An Empirical Survey of the Perceived Benefits of Executing BIM and Sustainability Practices in the Built Environment

Abstract

Purpose- The increasing urbanization of the built environment has bolstered the need to promote green Building Information Modelling (BIM) initiative in new construction projects and the rehabilitation of old premises. The study aims to explore and examine the key benefits of the implementation of BIM and sustainability practices in the built environment.

Design/methodology/approach- The study gathered the worldwide perceptions of 220 survey participants from 21 countries which were analyzed using descriptive and inferential analytical methods. The identified individual benefits of green BIM were further categorized into their underlying clusters using factor analysis.

Findings- The key benefits are related to enhancing project efficiency and productivity, ensuring real-time sustainable design and multi-design alternatives, facilitating the selection of sustainable materials and components, together with reducing material wastage and project's environmental impact, among others. The study analyzed and compared the perceptions of the diverse groups of the respondents as well.

Research implications– Effective blueprints and insightful recommendations for enhancing the various stakeholders' capacities to implement green BIM in their construction projects were put forward to achieve the aim of sustainable smart urbanization.

Originality/value– The study identified salient benefits of the adoption of BIM and sustainability practices. The proper integration of these concepts and the execution of the recommended useful strategies by construction stakeholders, policymakers, and local authorities will enable the built environment to reap the gains of its implementation.

Keywords: Sustainability, BIM, benefits, implementation, construction industry, built environment

Introduction

Green BIM is an emerging trend in the built environment which is described by Wu and Issa (2014) as a synergy between Building Information Modelling (BIM) and sustainability goals. It is a “symbiotic convergence of the two separate trends into an emerging practice” (McGraw-Hill Construction, 2013). The implementation of BIM in construction projects was categorized into two forms: (1) BIM products or technology; and (2) BIM process (Olawumi et al., 2018; Olawumi & Chan, 2019a); while sustainability is often defined on the basis of the holistic fulfillment of its three fundamental pillars; which are the environmental, social and economic sustainability (Olawumi & Chan, 2018a; Wong & Kuan, 2014). Moreover, to facilitate and ensure construction firms and the industry integrate green BIM into the projects, there must be a strategic plan and guidelines for its implementation (Wu & Issa, 2014).

Antón and Díaz (2014) noted that the construction industry has started to embrace the concept of BIM and sustainability and suggested that the concepts should be implemented early into the project as it provides the best opportunity to impact the project effectively. The need to integrate BIM and sustainability in a project was stressed by Sun et al. (2016) who noted that for a building to be energy-sufficient, enabling software is needed to simulate and predict the energy performance. Azhar et al. (2011) pointed out that there is an increasing demand for green buildings due to the minimal environmental impact of such buildings and its relatively low lifecycle costs. However, despite the hypothetical and some few real-life evidence-based project benefits of adopting BIM and sustainability practices, Wu and Issa (2014) observed that the potential of green BIM is yet to be explored in most construction projects, and Olawumi et al. (2017) revealed the inadequacy or lack of relevant standards on BIM and sustainability in most countries.

More so, Wu and Issa (2014) and McGraw-Hill Construction (2010) observed stakeholders’ inclinations for the adoption of green BIM had focused mostly on the technological-aspect and less on other areas such as the business process of implementing BIM and even the sustainability aspect of green BIM. Also, Cugurullo (2017) highlighted the differences and challenges in the built environment in the quest to decipher between eco-cities and smart cities and the appropriate approach to achieve the initiative. Clearly, these views emphasized the need to explore the benefits of BIM and sustainability practices to provide evidential support and to aid clients along with project teams in their quest to adopt green BIM in their projects.

Bring the perspectives together; the current study intends to bridge the gap in the knowledge and practice by identifying and assessing the practical benefits to the construction industry and the built environment when BIM and sustainability practices are implemented in construction projects. The study will consider the benefits from the various viewpoints of construction professionals such as civil engineers, construction managers, architects as well as those from diverse organizational setups such as public and private clients, contractors and project consultants. The study will also attempt to classify the identified green BIM implementation benefits as well as provide strategies and recommendations for construction organizations, project teams, local authorities and other key stakeholders towards enhancing the uptake of green BIM initiative in construction projects.

The current study is organized as follows. Section 1 provides an introduction to BIM and sustainability practices and its implementation in the built environment. It also clarifies what constitutes green-BIM. Section 2 highlights from relevant desktop literature the practical benefits and impacts of the application of green BIM in construction projects, and Section 3 deliberates on the adopted research designs and the statistical tools employed in the study. Section 4 focuses on the study's significant findings and highlights the viewpoints of the diverse groups of survey participants. Section 5 encapsulates how the aim of the study was achieved and provides practical recommendations and blueprints to ensure the achievement of sustainable smart cities.

The impact of the implementation of BIM and sustainability practices

The capacity of BIM as a platform that allows for multi-disciplinary data to be embedded in a single model (Azhar et al., 2011) provides project teams the opportunities to incorporate sustainability parameters into such building models; this informs the basis for simulating and analyzing the sustainability performance of buildings and for comparison purposes (Ahn et al., 2014; Olawumi et al., 2017). The impact of the adoption of BIM and sustainability practices have been identified in the literature as shown in Table 1 (Olawumi & Chan, 2018d). Wu and Issa (2014) stressed the importance of the implementation of green BIM in a project, and that it not only ensures the project team achieves the intended project goals and outcomes but also ensures the targeted sustainability goals are realized.

Kats et al. (2003) noted that although it might cost a project like two percent increase of the initial cost of the construction, such projects stand to make significant savings in the lifecycle costs of the project which can be up to 20 percent of the initial construction cost. Hence, per Azhar et al. (2011), green buildings are economically viable with little or no environmental impact on the locality. McGraw-Hill Construction (2010) stressed that the proper integration of green BIM in construction would enable project teams to successfully steer a construction project which is usually complex and sophisticated in a collaborative manner (Ayegun et al., 2018; Olatunji et al., 2017a; Olawumi & Ayegun, 2016). Also, Azhar et al. (2011) and Bynum et al. (2013) noted that the adoption of green BIM helps to facilitate a better decision-making process among the project stakeholders and aid the sustainability analysis of design models at the early stages of a project; and these combine to promote the project's sustainability goals.

Meanwhile, to assess the level of the implementation of green BIM, countries such as the United States, the United Kingdom, South Korea, Japan, Hong Kong has develop BIM standards and sustainability rating system to rate the performance of buildings (Azhar et al., 2011; Olawumi et al., 2017; Wong & Zhou, 2015). The standards provide the prerequisites to be met by a building or facility before it can be classified as a green building and contains practical and measurable criteria for implementing BIM and sustainability in those regions. Kriegel and Nies (2008) highlighted areas in which BIM can aid the sustainable design and these include daylighting analysis, selection of sustainable materials, selecting a good building orientation in order to reduce energy consumption, water harvesting and energy modeling among others. Saka et al. (2017) highlighted the significance of energy and its consumption to the economic development and growth of a nation. A survey study of 145 design and construction firms by Azhar (2010) revealed that a good number of the firms achieved time and cost savings when they implemented green BIM in their projects.

Meanwhile, Azhar et al. (2011) conducted a case study analysis on a project and discovered that there is no relationship between some sustainability parameters (like those of LEED) and some BIM-sustainability based analyses. However, it demonstrated the potential benefits of the synergy of BIM and sustainability towards the implementation of smart, sustainable cities. Also, Antón and Díaz (2014) while highlighting the necessity for the construction industry to adopt green BIM observed that 40% of total waste and resources are consumed in construction projects globally and that another 40% of energy consumed in the European Union is from the industry. Hence, Welter (2003) argued for construction stakeholders participation in its implementation, while Kummitha and Crutzen (2017) calls for local authorities to enact laws to promote the concept of sustainable smart city initiative which is the ultimate goal of implementing green BIM in the built environment. Olawumi and Chan (2019c) meanwhile, developed a benchmarking model to facilitate BIM implementation in developing countries and produce an assessment template for a comparative evaluation of BIM projects.

Pérez-Lombard et al. (2008) indicated that the energy consumption of buildings in recent years had exceeded those of other major sectors like transportation due to the growing demand for building services and human comforts. These various viewpoints from the literature further underlined the relevance of the integration of BIM and sustainability practices in the construction industry. A review of the literature shows increasing research on BIM and sustainability (Olawumi et al., 2017; Olawumi & Chan, 2017; Wong & Zhou, 2015).

Goldman et al. (2002), and Frankel and Turner (2008) buttressed the influence of BIM and sustainability in some reviewed LEED certified projects which shows significant energy savings in most of the building projects evaluated. The positive contribution of green BIM to the construction sector according to De Jong et al. (2015) has triggered a welcoming impression on local authorities in some major cities in the world who are now trying to upgrade the public infrastructure to create a better sustainable and attractive environment for its residents as well as enhancing the cities' overall competitiveness. Given the above reviews from existing studies, the subsequent aspects of the study will examine and assess the perception of the 220 survey participants on the benefits of the implementation of BIM and sustainability practices.

[Insert Table 1]

Research methodology

The study employed a quantitative research design to explore and assessed the benefits derivable by the construction industry when BIM initiatives and sustainability practices are implemented in construction projects. Primary data for the study were collected through empirical questionnaire surveys and secondary data via a review of relevant literature from journal papers, books, and web pages. As perceived by Olatunji et al. (2017a), the instrument and approach to data collection have a significant effect on the achievement of the study's aims and objectives.

The target respondents for the study's survey are construction professionals and stakeholders with a good knowledge of BIM and sustainability. The survey forms were prepared and sent in three formats to the survey participants, and these include: (1) fill-in PDF survey forms; (2) hand-delivered questionnaires; and (3) online survey forms. Most of the respondents were sent personalized emails with links to the online survey form and an attached fill-in PDF survey form. The questionnaire form and its items were pretested with a few related experts before distribution, and a total of 220 survey responses were received from respondents across 21 countries, and most of the responses were through the online survey form (161 responses), and the rest from hand-delivered questionnaires (45), and fourteen responses were gleaned by means of the fill-in PDF survey forms. The questionnaire form solicited necessary information on each respondent as well as their perceptions on the degree of importance of the listed factor items on the benefits on BIM and sustainability practices on a 5-point Likert scale (*1=strongly disagree, 3=neutral and 5=strongly agree*). The data collected were analyzed using statistical tools as explained in later sections of this paper.

Statistical tools and reliability test analysis

Descriptive and inferential statistical tools were employed to analyze the survey data, and these include: (1) Cronbach's alpha reliability test, α; (2) Mean ranking (M) and standard deviation (SD); (3) ANOVA, post-hoc Tukey tests & correlation analysis; and (4) Factor analysis and groupings. More so, before subjecting the data to further statistical analysis as recommended by Field (2009), a reliability test was conducted to assess the questionnaire items and its associated scale whether it measures the right construct (Field, 2009; Olawumi et al., 2018).

The Cronbach's alpha value for the study was 0.968 which is higher than the minimum threshold of 0.70 (Olawumi & Chan, 2018c, 2019b) which implies a good internal consistency and that the questionnaire scale measures the right construct which makes the data suitable for further analysis (Olawumi & Chan, 2018b). For this study, in a case where two or more items have the same mean value, the values of their SD are used to rank them. Items with smaller SD's values are ranked higher (Olatunji et al., 2017a; Olawumi & Chan, 2018d), and in cases, the items have the same mean and SD values, the items will be allocated the same rank.

Demographics of the survey participants

Survey participants from 21 countries participated in the study's questionnaire survey. Figure 1 shows the demographics of the working experience of survey participants in the construction industry with varied lengths. The two-hundred and twenty (220) participants have practical knowledge and understanding of BIM and sustainability concepts with 43.2 percent of the respondents having at least a high level of awareness of BIM process and a higher percentage (52.8%) with at least a high degree of awareness of the sustainability process. Also, 36.8 percent and 35.9 percent of the survey participants rated their level of awareness of BIM and sustainability respectively as an average. These findings lend credibility to the data and opinions collected from the survey respondents.

[Insert Figure 1]

Meanwhile, the analysis of the respondents' demographics based on their organization type reveals that majority of them are from the academics and the public-sector clients (*which included local authorities and policymakers, etc.*) with 39.5% and 25% respectively of the 220 survey respondents. Also, the analysis reveals the respondents from the main contractors (15.9%), project consultants (11.4%) and private clients (5.5%) as one of the significant groups of respondents for the study.

Moreover, an analysis of the survey participants revealed the quantity surveyors (25%), researchers (13.2%), architects (12,7%), project managers (12.3%), and civil engineers (10.9%) as the most represented professional groups among the survey participants. Furthermore, 56.8 percent of the survey participants suggested the planning stage at the best stage to implement BIM and sustainable practices in a project. Also, 37.3 percent of the respondents argued for the design stage, while 5.5 percent of the respondents considered the construction stage as the best time.

Analysis and discussion of survey results

This section presents the data collected via the empirical questionnaire surveys and discusses the findings of the statistical tools utilized in the study.

Descriptive statistical tests

The mean values for the 36 identified benefits range from M= 4.30 (SD= 0.784) for "*BN8 - facilitate sharing, exchange, and management of project information and data*" to M=3.51 (SD= 1.027) "*BN11 - ease the process to obtain building plan approvals and construction permits*" at a variance of 0.79 (see Table 2). More so, the study adopted the benchmark score of 4 out of 5 on a 5-point Likert scale (Lu et al., 2008; Olatunji et al., 2017a; Olawumi et al., 2018) to identified some factors have highly significant factors. Using this metric, the analysis revealed the top-five key benefits of implementing BIM and sustainability practices in construction projects. These include: "*BN8 - facilitate sharing, exchange, and management of project information and data*" (M= 4.30, SD= 0.784), "*BN1 - enhance overall project quality, productivity, and efficiency*" (M= 4.29, SD= 0.700), "*BN17 - real-time sustainable design and analysis early in the design phase*" (M= 4.20, SD= 0.733), *"BN15 - better design products and facilitate multi-design alternatives*", (M= 4.18, SD= 0.796) and "*BN22 - prevent and reduce materials wastage through reuse & recycling and ensure materials efficiency*" (M= 4.18, SD= 0.828". The study's findings and based on the perceptive of the survey participants, it is revealed that the implementation of these two concepts will have a vital effect on not only the final product (buildings and infrastructure) by massively improving it both in design and its efficiency; it can also enhance the process whereby construction products are delivered in the built environment. As advocated by Ayegun et al. (2018), project quality and effective communication is a vital ingredient to measure project success. More so, adopting BIM and sustainability in a project will reduce construction material wastages as well as facilitate the simulation analysis of design alternatives and building performance.

Also, there is an agreement by the respondents from various organization setups on some of the key factors such as "BN1 - enhance overall project quality, productivity, and efficiency" which is ranked among the top-five factors by most of the respondents' groups except the private clients which rated the factor as the eighth-ranked benefits. The findings is highly expressive and is consistent with the literature (Gu & London, 2010; Olatunji et al., 2017b; Olawumi et al., 2017) which argued that the innovative concepts such as BIM and sustainability has the capacity to improve the stakeholders' productivity and enhances the chances of achieving the project's goals. Also, among the professionals such as the architects, project managers, quantity surveyors, and civil engineers; there is a consensus on the five key benefits.

Moreover, on factor "BN17 - real-time sustainable design and analysis early in the design phase", the majority of the respondents' groups agreed on the factor as a significant benefit derivable when BIM and sustainability practices are implemented in construction projects. However, the project consultants averagely ranked the factor. The differing viewpoint from the project consultants group is consistent with the fact that it might be difficult to conduct a proper sustainable design analysis in the early phase of project design due to: (i) incomplete design and specifications at the early stages of building designs; and (ii) issues with and lack of collaboration and coordination among the project consultants (i.e. architects, structural engineers, building services engineers, etc.) involved in project designs. Also, the findings revealed that implementing these concepts (BIM and sustainability) as little effects on the process of securing building plan approvals and construction permits as well as the reduction of project risks or litigations. Adopting these concepts currently has little effects as captioned above because except in cities like Hong Kong, most governments are yet to enforce and incorporate as an incentive, the implementation of BIM and sustainability practices by clients in their construction projects.

Inferential statistical tests

Parametric statistical tools such as ANOVA was employed to investigate the differences in the perception of the various respondents' groups such as the organization setups (project consultants, public clients, main contractors, etc.) and the professional disciplines (civil engineers, architects, quantity surveyors, etc.). ANOVA is a parametric statistical measure of variance based on the mean of scores (Olatunji et al., 2017a; Tsai et al., 2014), and for factors that are significant ($p<0.05$) a further test, which is a post-hoc Tukey test was conducted (Mom et al., 2014; Olatunji et al., 2017a).

Statistical tests based on organizational setups

The ANOVA carried out on the survey data revealed some significant divergencies (at significance <5%) in the perceptions of the different groups of the respondents' organization setups on twelve factors. These include "BN1- enhance overall project quality, productivity, and efficiency" [$F(5,214) = 2.538$, $p = 0.030$]; "BN3- predictive analysis of performance (energy analysis, code analysis)" [$F(5,214) = 3.945$, $p = 0.002$]; "BN4- improve the operations and maintenance (facility management) of project infrastructure" [$F(5,214) = 2.312$, $p = 0.045$]; "BN7- Reduction in the cost of as-built drawings" [$F(5,214) = 2.373$, $p = 0.040$]; "BN13- reduced claims or litigation risks" [$F(5,214) = 2.386$, $p = 0.039$] among others (see Table 3). Furthermore, a post-hoc Tukey test was conducted on the twelve significant benefits, of which nine factors were found to be more important (p<0.05). These include "BN1- enhance overall project quality, productivity, and efficiency" with a moderate significance (p=0.014) of which the respondents from the academics (M= 4.48, SD= 0.626) perceived the factor to be of higher importance than their public client counterparts (M= 4.09, SD= 0.752). The high rating given to the factor by the academics could be likely be based on their previous reviews or experience of the impact of these concepts in the construction industry. Also, academics' perception could be based on happenings in other regions beyond their local context as argued by Olawumi and Chan (2018a), unlike their public-sector counterparts whose perception might be based solely on the impact of these concepts in their locality.

Moreover, for "BN3- predictive analysis of performance (energy analysis, code analysis)", there is a high significance (p= 0.003) between the public-sector clients (M= 3.93, SD= 0.716) and the academics (M= 4.39, SD= 0.653) with the academics rating the factor to be of higher importance the respondents from the public-sector clients. Likewise, at a moderate significance of p= 0.024, the survey participants from the academics perceived the factor to be of higher merit than the project consultants (M= 3.88, SD= 0.881). Evidently, these viewpoints of the respondents' groups emphasize the role of BIM software to aid the implementation and provide further support to the previous submissions in the literature (Jalaei & Jrade, 2015; Kivits & Furneaux, 2013; Olawumi & Chan, 2018a) that the implementation of BIM and sustainability practices in construction projects will facilitate smart and sustainable urbanization. The interlink between the academics and the industry is getting stronger (Olawumi et al., 2017), and since most research institutes constitute mostly the testbeds for most industrial innovation; it is believed that might have affected the higher rating by the academics for this factor (BN3). See Table 3 for the other results of the post-hoc Tukey test analysis.

Statistical tests based on professional disciplines

The ANOVA statistical analysis conducted on the data collected from the respondents' groups based on their professional disciplines yield some significant differences (at significance < 5%) in nine-factor such as "BN6- improve financial and investment opportunities" [$F(10,209) = 2.519$, $p = 0.022$]; "BN11- ease the process to obtain building plan approvals and construction permits" [$F(10,209) = 3.131$, $p = 0.001$]; "BN12- support collaboration and ease procurement relationships" [$F(10,209) = 2.068$, $p = 0.028$]; "BN25- facilitate the implementation of green building principles and practices" [$F(10,209) = 2.011$, $p = 0.034$]; "BN27- minimize carbon risk and improve energy efficiency" [$F(10,209) = 2.150$, $p = 0.022$]. A further analysis using post-hoc Tukey test reveals very high divergencies among the professional groups in three factors only. These include "BN11- ease the process to obtain building plan approvals and construction permits" which shows a very high significant difference (p= 0.000) in the perception of the construction managers (M= 3.18, SD= 0.951) and the academics (M= 4.00, SD= 0.707). Also, between the quantity surveyors (M= 3.71, SD= 0.875) and the construction managers at a very high significance (p= 0.005) for the same factor. The construction managers in both cases ranked the factor below average with their academics' counterpart ranking it the highest. Although, some countries such as the United Kingdom and Hong Kong has put into place incentives for BIM-compliance firms, however, it is yet to be replicated in the other 21 countries represented in the survey data. When such initiative is introduced in other regions, the factor can be a significant one for the construction industry as projected by the respondents from the academics.

Meanwhile, for "BN12- support collaboration and ease procurement relationships" there is a moderate significance (p= 0.035) as the architects (M= 4.11, SD= 0.832) identified the factor to be more important than the construction managers (M= 3.21, SD= 1.182). Although both sets of respondents are significant in the procurement process, the architects utilize the BIM software for building model designs and communicate their designs to other key stakeholders who utilize the designs to simulate various building performance. Hence, architects are more involved in the collaborative activities (especially, at the planning and design stages where these concepts are usually integrated into construction projects), and their perceptions about this factor as one of the benefits of BIM and sustainability practices in the built environment is crucial. Lastly, for "BN28- improve resource management and reduce environmental impact across the value chain" there is a highly significant difference (p= 0.002) between the project managers (M= 4.19, SD= 0.622) and the building services engineers (M= 3.18, SD= 1.015) with the project managers identifying the factor has a more significant benefit of the implementation of BIM and sustainability practices. Also, there is a highly significant divergence (p= 0.005) between the quantity surveyors (M= 4.04, SD=

0.793) and the building services engineers. However, since the project managers and the quantity surveyors are more involved in the management and control of project resources than the building services engineers, their perceptions on this factor will be of more importance to the study.

[Insert Table 2]

[Insert Table 3]

Factor Analysis

Factor analysis was employed to investigate the pattern of interrelationships among a large set of variables and identifying a smaller number of factors to represent the relationships. The principal component analysis (PCA) of the factor method was used in this study; the other type is the Promax rotation method (Chan & Hung, 2015). The basic concept of factor analysis (FA) is to use the underlying factors to explain the complex and obscure phenomenon (Xu et al., 2010), interpretation of 'nonrelated clusters' (Fang et al., 2004), and define the relationship of interrelated variables (Chan & Choi, 2015). Also, according to Chan and Hung (2015), factors can be rotated in two forms- oblique and orthogonal; for this study, the varimax rotation method, a subset of the orthogonal rotation method was adopted for the PCA.

Moreover, for a set of data to be sufficient for factor analysis, it is recommended for the number of variables in relation to the sample size to be in the ratio of 1:5 (Chan & Choi, 2015; Lingard & Rowlinson, 2006). The current study fulfills this requirement, that is, with 36 variables the sample size must not be less than 180, however, this study has 220 responses which is more than the minimum sample size. The Kaiser-Meyer-Olkin (KMO) tests which evaluate the sampling adequacy shows a KMO value of 0.952 which implies an 'excellent' degree of common variance (Field, 2009), and which is above the minimum threshold of 0.50 (Norusis, 1993). A KMO value close to 1 indicates a compact structure of the correlations and indicates that the clusters generated during the factor analysis are distinct and reliable (Chan & Choi, 2015).

Meanwhile, the study utilized Bartlett's test of sphericity (BTS) to examine the suitability of the PCA for factor extraction (Field, 2009), the BTS statistic tests reveal a substantial BTS value (chi-square=5750.610) with a minimal significance value (p=0.000, df=630) which indicates the correlation matrix is not an identity matrix (Chan & Choi, 2015). Given the above, the research data has met the various pre-conditions required before PCA can be applied to the data for further analysis and discussion. Hence, factor analysis can be carried out with confidence and reliability. The PCA extraction yielded five factors which constitute

64.663% of the total variance explained (see Table 4) which is higher than the minimum threshold of 60% (Chan & Choi, 2015; Hair et al., 2010; Malhotra, 1996). Meanwhile, per Proverbs et al. (1997), factors within a cluster with factor loading close to 1.0 have higher significance in the underlying cluster. The 36 factors represented within one of the five cluster factors have a factor loading which is close to 0.50 or higher. Also, according to Chan and Hung (2015), the value of each variable's factor loading is a reflection of the contribution of the variable to its underlying grouped factor.

[Insert Table 4]

Discussions of the clustered benefit factors

The underlying grouped factors are evaluated in Table 5 in descending order of significance based on their factor scale rating (Chong & Zin, 2012; Chan & Hung, 2015) which is based on the variables within each cluster. The factor scale rating is the ratio of the sum of the mean scores of individual variables in a cluster to the number of variables in the underlying grouped factor. More so, per Sato (2005), it is necessary to designate an attributable and collective tag to each cluster factor to ease its description, and according to Chan and Hung (2015), the tags are subjective and is based mostly on the researcher's intuitions. The study will expatiate on the top-three of the factor clusters to conserve space.

[Insert Table 5]

Efficiency and process-related benefits

Factor 2 comprises nine benefit-related factors and has the highest factor scale rating (M= 4.1467) of the five clusters. The cluster details how implementing BIM and sustainability practices can reduce site conflicts, enhance the management of project information, improve efficiency and productivity in a project, support the decision-making process, and ensure timely delivery of construction projects among others. Abanda et al. (2015) and Hanna et al. (2013) acknowledged that the introduction of BIM software in the construction market had affected the efficiency and quality assurance in a construction project. Olawumi et al. (2017) noted that there are BIM software that can be used for the simulation of sustainability-related issues in a building design such as EnergyPlus, Ecotect, Green Building Studio which can be used for building energy analysis and carbon-emission analysis.

Aibinu and Venkatesh (2014) reported that the benefits of the concepts to support and improve the decision-making process would be realistic when key stakeholders collaborate effectively to define the information from BIM software needed to ease the project tasks as well as perform sustainability analysis (Adamus, 2013). Moreover, Boktor et al. (2014) opined that there must be a cost-benefit analysis of the gains of its implementation as well as an assessment of the capacity of the construction workers to grasp the BIM and sustainability processes to ensure a realistic evaluation of the impact of these concepts in a project. Also, Olawumi and Chan (2018d) and Boktor et al. (2014) recommended the development of BIM and sustainability standards in countries which are yet to set up such to be able to have a guideline to measure the impact of the concepts on the built environment.

Performance and knowledge-related benefits

Factor 3 with a factor rating scale of M=4.066 is another significant underlying factor cluster with five key factors with a factor loading of more than 0.5. The cluster is concerned with the impact of BIM and sustainability practices in construction projects and its capacity to improve the competitiveness of a construction firm and its brand image. Also, it is related to its effect on business performance, facilitating better design products, boosting innovation capacities, and aid building layout flexibility and retrofitting. Antón and Díaz (2014) reiterated the benefit of these concepts to include the delivery of better design products which not only improves the well-being and life quality of the users but also improve the energy performance of such facilities. Aibinu and Venkatesh (2014) recognized its impact to enhance the skill sets and technical expertise of key stakeholders in a world in which technological advancement is the order of the day.

Moreover, the ability of BIM software to facilitate design and the visualization of what is to be built in a simulated environment allows the detection of any design flaws or operational issues as well as ease the production of multi-design alternatives (Azhar, 2011). Azhar (2011) also reported the economic benefits of implementing BIM in projects with an average performance of 634% on return on investment (ROI) which reveals a high potential for its implementation. Although, there are risks and challenges to the adoption of BIM and sustainability practices in the construction industry (Olawumi et al., 2018), however, its future looks exciting (Azhar, 2011). More so, to achieve the preceding, Antón and Díaz (2014) advocated for the adoption of the concepts at the early stage of a project, improved interoperability among BIM software, and increased research and development in the construction industry.

Sustainable building and technical-related benefits

Factor 1 with a factor rating scale of M= 4.0373, comprises fifteen key factors and eight of these factors has a factor loading of at least 0.70 and are considered significant within the cluster. The cluster is related to the ability of BIM to simulate building performances and energy usage, the ease of selecting sustainable materials and component for a construction project, simplify the implementation of green building principles and the implementation of clean technologies with the minimal use of energy. Also, it includes its capacity to aid the smooth integration of sustainability strategies with business planning, reduce the environmental impact of the project and improving resource management among others. Jalaei and Jrade (2014) attested to the growing concern about the energy performance of buildings and how designers and other consultants have been utilizing BIM tools to make energy-related decisions as well as the selection of the right type of materials and components. Accordingly, they noted that these decisions have a significant impact on the life cycle of a building (Antón & Díaz, 2014). Wu and Issa (2014) and Olawumi et al. (2017) stressed that despite the emerging success of green BIM in the construction, its full potential is yet to be tapped. Hence, they advocated for the formulation of an effectively BIM execution plan for use in green building projects.

Moreover, Akinade et al. (2015) affirmed that one of the essential functions of BIM that has added its acceptability in the built environment is the ability to simulate building energy performance, perform lighting analysis, and the evaluation of design models before actual construction on project site. Also, this allows the project team to identify any potential flaws in design and to select the most cost-effective and sustainable solution among a variety of design alternatives. Antón and Díaz (2014) pointed out that the integration of BIM and sustainability practices to generate synergies would enhance its robustness to tackle the environmental impact of buildings and the simplify the deployment of clean technologies in buildings. Also, Jalaei and Jrade (2014) found that green or sustainable buildings cost far less to operate and are attractive from a commercial perspective. Hence, Wu and Issa (2014) encouraged key stakeholders to show strong interests in green BIM implementation to facilitate more sustainable projects. Also, it is necessary to enhance the capacities and functionality of existing green BIM software to comply with existing standards and rating systems (Olawumi & Chan, 2018c; Wu & Issa, 2014).

Conclusions

The primary aim of this study was to review the impact of the implementation of BIM and sustainability practices in the built environment and to assess the potential benefits of its adoption in construction projects, and to construction firms. A review of reported literature formed the bedrock for gathering the thirty-six benefits which formed the questionnaire items sent to the survey participants. A total of 220 respondents from 21 countries participated in the empirical questionnaire survey which constitutes professionals of varied backgrounds and from different organization setups. The diversity of the survey participants was utilized as a basis to compare the ranking patterns and to detect any significant differences in their perceptions of the key factors.

Generally, most of the respondents' groups agreed on "BN1- enhance overall project quality, productivity, and efficiency" as a key benefit of BIM and sustainability practices implementation in construction projects, as the factor most as one of the top-five significant benefit in the groups' rankings. Also, the factor is consistent with similar assertions in the literature which expressed the capacity of the concepts to enhance the project's objectives, one of which includes meeting quality and productivity targets. More so, there is also a significant consensus among the groups on factor "BN17- real-time sustainable design and analysis early in the design phase" as one of the crucial impacts of the implementation of BIM and sustainability in projects. Meanwhile, adopting these concepts have little impacts on the ability of a construction firm or project team to secure building plans approval or construction permits. Moreover, the capacity of the concepts to support and enhance the collaborative working environment in the construction industry was highlighted as well as its ability to ease procurement relationship.

A factor analysis of the thirty-six benefit factors using PCA method resulted in five underlying clusters with a minimum of three factors and a maximum of fifteen factors; with each underlying grouped factor given an attributable and collective tag which is a representation of its sub-set factors. Moreover, the study conducted further analysis of the ranking patterns of the various respondents' groups which yielded impressive results of which effective blueprints and recommendation were suggested to increase the uptake of BIM and sustainability practices towards ensuring the construction industry maximizes these benefits. Some of the recommendations highlighted in the study include: (1) Local authorities and government departments should liaise with relevant professional bodies in the built environment towards setting up 'green-BIM compliance' incentives to motivate construction firms and clients to implement the concepts in their projects; and (2) Key stakeholders in the construction industry must streamline and improve the structure of their collaboration as well as the need to incorporate (as much as possible) every stakeholder in decision-making at the early stages of project development.

More so, for countries, who are yet to develop BIM and sustainability assessment standards; (3) The establishment of such standards is advocated, as this will provide both qualitative and quantitative guidelines to assess the impact of green BIM on the built environment. Also, (4) Enhancing the interoperability and functionality of green BIM software is imperative to the successful implementation of the concepts; (5) Early adoption of green BIM initiative at the planning stage of project development. (6) Increased and targeted research on green BIM; (7) Development of a green BIM execution plan for use in construction projects and to aid project teams. (8) The need for key stakeholders and construction firms to express a keen interest in green BIM adoption in their projects and training of their staff is essential to reap full benefits of the implementation of BIM and sustainability practices in the built environment.

It is evident from these significant research findings and collective perspectives that the implementation of BIM and sustainability practices have played an important role and has exerted profound impacts on construction projects and the built environment. It is recommended that future research studies can explore and conduct a quantitative cost-benefit analysis of the gains of green BIM implementation in the construction industry which is expected to provide a sound basis for project comparison and benchmarking. A concerted effort by the various construction stakeholders, local authorities, and policymakers will ensure that these concomitant benefits highlighted in the study are harvested and realized in the built environment.

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