings: A critical review and future directions. *Automation in Construction*, *83*(January), 134–148. https://doi.org/10.1016/j.autcon.2017.08.024

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*(6), 1–10. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000647.

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

Malleson, A. (2012). *National BIM report 2012*. London.

Marsal-Llacuna, M. L., Colomer-Llinàs, J., & Meléndez-Frigola, J. (2015). Lessons in urban monitoring taken from sustainable and livable cities to better address the Smart Cities initiative. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2014.01.012

Mom, M., Tsai, M.-H., & Hsieh, S.-H. (2014). Developing critical success factors for the assessment of BIM technology adoption: Part II. Analysis and results. *Journal of the Chinese Institute of Engineers*, *37*(7), 859–868. https://doi.org/10.1080/02533839.2014.888798

Nanajkar, A., & Gao, Z. (2014). BIM Implementation Practices at India’s AEC Firms. In *International Conference on Construction and Real Estate Management*. Kunming, China.

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*(11), 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*, *9*(2), 54–64.

Olawumi, T. O. (2016). Establishment of Critical Causal Factors for Electrical Cost Estimating Techniques. *World Scientific News*, *53*(3), 354–366. https://doi.org/https://doi.org/10.6084/m9.figshare.9642683

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*(1). https://doi.org/10.17632/sv23pvr252.1

Olawumi, T. O., & Chan, D. W. M. (2018a). 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. (2018b). Beneficial Factors of Integrating Building Information Modelling (BIM) and Sustainability Practices in Construction Projects. In *Hong Kong International Conference on Engineering and Applied Science (HKICEAS) 2018* (pp. 141–152). Hong Kong: Higher Education Forum, 24-26 January 2018. Retrieved from http://bit.ly/2moE0Ul

Olawumi, T. O., & Chan, D. W. M. (2018c). Critical Success Factors (CSFs) for Amplifying the Integration of BIM and Sustainability Principles in Construction Projects: A Delphi Study. In *RICS COBRA, RICS, London, 23-25 April, 2018*. London: RICS. Retrieved from https://goo.gl/eBfyVW

Olawumi, T. O., & Chan, D. W. M. (2018d). 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. (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). 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. (2019c). Concomitant Impediments to the implementation of Smart Sustainable Practices in the Built Environment. *Sustainable Production and Consumption*, *(in press)*. https://doi.org/10.1016/j.spc.2019.09.001

Olawumi, T. O., & Chan, D. W. M. (2019d). Critical Success Factors of 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. (2019e). 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., & 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/doi.org/10.1016/j.jobe.2018.06.017

Oti, a. H. H., Tizani, W., Abanda, F. H. H., Jaly-Zada, a., & Tah, J. H. M. H. M. (2016). Structural sustainability appraisal in BIM. *Automation in Construction*, *69*, 44–58. https://doi.org/10.1016/j.autcon.2016.05.019

Park, C. S., Lee, D. Y., Kwon, O. S., & Wang, X. (2013). A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. *Automation in Construction*, *33*, 61–71. https://doi.org/10.1016/j.autcon.2012.09.010

Peansupap, V., & Walker, D. (2005). Factors affecting ICT diffusion A case study of three large Australian construction contractors, *12*(1), 21–37. https://doi.org/10.1108/09699980510576871

Qi, J., Issa, R. R. A., Olbina, S., & Hinze, J. (2014). Use of Building Information Modeling in Design to Prevent Construction Worker Falls. *Journal of Computing in Civil Engineering*, *28*(5, SI), 1–10. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000365

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

Robinson, J., & Cole, R. J. (2015). Theoretical underpinnings of regenerative sustainability. *Building Research and Information*. https://doi.org/10.1080/09613218.2014.979082

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*(4), 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, SI), 1–11. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000303

Saka, A. B., Olaore, F. O., & Olawumi, T. O. (2019). Post-contract material management and waste minimization. *Journal of Engineering, Design and Technology*, *17*(4), 793–807.

https://doi.org/10.1108/JEDT-10-2018-0193

Sato, T. (2005). Factor analysis in personality psychology.

Saxon, R. G. (2013). *Growth through BIM. Construction Industry Council*. London.

Sheth, A. Z., Price, A. D., & Glass, J. (2010). BIM and refurbishment of exisiting healthcare facilities. In *Proceedings of the 26th Annual ARCOM Conference, 6-8 September*. Leeds, UK: ARCOM.

Shi, Q., Zuo, J., Huang, R., Huang, J., & Pullen, S. (2013). Identifying the critical factors for green construction - An empirical study in China. *Habitat International*, *40*, 1–8. https://doi.org/10.1016/j.habitatint.2013.01.003

Tah, J. H. M., & Abanda, H. F. (2011). Sustainable building technology knowledge representation: Using Semantic Web techniques. *Advanced Engineering Informatics*, *25*(3), 547–558. https://doi.org/10.1016/j.aei.2011.02.006

Tsai, M.-H., Mom, M., & Hsieh, S.-H. (2014a). Developing critical success factors for the assessment of BIM technology adoption: part I. Methodology and survey. *Journal of the Chinese Institute of Engineers*, *37*(7), 845–858. https://doi.org/10.1080/02533839.2014.888811

Tsai, M. H., Kang, S. C., & Hsieh, S. H. (2014b). Lessons learnt from customization of a BIM tool for a design-build company. *Journal of the Chinese Institute of Engineers*, *37*(2), 189–199. https://doi.org/10.1080/02533839.2013.781791

WCED. (1987). Our common future. In *Brundtland Report* (pp. 1–300). Brundtland: World Commission on Environment and Development- Oxford University Press. Retrieved from http://www.un-documents.net/our-common-future.pdf

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

Wong, K., & Fan, Q. (2013). Building information modelling (BIM) for sustainable building design. *Facilities*, *31*(3), 138–157. https://doi.org/10.1108/02632771311299412

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*(7), 929–943. https://doi.org/10.1016/j.autcon.2010.06.006

Yeomans, S. G., Bouchlaghem, N. M., & El-Hamalawi, A. (2006). An evaluation of current collaborative prototyping practices within the AEC industry. *Automation in Construction*, *15*(2), 139–149.

Zhang, S., Boukamp, F., & Teizer, J. (2015). Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA). *Automation in Construction*, *52*, 29–41. https://doi.org/10.1016/j.autcon.2015.02.005

Table 1: Summary of identified KDs for the execution of smart sustainable practices

Code	Key drivers	References
C1	Technical competence of staff	Gu and London (2010); Tsai et al. (2014); Deutsch (2011)
C2	Greater awareness and experience level within the firm	Chan (2014); Kassem et al. (2012)
C3	More training programs for cross-field specialists in BIM and Sustainability	Wong and Fan (2013); Jalaei and Jrade (2014)
C4	Increased research in the industry and academia	Abdirad (2016); Bolgani (2013)
C5	Government establishment of start-up funding for construction firms to kick-start BIM initiatives	Abubakar et al. (2014)
C6	Adequate construction cost allocated to BIM	Gu and London (2010); Kivits and Furneaux (2013)
C7	Availability of financial resources for BIM software, licenses, and its regular upgrades	Nanajkar and Gao (2014)
C8	Information and knowledge-sharing within the industry	Azhar (2011); Chan et al. (2019b)
C9	Effective collaboration and coordination among project participants	Antón and Díaz (2014); Hanna et al. (2014)
C10	Establishment of a model of good practice for BIM and sustainability execution	Antón and Díaz (2014); Adamus (2013)
C11	Availability and a well-managed in-house database of information on similar projects	Aibinu and Venkatesh (2014); Becerik-gerber and Kensek (2010)
C12	Development of appropriate legal framework for BIM use and deployment in	Aibinu and Venkatesh (2014);

Code	Key drivers	References
	projects	Azhar (2011)
C13	Security of intellectual property and rights	Kivits and Furneaux (2013)
C14	Shared risks, liability, and rewards among project stakeholders	Chan (2014); Park et al. (2013)
C15	Establishment of BIM standards, codes, rules, and regulations	Redmond et al. (2012)
C16	Appropriate legislation and governmental enforcement & credit for innovative performance	Antón and Díaz (2014); Hope and Alwan (2012)
C17	Increased involvement of project stakeholders in green projects	Alsayyar and Jrade (2015)
C18	Clarity in requirements and measures for achieving sustainable projects	Aibinu and Venkatesh (2014)
C19	Number of subcontractors experienced with BIM projects	Chan (2014)
C20	Client requirement and ownership	Ahn et al. (2014); Chan et al. (2019a)
C21	Early involvement of project teams	Kassem et al. (2012)
C22	Client satisfaction level on BIM projects	Ahn et al. (2014); Chan (2014)
C23	Supportive organizational culture and effective leadership	Yeomans et al. (2006)
C24	Project complexity (regarding building shape or building systems)	Hope and Alwan (2012); Kivits and Furneaux (2013)
C25	Availability and affordability of cloud-based technology	Ahn et al. (2014); Yeomans et al. (2006)
C26	Interoperability and data compatibility	Adamus (2013); Saxon (2013)
C27	Standardization & simplicity of BIM and sustainability assessment software	Akinade et al. (2017); Aksamija (2012)
C28	Technical support from software vendors	Redmond et al. (2012)
C29	Availability of BIM and sustainability databases	Abolghasemzadeh (2013); Antón and Díaz (2014)
C30	Open-source software development	Hope and Alwan (2012)

Note: The key drivers were modified from Olawumi and Chan (2019c)*.*

Table 2: Key drivers for the execution of smart sustainable practices in the construction industry: inter-group comparisons

KDs	Architects		Civil Engineers		Project Managers		Building Serv. Engr.		Constr. Managers		Overall				
	Mean	**Rk**	**Mean**	**Rk**	**Mean**	**Rk**	**Mean**	**Rk**	**Mean**	**Rk**	**Mean**	**SD**	**Rk**	**F**	**Sig.**
C1	4.64	2	4.33	8	4.20	1	4.20	3	4.48	1	4.34	0.780	1	1.137	0.336
C2	4.54	3	4.00	28	3.84	24	3.77	31	4.03	26	4.22	0.728	4	1.040	0.411
C3	4.64	1	4.08	23	3.88	22	4.03	15	4.39	4	4.27	0.738	2	1.770	0.068
C4	4.21	18	4.25	16	4.04	8	3.91	24	4.34	7	4.05	0.803	13	2.491	**0.008**
C5	4.11	23	4.17	19	3.76	30	3.86	27	3.89	32	4.01	0.917	19	1.230	0.273
C6	4.00	29	4.17	19	3.92	19	3.86	28	3.72	30	3.87	0.898	28	0.968	0.473
C7	4.36	10	4.33	8	3.96	16	3.97	21	3.89	31	3.98	0.924	22	1.280	0.243
C8	4.32	15	4.25	16	4.04	7	4.09	10	4.48	2	4.07	0.805	10	1.117	0.351
C9	4.39	8	4.50	3	3.92	17	3.86	29	4.20	13	4.17	0.784	5	0.929	0.507
C10	4.36	12	3.92	31	4.12	3	3.74	32	4.17	19	4.11	0.783	7	1.308	0.228
C11	4.32	15	3.50	36	3.28	30	3.49	36	3.76	34	4.01	0.791	18	1.037	0.413
C12	4.11	22	4.00	28	3.64	33	3.69	33	3.99	30	4.03	0.807	15	1.049	0.403
C13	4.00	28	3.67	35	3.64	34	3.63	34	3.74	35	3.87	0.884	27	1.809	0.061
C14	4.07	26	3.92	31	3.44	35	3.54	35	3.85	33	3.94	0.823	24	1.017	0.430
C15	4.43	6	4.33	8	4.08	5	4.17	5	4.34	8	4.15	0.820	6	1.564	0.119

KDs	Architects		Civil Engineers		Project Managers		Building Serv. Engr.		Constr. Managers		Overall				
	Mean	Rk	Mean	Rk	Mean	Rk	Mean	Rk	Mean	Rk	Mean	SD	Rk	F	Sig.
C16	4.39	9	4.25	15	3.96	13	4.17	5	4.18	15	3.99	0.833	20	2.035	**0.031**
C17	4.21	19	4.42	5	3.92	19	4.14	8	4.41	3	4.02	0.785	17	0.989	0.454
C18	4.14	21	4.33	12	3.92	17	4.03	14	4.31	10	4.03	0.746	14	0.585	0.825
C19	4.00	27	3.75	34	3.96	14	4.06	13	4.02	28	3.93	0.805	25	0.825	0.604
C20	4.00	30	3.83	33	4.00	9	4.09	10	4.02	28	3.98	0.883	21	1.031	0.419
C21	4.46	5	4.08	24	3.96	14	4.26	1	4.20	14	4.24	0.821	3	1.140	0.334
C22	4.11	24	4.08	26	4.08	6	4.23	2	4.34	9	4.05	0.801	12	0.752	0.675
C23	4.39	7	4.00	30	3.84	24	3.89	26	4.08	25	4.07	0.782	9	1.433	0.168
C24	4.11	25	4.17	19	4.00	9	4.11	9	4.16	20	3.91	0.879	26	1.494	0.143
C25	4.21	20	4.25	14	4.00	9	3.91	23	4.21	12	3.79	0.919	30	1.754	0.071
C26	4.36	10	4.42	5	3.80	26	4.00	17	4.18	17	4.06	0.817	11	1.608	0.106
C27	4.36	12	4.00	27	3.88	22	3.89	25	4.10	23	4.08	0.843	8	1.535	0.129
C28	4.36	12	4.42	5	3.80	26	3.83	30	4.14	21	3.95	0.890	23	2.664	**0.004**
C29	4.50	4	4.17	19	3.72	31	4.06	12	4.18	18	4.03	0.883	16	1.394	0.185
C30	4.25	17	4.17	18	3.76	29	3.94	22	4.03	27	3.86	0.926	29	1.591	0.111

Note: Rk = Rank

Table 3: Factor structure for the PCA analysis of the KDs

Code	KDs for implementing smart sustainable practices	Factor loading	Eigenvalue	Percentage of variance explained	Cumulative percentage of variance explained
Factor 1 – Knowledge & industry-related drivers			15.236	50.786	50.786
C1	Technical competence of staff	0.746			
C3	More training programs for cross-field specialists in BIM and Sustainability	0.745			
C9	Effective collaboration and coordination among project participants	0.668			
C2	Greater awareness and experience level within the firm	0.641			
C11	Availability and a well-managed in-house database of information on similar projects	0.634			
C10	Establishment of a model of good practice for BIM and sustainability execution	0.596			
C23	Supportive organizational culture and effective leadership	0.563			
C8	Information and knowledge-sharing within the industry”	0.546			
C4	Increased research in the industry and academia	0.503			
Factor 2 – Financial, legal & statutory drivers			1.518	5.059	55.845
C7	Availability of financial resources for BIM software, licenses, and its regular upgrades	0.745			
C6	Adequate construction cost allocated to BIM	0.712			
C5	Government establishment of start-up funding for construction firms to kick-start BIM initiatives	0.659			

Code	KDs for implementing smart sustainable practices	Factor loading	Eigenvalue	Percentage of variance explained	Cumulative percentage of variance explained
C12	Development of appropriate legal framework for BIM use and deployment in projects	0.601			
C16	Appropriate legislation and governmental enforcement & credit for innovative performance	0.543			
C15	Establishment of BIM standards, codes, rules, and regulations	0.499			
C13	Security of intellectual property and rights	0.463			
Factor 3 – Organizational & project-related drivers			1.392	4.641	60.486
C22	Client satisfaction level on BIM projects	0.669			
C24	Project complexity (regarding building shape or building systems)	0.646			
C25	Availability and affordability of cloud-based technology	0.604			
C21	Early involvement of project teams	0.572			
C26	Interoperability and data compatibility	0.527			
Factor 4 – Technical drivers			1.301	4.337	64.823
C30	Open-source software development	0.797			
C29	Availability of BIM and sustainability databases	0.762			
C28	Technical support from software vendors	0.700			
C27	Standardization & simplicity of BIM and sustainability assessment software	0.677			
Factor 5 – Information, risks & attitude-related drivers			1.062	3.541	68.363
C19	Number of subcontractors experienced with BIM projects	0.770			
C20	Client requirement and ownership	0.648			
C17	Increased involvement of project stakeholders in green projects	0.616			
C18	Clarity in requirements and measures for achieving sustainable projects	0.567			
C14	Shared risks, liability, and rewards among project stakeholders	0.459			

Source (of the KD's items): Olawumi and Chan (2019c)

Table 4: Ranking results of the factor scale rating for the KDs clusters

Clustered factor	Factor label	Factor scale rating	Ranking
1	Knowledge & industry-related drivers	4.1456	1
3	Organizational & project-related drivers	4.01	2
2	Financial, legal & statutory drivers	3.9857	3
4	Technical drivers	3.98	4
5	Information, risks & attitude-related drivers	3.98	4

Table 5: Comparative assessment of the KDs based on the respondents' regions

Africa		Asia		Europe		America		Overall		Ranking
Factors	**Mean**	**Factors**	**Mean**	**Factors**	**Mean**	**Factors**	**Mean**	**Factors**	**Mean**	
C1	4.55	C1	4.17	C21	4.70	C1	4.83	C1	4.34	1
C21	4.50	C3	4.11	C9	4.45	C9	4.67	C3	4.27	2
C3	4.48	C2	4.09	C3	4.40	C21	4.58	C21	4.24	3
C9	4.45	C27	4.02	C26	4.40	C4	4.58	C2	4.22	4
C2	4.44	C15	4.02	C12	4.40	C2	4.58	C9	4.17	5
…		…		…		…		…		…
C30	4.08	C14	3.76	C6	3.70	C5	3.92	C6	3.87	28
C19	4.06	C13	3.69	C28	3.65	C30	3.75	C30	3.86	29
C6	3.92	C25	3.52	C7	3.45	C24	3.75	C25	3.79	30

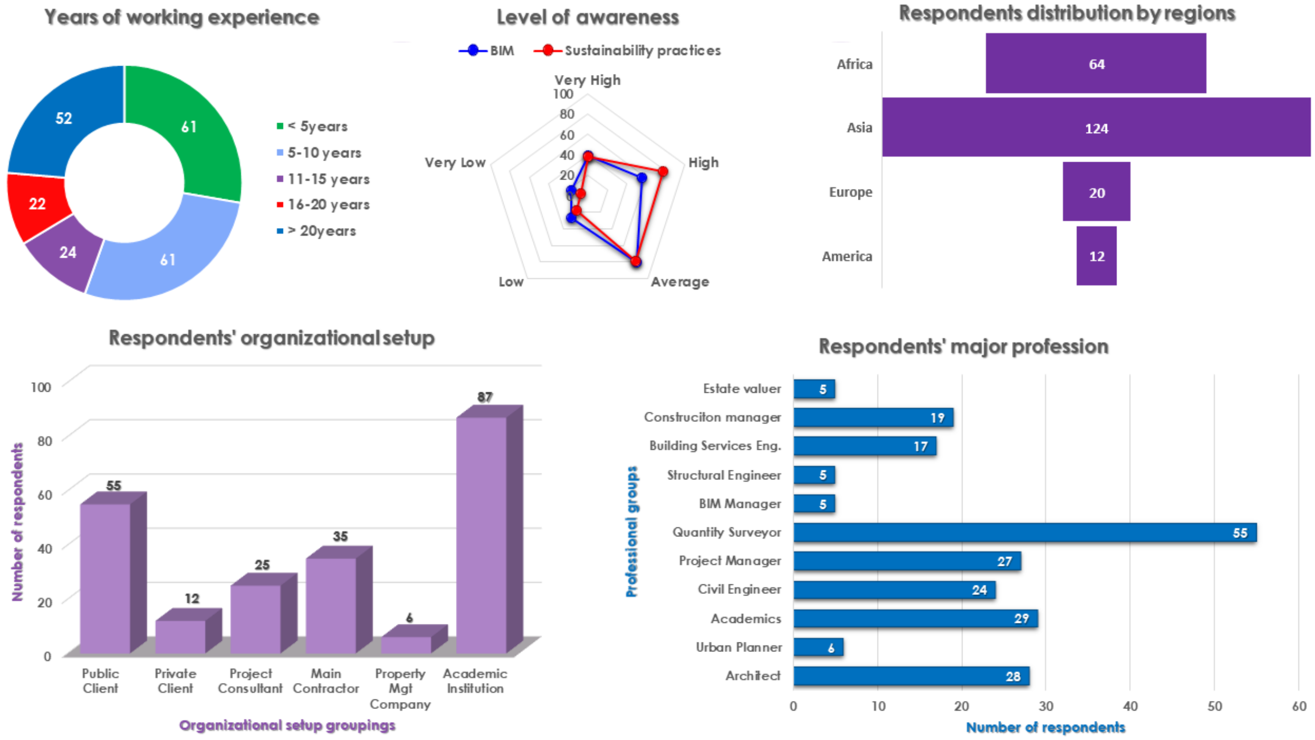

Figure 1: Respondents' demographics