# Identifying and Prioritizing the Benefits of Integrating BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts

## Abstract

The recent initiatives of the construction industry to embed sustainable strategies in its processes can be enhanced when clear and practical benefits of such integration are available to project stakeholders to support their decision-making. Hence, this study purports to evaluate the perceived benefits of integrating BIM initiatives and sustainability practices in construction projects. Delphi survey technique was used to solicit the perceptions of expert panel on the 36 identified benefits. Statistical tools were employed to analyze the derived data, and the consensus reached by the expert panel was validated using the interrater agreement statistics. The three most important benefits included the ability to enhance overall project quality and efficiency and improve the ability to simulate building performances and energy usage and facilitate better design products and multi-design alternatives. Comparative analyses among the expert groups lend credence to the strong consensus reached by the expert panel. Meanwhile, the study recommended strategies to enable the construction industry to key-in to these benefits as well as identifying prevalent research gaps in practice. The study's findings will enhance the drive for the realization of the sustainable smart city as well as equip various stakeholders of the possibilities in its full adoption and implementation.

**Keywords:** BIM, sustainability practices, Benefits, Delphi survey technique, construction industry

## 1.0 Introduction

The input of technological innovations and salience to sustainability issues in the construction industry has been argued as the best approach for the built environment to achieve its goal of a sustainable smart city and buildings. Aasa et al. (2016) noted that sustainable development is achievable through the implementation of green innovations which involve implementing sustainable solutions using adaptable technologies. An excellent example of a versatile technology is the Building Information Modelling (BIM) system which is described by Olatunji et al. (2017b) as a set of applications and process capable of generating and managing project information throughout the project development phases with numerous benefits to the project stakeholders.

Malleson (2012) noted that BIM adoption had improved significantly in the United Kingdom (UK) as well in North America (Bernstein et al., 2012); and a sizeable number of contracting and client's organizations have switched to 3D CAD from 2D CAD. Leveraging on this significant improvement in BIM adoption and implementation in the industry, project stakeholders can enhance the adoption of sustainability practices by developing new tools and plugins where existing ones might be limited in its functionality. Abanda and Byers (2016), and Bynum et al. (2013) reported that building facilities account for 32 percent of global energy consumption and one-fifth of the associated greenhouse gases (GHS). Hence, Gourlis and Kovacic (2017) reported that emerging technologies such as BIM offers promises in the optimization of energy needs as well as identification of the potentials in synergizing building envelope and services to reduce the carbon footprints of buildings. A practical example is a real-life case study building project in which BIM was used to model the energy performance (one of several sustainability parameters) which yielded a significant energy cost savings across the building lifecycle.

Also, Tsai et al. (2014b) test-run a customized BIM tool for a design firm. Also, Oti et al. (2016) demonstrated the use of Application Programming Interface (API) in BIM tools to appraise the ability of BIM to embed sustainability ontologies as a new approach to assess some 'quantitative' parameters of sustainability. BIM without doubt promising and innovative tool capable of changing the landscapes of construction processes and activities even though, according to Oti et al. (2016), and NIBS (2007), BIM is still a maturing technology. Oti et al. (2016) noted that the existence of some proprietary functions in BIM and the flexibility to add plugins had extended its capacity to address issues such as sustainability as well as for end-user customization. More so, Tah and Abanda (2011) also explored the use of semantic web technology and ontologies to represent sustainability knowledge, although, semantic web technologies are still new, it offers a good prospect to assess sustainability parameters and ease the decision-making process.

Moreover, current application of BIM to sustainability practices include (i) lifecycle cost assessment (LCA) (Lundin & Morrison, 2002; Soust-Verdaguer et al., 2017); (ii) sustainable design (Bynum et al., 2013). (iii) Sustainable material selection (Govindan et al., 2015); (iv) waste management (Akinade et al., 2015); (v) daylighting simulation and analysis (Kota et al., 2014); (vi) energy consumption and performance (Abanda & Byers, 2016; Kuo et al., 2016); and (vii) carbon footprint (Shadram et al., 2016). Habibi (2017) examined the potential of BIM to improve the energy efficiency and indoor environmental quality of building facilities.

Given the above, the direction of the current study is to identify and assess the benefits of integrating BIM and sustainability practices in construction projects. Throughout the literature and in practice, we have seen construction projects which either adopt BIM or sustainability practices with varying project success and results. However, this study addresses the benefits achievable in projects in which the clients or the project team intends to use innovative technology such as BIM to amplify the sustainability practices in construction projects. The study will identify the benefits from both case study projects and literature.

More so, the integration of BIM and sustainability practices implies the use of BIM technologies such as BIM software, cloud-BIM, plugins such as those developed by Oti et al. (2016) and the use of semantic web technology (Tah & Abanda, 2011) among others for sustainability assessment and simulation in projects. It is advisable according to Ghaffarianhoseini et al. (2017) to leverage on technology tools such as BIM to reinvent the current design and delivery practices in the industry. Hence, it is conceivable that integrating the two concepts in construction projects will assist the project team to exploit the benefits of adopting innovative technologies as well as achieve objectives such as green buildings and neighborhoods, reduced carbon footprints, etc.

The structure of the study is organized as follows. Section 1.1 clarifies the knowledge gap, objectives and provide the value the current study intends to offer to both the body of knowledge and practice. Section 2.0 illustrates from the literature the practical benefits of BIM and sustainability practices implementation in construction projects. Section 3.0 discusses the research methods, and hypotheses postulated. Section 4 discusses the study's findings, section 5 provides recommended strategies for the industry to 'key-in' to these benefits; and section 6 concluding the study and provide guides for future directions.

### *1.1 Knowledge gap, objectives and value*

Studies by De Boeck et al. (2015), and Chandel et al. (2016) highlighted significant research gap in research and practice on the utilization of innovative tools like BIM in sustainability practices. Accordingly, they noted that much emphasis is being placed on the analysis and optimization of energy performance on residential buildings (Chandel et al., 2016; De Boeck et al., 2015) and less on other building typologies such as commercial and industrial buildings (Ruparathna et al., 2016). Also, Abanda and Byers (2016) examined the practical use of BIM in the simulation of energy performance. Moreover, it is necessary to point out that 'energy performance' of buildings is a subset of the environmental aspect of sustainable development and green buildings; and according to Ahmad and Thaheem (2017) to achieve sustainable smart cities initiative and green buildings, there must be a balanced play between the economic, social and environmental pillars of sustainability. Moreover, recent studies (*see* Hosseini et al., 2016; Mao et al., 2016) revealed that inadequate knowledge of the benefits of these concepts had hindered its implementation in the construction industry.

Therefore, the primary research question, this study intends to answer is- What are the practical benefits of utilizing BIM to amplify sustainability practices in construction projects? In answering this question, the study will examine the impact of BIM to advance the implementation of the three pillars of sustainability in construction projects and not just the 'energy performance' aspect. The findings are expected to apply to any buildings projects whether residential, commercial or industrial buildings; and with a focus to facilitate the support and commitment of clients and key project stakeholders by presenting the key benefits achievable via the use of BIM to enhance sustainable parameters of their projects.

Meanwhile, studies such as Mom et al. (2014), and Tsai et al. (2014) have examined some benefits and drivers of BIM adoption in Taiwan. However, these studies focused solely on BIM. Previous studies (*see* Abdirad, 2016; Ahmad & Thaheem, 2017; Antón & Díaz, 2014; Azhar, 2011) which employed BIM for sustainable construction practices have been limited by their scope. Some of the authors either focused on a subcategory item of sustainability such as energy or LCA, other studies were defined by being confined to a country or building typology. Although some of the benefits identified by previous authors might apply to a single application of either BIM or sustainability practices in construction projects; the study aims to fill the gap by identifying the key benefits that are obtainable when both concepts are adopted in a project as well as categorize them based on the measures of assessment- either qualitative/quantitative or both. Also, the current study will attempt to rank these factors based on two parameters- their level of significance and the agreement level of the expert panel on each benefit.

The expert panel for this study will be constituted of professionals from the academics and the industry practitioners. More so, since these experts might have differing opinions or perceptions on the ranked benefits due to their level of experience, exposure, region, and professional backgrounds; Zahoor et al. (2017) argued for the need for a consensus among the experts as well as the validation of their agreement level. Hence, the study will test the null hypothesis ($H_0$) which states that “there is no significant correlation between the expert groups on the rankings of the benefits." Also, a cross-region (west and east regions) comparison of the significant benefits will be undertaken to examine how the differing maturity of BIM and implementation of sustainability practices influenced the opinions of experts from such countries. Moreover, the ranking of the factors is expected to assist the client and project team to strategize and streamline their efforts to achieve the key benefits identified since it would be difficult to achieve the thirty-six benefits in just one construction project.

In summary, the study aims to achieve the following objectives (i) identify the benefits of incorporating BIM initiatives and sustainability practices in construction. (2) To prioritize the beneficial factors based on their significance and expert’s agreement levels; and (3) to analyze the level of agreement among the experts’ groups on the benefits of BIM and sustainable practices implementation. The findings of this study will contribute to the existing body of knowledge on BIM and sustainability by presenting academics and industry experts alike with comprehensive benefits achievable via the implementation of sustainable construction practices. The correlations between the maturity level of BIM and sustainability practices between the experts’ groups and the perspective of the experts on each factor will be established which will provide a clear indication on the influence of the maturity levels on the perception of the experts. The results are expected to assist the project team in encouraging construction clients to allow the integration of BIM innovation and sustainable strategies in their projects to enhance the optimal goal of sustainable smart city initiatives.

## 2.0 Benefits of BIM and Sustainability Practices Implementation in Construction Projects

Previous studies have demonstrated the endless benefits (*see* Table 1) obtainable when either BIM or sustainable practices are implemented in construction projects. There has also been an increase in cross-field research in BIM and sustainability in recent years (Olawumi et al., 2017; Olawumi & Chan, 2017). Adamus (2013) reviewed some BIM-based sustainability analysis tools and highlighted the benefits that can be gained when full interoperability is achievable between BIM design and analysis tools. Accordingly, the author argued for the development of the current data formats such as gbXML and IFC towards facilitating sustainable development. However, the previous study only highlighted few benefits which are solely related to BIM adoption.

Some benefits of adopting BIM in construction projects were also identified by Mom et al. (2014) and Azhar (2011). One of the key benefits identified by the literature is the use of BIM to identify potential issues relating to the building design, construction, and operation. Also, Olawumi et al. (2017) reported that BIM could be used to advance sustainability practices in construction projects such as the management and profiling of energy usage in buildings. Akadiri et al. (2013) regard BIM as a veritable tool for the selection of sustainable materials for construction projects. The use of BIM software and associated simulation tools to enhance the sustainability parameters of buildings such as to reduce its carbon footprints, improve building energy performances and green neighborhoods is noteworthy. Akinade et al. (2015) developed a BIM-based algorithm to measure the practicability of measuring the deconstructability of building designs to minimize waste and facilitate efficient materials use. GhaffarianHoseini et al. (2017) revealed that BIM has helped project stakeholders to achieve the Australian Green Star rating and improve the design strategy.

Also, Khaddaj and Srour (2016) observed that BIM could be utilized to simulate building maintenance and retrofitting; hence when linked with sustainable measures using associated plugins or APIs, it could help advance the implementation of sustainability practices to the facility management stage. Moreover, the aim of implementing these sustainable measures in a construction project is to achieve sustainable development as well as the construction of green buildings which can mitigate against negative of constructed structures on the environment as well as on human lives (Maleki & Zain, 2011). Other positive effects of achieving green buildings or sustainable smart cities are the added benefits on human health, occupant productivity, organizational marketability (Ali & Al Nsairat, 2009) and green neighborhoods. These previous studies have focused mostly on the environmental aspect of sustainable development. Also, according to Ahmad and Thaheem (2017) majority of BIM software available to simulate sustainability parameters focused on the environmental aspect; hence, it is difficult to assess the benefits of using BIM technologies for the three pillars of sustainability.

Practical examples of the benefits of BIM implementation in construction projects was illustrated by Abanda et al. (2017) who identified several parameters such as cost, time, quality, productivity, and process, etc. as areas in which the adoption of BIM can profit the construction project. The study also listed some BIM software that is available in the market. Gourlis and Kovacic (2017) enumerated that utilizing BIM to simulate and model the energy needs of industrial buildings can minimize the high energy consumption of such building typologies. Also, the ability of BIM tools to embed other knowledge databases can be advantageous in evaluating some qualitative measures such as some social sustainability parameters. The development of data schemas such as the industry foundation class (IFC) and gbXML allows for data transfer from BIM design tools to simulation tools (Olawumi et al., 2017), although the challenge of interoperability is still prevalent in the industry (Jeong et al., 2016).

Huang et al. (2012) underlined the potential of BIM for the management of industrial parks in Taiwan throughout its lifecycle. In the management of these parks, BIM was augmented with other associated tools for GIS, visualization, navigation solutions; which allows real-time monitoring, feedback, and communication. Wang et al. (2013) also utilized BIM to optimize the workflow processes. There are endless possibilities in integrating to different domain areas such safety, scheduling, cost management, procurement, project management as well as sustainability. According to Gourlis and Kovacic (2017), the potential of BIM in sustainability in areas such as building performance is an increasingly exciting research area in the literature. However, the study is advocating a more adept application of BIM to more aspects of sustainability to garner maximum benefits.

Meanwhile, some difficulties are still being faced in the industry to advance BIM application in sustainability practices such as interoperability (Kovacic et al., 2013), procedural uncertainties (Gourlis & Kovacic, 2017; Morgan et al., 1992). However, the construction industry will stand to gain more possibilities by deploying BIM infrastructures to amplify sustainability practices in their projects as highlighted in the literature discussed in this section.

***Table 1: Benefits of integrating BIM and sustainability practices***

| Code | Factors | References |
|---|---|---|
| A1 | Enhance overall project quality, productivity, and efficiency | Azhar (2011) |
| A2 | Schedule compliance in the delivery of construction projects | Azhar (2011); Philipp (2013) |
| A3 | Predictive analysis of performance (energy analysis, code analysis) | Lee et al. (2015) |
| A4 | Improve the operations and maintenance (facility management) of project infrastructure | Azhar (2011) |
| A5 | Reduction in cost of construction works and improvement in project's cost performance | Bynum et al. (2013) |
| A6 | Improve financial and investment opportunities | Ku and Taiebat (2011); Lee et al. (2012) |
| A7 | Reduction in the cost of as-built drawings | Boktor et al. (2014) |
| A8 | Facilitate sharing, exchange, and management of project information and data | Olatunji et al. (2017b); Wong et al. (2014) |
| A9 | Facilitates resource planning and allocation | Akintoye et al. (2012) |
| A10 | Reduction in site-based conflicts | Hanna et al. (2013) |
| A11 | Ease the process to obtain building plan approvals and construction permits | Antón and Díaz (2014) |
| A12 | Support collaboration and ease procurement relationships | Aibinu and Venkatesh (2014) |
| A13 | Reduced claims or litigation risks | Bolgani (2013) |
| A14 | Increase firms' capability to comply with prevailing statutory regulations | Aibinu and Venkatesh (2014); Antón |

| | | |
|---|---|---|
| | | and Díaz (2014) |
| A15 | Better design products and facilitate multi-design alternatives | Lee et al. (2012) |
| A16 | Facilitate building layout flexibility and retrofitting | Webster and Costello (2005) |
| A17 | Real-time sustainable design and analysis early in the design phase | Alsayyar and Jrade (2015) |
| A18 | Facilitate, support and improve project-related decision-making | Sacks et al. (2010) |
| A19 | Improved organization brand image and competitive advantage | Antón and Díaz (2014) |
| A20 | Enhance business performance and technical competence of professional practice | Deutsch (2011) |
| A21 | Enhance innovation capabilities and encourage the use of new construction methods | Deutsch (2011) |
| A22 | Prevent and reduce materials wastage through reuse & recycling and ensure materials efficiency | Akinade et al. (2017) |
| A23 | Reduce safety risks and enhance project safety & health performance | Vacharapoom and Sdhabhon (2010) |
| A24 | Control of lifecycle costs and environmental data | Ku and Taiebat (2011) |
| A25 | Facilitate the implementation of green building principles and practices | Wu and Issa (2015) |
| A26 | Ease the integration of sustainability strategies with business planning | Autodesk (2010) |
| A27 | Minimize carbon risk and improve energy efficiency | Wu and Issa (2015) |
| A28 | Improve resource management and reduce environmental impact across the value chain | Ajayi et al. (2016) |
| A29 | Facilitate the selection of sustainable materials, components, and systems for projects | Jalaei and Jrade (2014) |
| A30 | Higher capacity for accommodating the three pillars of sustainability (social, economic & environmental sustainability) | Antón and Díaz (2014) |
| A31 | Enhance the accuracy of as-built drawings | Akintoye et al. (2012) |
| A32 | Facilitate integration with domain knowledge areas such as project management, safety, and sustainability | Kam et al. (2012) |
| A33 | Allow the checking of architectural design of buildings from the sustainability point of view | Abolghasemzadeh (2013) |
| A34 | Facilitate accurate geometrical representations of a building in an integrated data environment | Azhar (2011) |
| A35 | Ability to simulate building performances and energy usage | Aksamija (2012) |
| A36 | Encourage the implementation of clean technologies that require less energy consumption | Bonini and Görner (2011) |

## 3.0 Research Methodology

A Delphi survey technique forms the primary research approach to achieve the aim of the study of identifying and prioritizing the benefits of the integration of BIM initiatives and sustainability practices at the design stage of construction projects. Chan and Chan (2012), and Hallowell and Gambatese (2010) defined the Delphi survey technique as a “systematic and interactive research technique to obtain the judgment of a group of experts on a specific topic.” It is a useful approach for reaching consensus in cross-field research topic (Hasson et al., 2000) or for new and complex concepts (Yeung et al., 2007).

Olatunji et al. (2017) noted that the data collection technique adopted is significant in establishing the objectives of such study. Hence, a quantitative research technique using empirical questionnaire surveys was adopted. Previous Delphi surveys in other research studies such as construction accidents (Zahoor et al., 2017) and construction partnering (Chan et al., 2015; Yeung et al., 2009) also used questionnaire surveys to collect responses from the respondents. The study participants were invited on a two-round Delphi survey to rank 36 beneficial factors of integrating BIM and sustainability studies. Responses from the experts were then analyzed using various statistical tools such as Cronbach's alpha reliability test, mean score ranking, Shapiro-Wilk test of normality, Kendall's concordance test and Chi-square test, inter-rater agreement (IRA) statistics, Spearman's rank correlation test and Mann-Whitney analysis.

### *3.1 Format of the two-round Delphi technique*

An in-depth review of the extant literature was carried out to identify the beneficial factors of integrating BIM initiatives and sustainability practices at the design stage of construction projects. After the review of the literature, 51 factors were initially deduced and were consolidated to 41 factors after a rigorous review and pretesting of the factors. More so, a pilot survey was conducted involving four participants (academics and industry experts) to review and validate the factors which helped to further consolidate the factors to 36 factors which were then included in the study's Delphi questionnaire survey. The questionnaire survey also collected some personal information about the respondents and asked the experts to rate their levels of agreement on the factors on a 5-point Likert scale: 1 = strongly disagree and 5 = strongly agree.

A purposive sampling technique was utilized in the selection of the Delphi expert panel, since the credibility and success of a Delphi technique largely depend on the selection of the right set of respondents for the study as well as their expertise on the subject matters (Chan et al., 2001, 2015). Meanwhile, the authors devised some set of criteria for identifying and inviting the respondents to the Delphi panel, and these include: (1) respondents with extensive experience and leadership in the construction industry; (2) respondents who have utilized BIM and sustainability practices in current or past construction projects; and (3) respondents with robust and solid knowledge and understanding of the concepts of BIM and sustainability practices.

A two-round Delphi survey was launched in this study over a 5-month span. Meanwhile, due diligence was observed to ensure a consensus was reached after the second round of the Delphi survey as argued by Hasson et al. (2000). Mostly, a 2-3 round of Delphi surveys is adequate to achieve consensus among the invited respondents (Giel & Issa, 2016; Grisham, 2009) with at least seven participating experts (Hon et al., 2011; Mullen, 2003) and at most fifty respondents (Turoff, 1970).

Hence, this Delphi study involved fourteen (14) respondents who responded to the authors' invitation out of the invited 27 respondents based on the pre-defined criteria. More so, after the first round of Delphi survey, the experts were given feedback on the results and asked to adjust or change the rating on each factor wherever they deem it fit in the second round. The authors, meanwhile, ensure the anonymity of the experts and provided regular updates to the panel members.

### *3.2 Expert panel's demographics*

Fourteen (14) respondents from eight countries made up the expert panel for the study with seven experts each from the academics and practitioners respectively. We have four (4) respondents from the United Kingdom, three (3) from Hong Kong, two (2) from the United States and one respondent each from Australia, South Korea, Mainland China, Sweden, and Germany. The respondents have exhibited a good level of working experience in the construction industry with five (5) experts having at least 20 years of experience and another four respondents within the range of 11 and 20 years of working experience. Also, the Delphi expert panel has used BIM and implemented sustainability practices in their current or past construction projects.

Meanwhile, the respondents noted that BIM and sustainability practices are mostly applied in building projects, refurbishment/redevelopment works, civil engineering works and in industrial projects in descending order of preference. Also, the expert panel regards government agencies and parastatals as the key stakeholders that have influenced the implementation of BIM and sustainability practices in their projects. More so, other stakeholders such as the clients, project managers, and contractors are the other key initiators of BIM and sustainability practices in construction projects.

Meanwhile, most of the respondents (10) argued for the implementation of BIM and sustainability practices at the planning phase of project development. However, two experts each advocated for its integration at the design and construction stages respectively. In a similar vein, the authors sub-divided the respondents based on their working regions (West vs. East), following the dichotomy used by Chan et al. (2011). Hence, we have eight experts from the 'West' group consisting of countries such as the UK, the US, Germany and Sweden and six experts from the 'East' group consisting of the other countries (i.e., Hong Kong, Australia, South Korea and Mainland China).

## 4.0 Data Analysis and Discussion of Findings

Descriptive and inferential statistical tools were employed to analyze the responses from the Delphi expert panel, and deductions arrived based on the findings. These tools include: (1) Cronbach's alpha reliability test; (2) Shapiro-Wilk test of normality; (3) mean score ranking; (4) Kendall's coefficient of concordance and Chi-square value; (5) inter-rater agreement (IRA) statistics; (6) Spearman's rank correlation coefficient; and (7) Mann-Whitney analysis.

### *4.1 Reliability test and Normality test*

Cronbach's alpha (α) reliability test is useful in assessing the questionnaire, and it's associated scale whether it measures the right construct and checks its internal consistency (Olatunji et al., 2017a). Its value ranges from 0 to 1, and a value of 0.7 or above is considered acceptable for further analysis (Field, 2009; Olatunji et al., 2017a). The alpha (α) value for the Delphi first round was 0.965 while that of the second round was 0.966 which were both greater than 0.70.

Meanwhile, to test the normality of the data to help decide whether parametric or non-parametric tests are suitable for further analysis, a Shapiro-Wilk normality test was conducted. All the 36 factors have a significance level (p) less than 0.05 which implies that the data are not normally distributed and hence, non-parametric tests would be fitting for further analysis of the data.

### *4.2 Overall ranking of the beneficial factors*

In ranking the 36 factors based on the responses from the expert panel across the two-rounds of Delphi survey, we used both their mean scores (M) and the standard deviation (SD) values. In a scenario where two or more factors have the same value for their mean score, the SD value is taken into consideration. Therefore, the factor with the smaller SD value is assigned higher rank, otherwise, if the same SD, the factors will maintain the same rank (Olatunji et al., 2017a).

Table 2 shows the overall ranking of the factors for the first round of Delphi survey and Table 3 reveals the factors ranking for the second round. In the first round Delphi survey, the mean score for the 36 ranked factors ranges from M=3.43 (SD=0.646) for "*A6- improve financial and investment opportunities*" to M=4.79 (SD=0.579) for "*A8- facilitate sharing, exchange, and management of project information and data*" at a variance of 1.36. Moreover, after the second round, we have a slightly higher variance of 1.50 with a mean range from M=3.43 (SD=0.646) for "*A6- improve financial and investment opportunities*" to M=4.93 (SD=0.267) for "*A8- facilitate sharing, exchange, and management of project information and data*".

Moreover, an analysis of the findings reveals that the expert panel made changes to their ratings of the some of the factors. For example, some factors such as factor a21 to a16 (ranked 11$^{th}$), factor a31 to a3 (ranked 8$^{th}$), factor a1 to a34 (ranked 2$^{nd}$), etc. traded their rankings after the second round of Delphi survey. Also, some factors have improved rating after the second round such as factor a34 and a35 from rank 4 to 2, factor a10 from rank 15 to 12, and factor a16 from rank 13 to 11, etc. However, some factors rankings were reduced by the expert panel after the second rank and this included factor a1 from rank 2 to 5, factor a2 from 20 to 26, factor a18 from rank 11 to 15 among others. Meanwhile, some factors such as a8, a5, a6, a11, a12, a15, a17, a22, etc. retained their ranks after the second round of Delphi survey.

The core aim of Delphi technique is the achievement of consensus among respondents after the closure of the Delphi survey rounds. Hence, an analysis of the findings after the second of Delphi survey reveals consensus was achieved among the respondents' groups on the top-five key benefits of integrating BIM and sustainability practices in construction projects. The academics and the West group featured all overall top-5 key factors in their rankings while the practitioners' group featured 4 of the top-5 key factors and the East group featured only three (3) key factors. Moreover, there is a relative consensus on factor a8 as the most important benefits and was ranked 1st across the respondents' group. Also, there was improved agreement by the expert panel groups on the two (2) least important factors after the second round of Delphi survey.

### *4.3 Agreement of respondents within the expert groups*

Chan and Chan (2012) described Kendall's coefficient of concordance (W) as a non-parametric test useful in measuring the level of agreement within an expert group and ascertain the consistency of the agreement across the Delphi rounds. W's value ranges from 0 (perfect disagreement) and 1 (perfect agreement). The W's value of the expert panel increased from 0.255 in the first round to 0.335 after the second round of Delphi survey (see Tables 2 and 3).

In a similar vein, Kendall's coefficient of the respondents' groups was improved after the second round of Delphi survey such as 0.324 to 0.374 (academics), 0.280 to 0.375 (practitioners), 0.245 to 0.310 (West) and 0.355 to 0.464 (East). Although, the values of Kendall's coefficient are slightly less than the moderate value of 0.5; Zahoor et al. (2017) considered the W's value to be significant. According to Gisev et al. (2013), an increase in the size of the expert panel members would only result in much lower W values. More so, chi-square ($X^2$) tests were conducted since the questionnaire item for the Delphi survey is higher than seven (Hon et al., 2011). The $X^2$ values for the Delphi experts and the individual respondent group improved after the second round of Delphi survey (Tables 2 and 3).

The $X^2$ value of the expert panel was improved from 124.968 to 164.364 after the second round of Delphi survey which is higher than the $X^2$ critical values of 49.802 (for p=0.05) and 57.342 (for p=0.01) from the statistical table at a degree of freedom (df) of 35. The respondents' group chi-square values increased after the second round with $X^2$ values of 91.684, 91.815, 86.828, and 97.430 for the academics, practitioners, West and East groups respectively. These chi-square values are also higher than the $X^2$ critical values of 49.802

and 57.342 from the statistical table and a significance level of 0.000 across the respondents' groups which implies a robust consensus was reached after the second round.

***Table 2: 1st round of Delphi survey- Benefits of the integration of BIM and sustainability practices in construction projects***

| Code | All Experts | | | Academics | | | Practitioners | | | West | | | East | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SD** | **Rk** | **Mean** | **SD** | **Rk** | **Mean** | **SD** | **Rk** | **Mean** | **SD** | **Rk** | **Mean** | **SD** | **Rk** |
| A1 | 4.64 | .497 | 2 | 4.71 | .488 | 3 | 4.57 | .535 | 1 | 4.75 | .463 | 1 | 4.50 | .548 | 5 |
| A2 | 4.14 | .770 | 20 | 4.43 | .535 | 12 | 3.86 | .900 | 29 | 4.25 | .707 | 19 | 4.00 | .894 | 24 |
| A3 | 4.43 | .514 | 9 | 4.57 | .535 | 8 | 4.29 | .488 | 12 | 4.50 | .535 | 8 | 4.33 | .516 | 10 |
| A4 | 4.57 | .514 | 4 | 4.71 | .488 | 3 | 4.43 | .535 | 4 | 4.63 | .518 | 4 | 4.50 | .548 | 5 |
| A5 | 3.57 | .938 | 35 | 3.86 | .900 | 31 | 3.29 | .951 | 36 | 3.50 | 1.069 | 36 | 3.67 | .816 | 33 |
| A6 | 3.43 | .646 | 36 | 3.29 | .488 | 36 | 3.57 | .787 | 35 | 3.50 | .756 | 35 | 3.33 | .516 | 36 |
| A7 | 3.93 | .616 | 29 | 3.86 | .690 | 33 | 4.00 | .577 | 21 | 3.88 | .835 | 30 | 4.00 | .000 | 23 |
| A8 | 4.79 | .579 | 1 | 5.00 | .000 | 1 | 4.57 | .787 | 3 | 4.75 | .707 | 3 | 4.83 | .408 | 1 |
| A9 | 4.14 | .770 | 20 | 4.43 | .535 | 12 | 3.86 | .900 | 29 | 4.13 | .641 | 25 | 4.17 | .983 | 20 |
| A10 | 4.36 | .842 | 15 | 4.57 | .787 | 10 | 4.14 | .900 | 18 | 4.38 | .916 | 16 | 4.33 | .816 | 15 |
| A11 | 3.64 | .745 | 34 | 3.43 | .787 | 35 | 3.86 | .690 | 28 | 3.63 | .916 | 34 | 3.67 | .516 | 32 |
| A12 | 3.93 | .997 | 32 | 4.14 | 1.069 | 27 | 3.71 | .951 | 32 | 3.88 | 1.126 | 33 | 4.00 | .894 | 24 |
| A13 | 3.79 | .893 | 33 | 3.86 | .900 | 31 | 3.71 | .951 | 32 | 3.88 | .991 | 32 | 3.67 | .816 | 33 |
| A14 | 3.93 | .829 | 30 | 3.86 | .690 | 33 | 4.00 | 1.000 | 25 | 4.00 | .756 | 27 | 3.83 | .983 | 30 |
| A15 | 4.64 | .497 | 2 | 4.86 | .378 | 2 | 4.43 | .535 | 4 | 4.63 | .518 | 4 | 4.67 | .516 | 2 |
| A16 | 4.36 | .745 | 13 | 4.57 | .535 | 8 | 4.14 | .900 | 18 | 4.25 | .886 | 21 | 4.50 | .548 | 5 |
| A17 | 4.57 | .646 | 7 | 4.57 | .787 | 10 | 4.57 | .535 | 1 | 4.50 | .756 | 9 | 4.67 | .516 | 2 |
| A18 | 4.36 | .497 | 11 | 4.43 | .535 | 12 | 4.29 | .488 | 12 | 4.38 | .518 | 10 | 4.33 | .516 | 10 |
| A19 | 4.07 | .829 | 27 | 4.00 | .816 | 29 | 4.14 | .900 | 18 | 4.00 | .756 | 27 | 4.17 | .983 | 20 |
| A20 | 4.14 | .770 | 20 | 4.29 | .756 | 18 | 4.00 | .816 | 22 | 4.13 | .835 | 26 | 4.17 | .753 | 17 |
| A21 | 4.36 | .497 | 11 | 4.29 | .488 | 17 | 4.43 | .535 | 4 | 4.25 | .463 | 18 | 4.50 | .548 | 5 |
| A22 | 4.43 | .852 | 10 | 4.43 | .976 | 16 | 4.43 | .787 | 10 | 4.63 | .744 | 7 | 4.17 | .983 | 20 |
| A23 | 4.14 | .949 | 26 | 4.14 | 1.215 | 28 | 4.14 | .690 | 17 | 4.00 | 1.069 | 29 | 4.33 | .816 | 15 |
| A24 | 4.14 | .864 | 23 | 4.29 | .951 | 20 | 4.00 | .816 | 24 | 4.38 | .744 | 13 | 3.83 | .983 | 30 |
| A25 | 4.21 | .802 | 18 | 4.43 | .535 | 12 | 4.00 | 1.000 | 25 | 4.38 | .518 | 10 | 4.00 | 1.095 | 27 |
| A26 | 4.21 | .802 | 18 | 4.00 | .816 | 29 | 4.43 | .787 | 10 | 4.25 | .886 | 21 | 4.17 | .753 | 17 |
| A27 | 4.36 | .745 | 13 | 4.29 | .951 | 22 | 4.43 | .535 | 4 | 4.38 | .916 | 16 | 4.33 | .516 | 10 |
| A28 | 4.14 | .864 | 23 | 4.29 | .756 | 18 | 4.00 | 1.000 | 25 | 4.25 | .707 | 19 | 4.00 | 1.095 | 27 |
| A29 | 4.29 | .726 | 16 | 4.29 | .756 | 21 | 4.29 | .756 | 14 | 4.38 | .744 | 13 | 4.17 | .753 | 17 |
| A30 | 4.07 | .997 | 28 | 4.29 | .951 | 22 | 3.86 | 1.069 | 31 | 4.38 | .744 | 13 | 3.67 | 1.211 | 35 |
| A31 | 4.50 | .650 | 8 | 4.71 | .488 | 3 | 4.29 | .756 | 14 | 4.38 | .744 | 10 | 4.67 | .516 | 2 |
| A32 | 3.93 | .917 | 31 | 4.14 | .690 | 26 | 3.71 | 1.113 | 34 | 3.88 | .835 | 30 | 4.00 | 1.095 | 27 |
| A33 | 4.29 | .825 | 17 | 4.29 | .951 | 22 | 4.29 | .756 | 14 | 4.25 | 1.035 | 24 | 4.33 | .516 | 10 |
| A34 | 4.57 | .514 | 4 | 4.71 | .488 | 3 | 4.43 | .535 | 4 | 4.63 | .518 | 4 | 4.50 | .548 | 5 |
| A35 | 4.57 | .514 | 4 | 4.71 | .488 | 3 | 4.43 | .535 | 4 | 4.75 | .463 | 1 | 4.33 | .516 | 10 |
| A36 | 4.14 | .864 | 23 | 4.29 | .951 | 22 | 4.00 | .816 | 22 | 4.25 | .886 | 21 | 4.00 | .894 | 24 |
| Cronbach's α reliability value | 0.965 | | | 0.953 | | | 0.974 | | | 0.960 | | | 0.974 | | |
| Number of respondents (n) | 14 | | | 7 | | | 7 | | | 8 | | | 6 | | |
| Kendall's coefficient of concordance (W) | 0.255 | | | 0.324 | | | 0.280 | | | 0.245 | | | 0.355 | | |
| $\chi^2$ | 124.968 | | | 80.216 | | | 68.612 | | | 68.641 | | | 74.605 | | |
| $\chi^2$- Critical value from statistical table [a: p=0.05; b: p=0.01] | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | |
| Degree of freedom (df) | 35 | | | 35 | | | 35 | | | 35 | | | 35 | | |
| Significance level (p) | 0.000 | | | 0.000 | | | 0.001 | | | 0.001 | | | 0.000 | | |

Note: Rk - Rank

***Table 3: 2nd round of Delphi survey- Benefits of the integration of BIM and sustainability practices in construction projects***

| Code | All Experts | | | Academics | | | Practitioners | | | West | | | East | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Rk | Mean | SD | Rk | Mean | SD | Rk | Mean | SD | Rk | Mean | SD | Rk |
| A1 | 4.64 | .497 | 5 | 4.71 | .488 | 3 | 4.57 | .535 | 5 | 4.75 | .463 | 3 | 4.50 | .548 | 7 |
| A2 | 4.07 | .730 | 26 | 4.43 | .535 | 14 | 3.71 | .756 | 32 | 4.13 | .641 | 25 | 4.00 | .894 | 24 |
| A3 | 4.57 | .514 | 8 | 4.57 | .535 | 8 | 4.57 | .535 | 5 | 4.63 | .518 | 5 | 4.50 | .548 | 7 |
| A4 | 4.64 | .497 | 5 | 4.71 | .488 | 3 | 4.57 | .535 | 5 | 4.63 | .518 | 5 | 4.67 | .516 | 4 |
| A5 | 3.50 | .855 | 35 | 3.71 | .756 | 34 | 3.29 | .951 | 36 | 3.50 | 1.069 | 36 | 3.50 | .548 | 35 |
| A6 | 3.43 | .646 | 36 | 3.29 | .488 | 36 | 3.57 | .787 | 35 | 3.50 | .756 | 35 | 3.33 | .516 | 36 |
| A7 | 3.86 | .663 | 31 | 3.86 | .690 | 31 | 3.86 | .690 | 28 | 3.75 | .886 | 33 | 4.00 | .000 | 23 |
| A8 | 4.93 | .267 | 1 | 5.00 | .000 | 1 | 4.86 | .378 | 1 | 4.88 | 0.354 | 1 | 5.00 | .000 | 1 |
| A9 | 4.14 | .663 | 22 | 4.29 | .488 | 20 | 4.00 | .816 | 24 | 4.25 | .463 | 21 | 4.00 | .894 | 24 |
| A10 | 4.43 | .756 | 12 | 4.57 | .787 | 11 | 4.29 | .756 | 16 | 4.50 | .756 | 11 | 4.33 | .816 | 16 |
| A11 | 3.71 | .726 | 34 | 3.57 | .787 | 35 | 3.86 | .690 | 28 | 3.63 | .916 | 34 | 3.83 | .408 | 30 |
| A12 | 3.86 | .949 | 32 | 4.00 | 1.000 | 29 | 3.71 | .951 | 33 | 3.88 | 1.126 | 32 | 3.83 | .753 | 31 |
| A13 | 3.79 | .893 | 33 | 3.86 | .900 | 33 | 3.71 | .951 | 33 | 3.88 | .991 | 31 | 3.67 | .816 | 33 |
| A14 | 3.93 | .829 | 30 | 3.86 | .690 | 31 | 4.00 | 1.000 | 25 | 4.00 | .756 | 27 | 3.83 | .983 | 32 |
| A15 | 4.71 | .469 | 2 | 4.86 | 0.378 | 2 | 4.57 | .535 | 5 | 4.63 | 0.518 | 5 | 4.83 | .408 | 2 |
| A16 | 4.43 | .646 | 11 | 4.57 | .535 | 8 | 4.29 | .756 | 16 | 4.38 | .744 | 17 | 4.50 | .548 | 7 |
| A17 | 4.64 | .633 | 7 | 4.57 | .787 | 11 | 4.71 | .488 | 2 | 4.50 | .756 | 11 | 4.83 | .408 | 2 |
| A18 | 4.36 | .497 | 15 | 4.43 | .535 | 14 | 4.29 | .488 | 15 | 4.38 | .518 | 16 | 4.33 | .516 | 13 |
| A19 | 4.14 | .770 | 23 | 4.14 | .690 | 26 | 4.14 | .900 | 22 | 4.00 | .756 | 27 | 4.33 | .816 | 16 |
| A20 | 4.29 | .611 | 18 | 4.43 | .535 | 14 | 4.14 | .690 | 19 | 4.25 | .707 | 23 | 4.33 | .516 | 13 |
| A21 | 4.36 | .497 | 15 | 4.29 | .488 | 20 | 4.43 | .535 | 10 | 4.25 | .463 | 21 | 4.50 | .548 | 7 |
| A22 | 4.50 | .760 | 10 | 4.57 | .787 | 11 | 4.43 | .787 | 13 | 4.63 | .744 | 8 | 4.33 | .816 | 16 |
| A23 | 4.07 | .917 | 27 | 4.00 | 1.155 | 30 | 4.14 | .690 | 19 | 4.00 | 1.069 | 30 | 4.17 | .753 | 19 |
| A24 | 4.29 | .825 | 20 | 4.43 | 0.787 | 17 | 4.14 | .900 | 22 | 4.50 | 0.756 | 11 | 4.00 | .894 | 24 |
| A25 | 4.29 | .825 | 20 | 4.57 | .535 | 8 | 4.00 | 1.000 | 25 | 4.50 | .535 | 9 | 4.00 | 1.095 | 27 |
| A26 | 4.14 | .770 | 23 | 4.00 | .816 | 28 | 4.29 | .756 | 16 | 4.13 | .835 | 26 | 4.17 | .753 | 19 |
| A27 | 4.43 | .756 | 12 | 4.29 | .951 | 24 | 4.57 | .535 | 5 | 4.50 | .926 | 15 | 4.33 | .516 | 13 |
| A28 | 4.14 | .864 | 25 | 4.29 | .756 | 22 | 4.00 | 1.000 | 25 | 4.25 | .707 | 23 | 4.00 | 1.095 | 27 |
| A29 | 4.36 | .745 | 17 | 4.29 | .756 | 22 | 4.43 | .787 | 13 | 4.50 | .756 | 11 | 4.17 | .753 | 19 |
| A30 | 4.07 | .997 | 28 | 4.29 | .951 | 24 | 3.86 | 1.069 | 30 | 4.38 | .744 | 17 | 3.67 | 1.211 | 34 |
| A31 | 4.57 | .514 | 8 | 4.71 | .488 | 3 | 4.43 | .535 | 10 | 4.50 | .535 | 9 | 4.67 | .516 | 4 |
| A32 | 4.00 | .877 | 29 | 4.14 | .690 | 26 | 3.86 | 1.069 | 30 | 4.00 | .756 | 27 | 4.00 | 1.095 | 27 |
| A33 | 4.43 | .756 | 12 | 4.43 | .976 | 19 | 4.43 | .535 | 10 | 4.38 | .916 | 20 | 4.50 | .548 | 7 |
| A34 | 4.71 | .469 | 2 | 4.71 | .488 | 3 | 4.71 | .488 | 2 | 4.75 | .463 | 3 | 4.67 | .516 | 4 |
| A35 | 4.71 | .469 | 2 | 4.71 | .488 | 3 | 4.71 | .488 | 2 | 4.88 | .354 | 1 | 4.50 | .548 | 7 |
| A36 | 4.29 | .726 | 19 | 4.43 | .787 | 17 | 4.14 | .690 | 19 | 4.38 | .744 | 17 | 4.17 | .753 | 19 |
| Cronbach's α value | 0.966 | | | 0.960 | | | 0.973 | | | 0.959 | | | 0.978 | | |
| Number of respondents (n) | 14 | | | 7 | | | 7 | | | 8 | | | 6 | | |
| Kendall's coefficient of concordance, W | 0.335 | | | 0.374 | | | 0.375 | | | 0.310 | | | 0.464 | | |
| $\chi^2$ | 164.364 | | | 91.684 | | | 91.815 | | | 86.828 | | | 97.430 | | |
| $\chi^2$- Critical value from statistical table | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | | 49.802[a] (57.342[b]) | | |
| Degree of freedom (df) | 35 | | | 35 | | | 35 | | | 35 | | | 35 | | |
| Significance level (p) | 0.000 | | | 0.000 | | | 0 | | | 0.000 | | | 0.000 | | |

### *4.4 Significance of the factors and validation of experts' agreement via IRA analysis*

The data referenced for analysis are based on the mean score values of the 36 identified factors after the second round of Delphi survey. More so, in prioritizing the factors based on their significance levels, the scale interval interpretation proposed by Li et al. (2013) was adopted as follows: "not important" (M< 1.5), "somewhat important" (1.51 ≤ M ≤ 2.5), "important" (2.51 ≤ M ≤ 3.5), "very important" (3.51 ≤ M ≤ 4.5) and "extremely important" (M≥ 4.51). More so, all the 36 factors are considered important by the expert panel at both rounds of Delphi survey with no factor below the 2.51 grade (see Table 4).

Moreover, two factors such as factor a3- "*predictive analysis of performance (energy analysis, code analysis)*" (Eastman et al., 2008); and a31- "*enhance the accuracy of as-built drawings*" (Akintoye et al., 2012) improved their significance level from "very important" to "extremely important" after the second round of Delphi survey. However, factor a5- "*reduction in the cost of construction works and improvement in project's cost performance*" (Azhar, 2011); reduced in its significance level from "very important" to "important." Meanwhile, nine (9) of the factors was considered "extremely important" by the respondents after the second as against seven factors in the first round, and these factors include factor a1, a3, a4, a8, a15, a17, a31, a34, and a35. Two (2) factors a5 and a6 were graded as "important" while the remaining 25 factors were considered "very important" by the expert panel.

More so, an analysis of the factors based on their categories reveals four (4) key areas in which project stakeholders can get substantial benefits when BIM initiatives and sustainability practices are implemented in construction projects. These key categories include "efficiency and productivity" with related factors such as a1, a3 and a4 (Aibinu & Venkatesh, 2014; Bolgani, 2013) graded "extremely important" by the expert panel. Similarly, for category "technology-related issues" with factor a31, a34 and a35 (Akinade et al., 2015; Aksamija, 2012); category "planning and design" with factor a15 and a17 (Alsayyar & Jrade, 2015; Yang & Ergan, 2014); and category "information and process-related issues" with factor a8 (Abanda et al., 2015). All the related factors for these categories are considered "extremely important" by the respondents.

Meanwhile, the interrater agreement statistics (IRA $a_{wg(1)}$) was used in analyzing and validating the expert agreements among the respondent groups. The IRA was developed by Brown & Hauenstein (2005), and it is leverage upon in this study because it is not dependent on the sample size nor the scale of the data. The IRA and the significance level analysis was used to evaluate the strength of consensus among the expert at both rounds of Delphi survey and validate the agreement obtained for each factor (see Table 4). The coding for the IRA analysis was deduced by Lebreton and Senter (2008) as follows: 0.00 - 0.30 “lack of agreement,” 0.31-0.50 “weak agreement,” 0.51-0.70 “moderate agreement,” 0.71-0.90 “strong agreement” and 0.91-1.00 “very strong agreement.”

The IRA formula (equation 1) was used in the analysis and validation of the agreement for each factor. Meanwhile, the IRA statistics cannot measure the agreement for means at the boundary of a scale, say 1 and 5 on a 5-point Likert scale. Hence, equations 2 and 3 helped to delineate the mean upper and lower limits when computing the IRA analysis.

$$a_{wg(1)} = 1 - \frac{(2 * SD^2)}{\{(A+B)M - (M^2) - (A * B)\} * \frac{n}{n-1}} - - - - - - - eqn\ (1)$$

$$M_{lower} = \frac{B\ (n-1) + A}{n} - - - - - - eqn\ (2)$$

$$M_{upper} = \frac{A\ (n-1) + B}{n} - - - - - - eqn\ (3)$$

Where SD= standard deviation, A= maximum scale value (i.e. 5), B= minimum scale value (i.e. 1), M= mean value of that factor, n= sample size of respondents (i.e. 14 in this study). The mean boundaries for both rounds of Delphi survey that is $M_{lower}$ and $M_{upper}$ are 1.29 and 4.71 respectively. Although, we have one factor a8- “*facilitate sharing, exchange, and management of project information and data*” with ‘lack of agreement’ grade in the first round of Delphi survey, it improved to a moderate agreement level after the second round.

More so, three (3) factors’ expert agreement level increased after the second round, such as factors a36 and 32 which improved from a “weak” to “moderate” agreement, while, factor a8 increased significantly from “lack” to “moderate” agreement.” However, three factors reduced in their agreement level after the second round such as factors a25 and a27 decreasing from “moderate” to “weak” agreement and factor a3 from “strong” to “moderate” agreement. Meanwhile, five factors (such as a6, a7, a11, a18, and a21) achieved “strong” agreement after the second round of Delphi survey. The IRA and significance level analysis for the factors lends credence to the consensus achieved by the expert panel after the second round of Delphi surveys and validate the agreements.

The significance level and the IRA statistics ratings for each factor was used to rank the factors firstly on their significance level and then with the IRA in descending order as shown in Table 5. The factors’ significance levels are in the range of “extremely important” to “important” and the IRA analysis range from “strong” to “weak” agreement. The ranking was based on the results of the second round of Delphi survey. The five salient factors as ranked in descending order of significance (see Table 5) are: a1- “enhance overall project quality, productivity, and efficiency"; a35- "ability to simulate building performances and energy usage."

Others are; a15- better design products and facilitate multi-design alternatives"; a3- "predictive analysis of performance (energy analysis, code analysis)"; and a4- "improve the operations and maintenance (facility management) of project infrastructure." These key factors as identified by the expert panel are the five most important benefits of integrating BIM initiatives and sustainability practices in construction projects.

***Table 4: Significance grading & IRA analysis of the factors (benefits)***

| Factor Coding | Round 1 | | Round 2 | | Round 1 | Round 2 |
|---|---|---|---|---|---|---|
| | $a_{wg(1)}$ score | Agreement level | $a_{wg(1)}$ score | Agreement level | Significance grade | Significance grade |
| A1 | 0.649 | Moderate | 0.649 | Moderate | E. important | E. important |
| A2 | 0.593 | Moderate | 0.655 | Moderate | V. important | V. important |
| A3 | 0.751 | Strong | 0.682 | ↓Moderate | V. important | ↑E. important |
| A4 | 0.682 | Moderate | 0.649 | Moderate | E. important | E. important |
| A5 | 0.558 | Moderate | 0.640 | Moderate | V. important | ↓Important |
| A6 | 0.798 | Strong | 0.798 | Strong | Important | Important |
| A7 | 0.777 | Strong | 0.751 | Strong | V. important | V. important |
| A8 | 0.237 | Lack | 0.530 | ↑Moderate | E. important | E. important |
| A9 | 0.593 | Moderate | 0.699 | Moderate | V. important | V. important |
| A10 | 0.394 | Weak | 0.462 | Weak | V. important | V. important |
| A11 | 0.714 | Strong | 0.721 | Strong | V. important | V. important |
| A12 | 0.415 | Weak | 0.491 | Weak | V. important | V. important |
| A13 | 0.565 | Moderate | 0.565 | Moderate | V. important | V. important |
| A14 | 0.596 | Moderate | 0.596 | Moderate | V. important | V. important |
| A15 | 0.649 | Moderate | 0.618 | Moderate | E. important | E. important |
| A16 | 0.525 | Moderate | 0.607 | Moderate | V. important | V. important |
| A17 | 0.496 | Weak | 0.431 | Weak | E. important | E. important |
| A18 | 0.788 | Strong | 0.788 | Strong | V. important | V. important |
| A19 | 0.555 | Moderate | 0.593 | Moderate | V. important | V. important |
| A20 | 0.593 | Moderate | 0.706 | Moderate | V. important | V. important |
| A21 | 0.788 | Strong | 0.788 | Strong | V. important | V. important |
| A22 | 0.317 | Weak | 0.391 | Weak | V. important | V. important |
| A23 | 0.382 | Weak | 0.456 | Weak | V. important | V. important |
| A24 | 0.488 | Weak | 0.464 | Weak | V. important | V. important |
| A25 | 0.530 | Moderate | 0.464 | ↓Weak | V. important | V. important |
| A26 | 0.530 | Moderate | 0.593 | Moderate | V. important | V. important |
| A27 | 0.525 | Moderate | 0.462 | ↓Weak | V. important | V. important |
| A28 | 0.488 | Weak | 0.488 | Weak | V. important | V. important |
| A29 | 0.585 | Moderate | 0.525 | Moderate | V. important | V. important |
| A30 | 0.356 | Weak | 0.356 | Weak | V. important | V. important |
| A31 | 0.554 | Moderate | 0.682 | Moderate | V. important | ↑E. important |
| A32 | 0.505 | Weak | 0.527 | ↑Moderate | V. important | V. important |
| A33 | 0.464 | Weak | 0.462 | Weak | V. important | V. important |
| A34 | 0.682 | Moderate | 0.618 | Moderate | E. important | E. important |
| A35 | 0.682 | Moderate | 0.618 | Moderate | E. important | E. important |
| A36 | 0.488 | Weak | 0.585 | ↑Moderate | V. important | V. important |

Note: Lack = Lack of agreement; V. important = Very important; E. important = Extremely important; ↓- decrease & ↑- increase

*Table 5: Summary of the significant benefits in descending order of significance*

| Code | Factors | Ranking | Significance | Agreement level |
|---|---|---|---|---|
| A1 | Enhance overall project quality, productivity, and efficiency | 1 | Extremely important | Moderate |
| A35 | Ability to simulate building performances and energy usage | 2 | Extremely important | Moderate |
| A15 | Better design products and facilitate multi-design alternatives | 3 | Extremely important | Moderate |
| A3 | Predictive analysis of performance (energy analysis, code analysis) | 4 | Extremely important | Moderate |
| A4 | Improve the operations and maintenance (facility management) of project infrastructure | 5 | Extremely important | Moderate |
| A8 | Facilitate sharing, exchange, and management of project information and data | 6 | Extremely important | Moderate |
| A31 | Enhance the accuracy of as-built drawings | 7 | Extremely important | Moderate |
| A34 | Facilitate accurate geometrical representations of a building in an integrated data environment | 8 | Extremely important | Moderate |
| A17 | Real-time sustainable design and analysis early in the design phase | 9 | Extremely important | Weak |
| A7 | Reduction in the cost of as-built drawings | 10 | Very important | Strong |
| A11 | Ease the process to obtain building plan approvals and construction permits | 11 | Very important | Strong |
| A18 | Facilitate, support and improve project-related decision-making | 12 | Very important | Strong |
| A21 | Enhance innovation capabilities and encourage the use of new construction methods | 13 | Very important | Strong |
| A2 | Schedule compliance in the delivery of construction projects | 14 | Very important | Moderate |
| A9 | Facilitates resource planning and allocation | 15 | Very important | Moderate |
| A13 | Reduced claims or litigation risks | 16 | Very important | Moderate |
| A14 | Increase firms' capability to comply with prevailing statutory regulations | 17 | Very important | Moderate |
| A16 | Facilitate building layout flexibility and retrofitting | 18 | Very important | Moderate |
| A19 | Improved organization brand image and competitive advantage | 19 | Very important | Moderate |
| A20 | Enhance business performance and technical competence of professional practice | 20 | Very important | Moderate |
| A26 | Ease the integration of sustainability strategies with business planning | 21 | Very important | Moderate |
| A29 | Facilitate the selection of sustainable materials, components, and systems for projects | 22 | Very important | Moderate |
| A32 | Facilitate integration with domain knowledge areas such as project management, safety, and sustainability | 23 | Very important | Moderate |
| A36 | Encourage the implementation of clean technologies that require less energy consumption | 24 | Very important | Moderate |
| A10 | Reduction in site-based conflicts | 25 | Very important | Weak |
| A12 | Support collaboration and ease procurement relationships | 26 | Very important | Weak |
| A22 | Prevent and reduce materials wastage through reuse & recycling and ensure materials efficiency | 27 | Very important | Weak |
| A23 | Reduce safety risks and enhance project safety & health performance | 28 | Very important | Weak |
| A24 | Control of lifecycle costs and environmental data | 29 | Very important | Weak |
| A25 | Facilitate the implementation of green building principles and practices | 30 | Very important | Weak |
| A27 | Minimize carbon risk and improve energy efficiency | 31 | Very important | Weak |
| A28 | Improve resource management and reduce environmental | 32 | Very | Weak |

| | | | | |
|---|---|---|---|---|
| | impact across the value chain | | important | |
| A30 | Higher capacity for accommodating the three pillars of sustainability (social, economic & environmental sustainability) | 33 | Very important | Weak |
| A33 | Allow the checking of architectural design of buildings from the sustainability point of view | 34 | Very important | Weak |
| A6 | Improve financial and investment opportunities | 35 | Important | Strong |
| A5 | Reduction in cost of construction works and improvement in project's cost performance | 36 | Important | Moderate |

### *4.5 Agreement of respondents between the expert groups*

The Spearman rank correlation coefficient ($r_s$) and the Mann-Whitney U statistical tools were employed in the comparative analysis among the respondents' groups.

#### 4.5.1 Spearman rank correlation

Spearman rank correlation ($r_s$) test is useful in evaluating the level of agreement between any two groups which is based on mean ranks (Chan et al., 2010). The $r_s$ value ranges from -1 and +1 with +1 coefficients indicating a perfect positive correlation and -1 shows a perfect negative correlation. More so, when $r_s$ significance level is less than 0.05 ($p<0.05$), the null hypothesis ($H_{0a}$) which states that "there is no significant correlation between the two respondent groups on the rankings of the benefits" can be rejected. The $r_s$ analysis for the West group and East group presented a significant correlation at a coefficient of 0.763 and a significance level (p) of 0.000. Hence, for the West vs. East group, the null hypothesis is rejected.

More so, $r_s$ analysis for the academics and practitioners group resulted in a high correlation at a coefficient value of 0.778 and a p-value of 0.000. Hence, there is sufficient evidence to conclude that there is a significant correlation between the rankings of the academics and practitioners' groups on the factors. Therefore, the null hypothesis is rejected. The West and East groups shared a significant level of consensus on two factors (a8 and a32). Also, the academics and practitioners' groups ranked two factors (a8 and a13) similarly, which implies the two groups have a satisfactory level of agreement on the two items.

#### 4.5.2 Mann-Whitney U-test

Chan et al. (2010) pointed out that Mann-Whitney U test as a non-parametric statistical tool is useful in detecting the existence of differences in the median values of the same factor when evaluating two respondents' groups. When the significance level (p) is less than 0.05, the null hypothesis is rejected. The null hypothesis ($H_{0b}$) states that "there is no significant differences in the median values of the same factor between the two respondents' groups" will be rejected.

The Mann-Whitney tests were carried out for both the academics and practitioners' groups as well as the West versus the East groups. In both cases, the p-value for each of the factor for both groups pairing (academics vs. practitioners and West vs. East) was greater than 0.05 (i.e., $p>0.05$). Hence, the null hypothesis cannot be rejected for both cases since none of the factors reveals any significant divergence in the median values of the groups pairing. The findings reinforced that the academics and practitioners' groups, as well as the respondents from both the west and east, shared a similar level of agreement on each factor.

## 5.0 Recommended strategies

This study has highlighted some benefits to be gained by the clients, construction firms, government as well as the building project itself when BIM is used to amplify the implementation of sustainability practices in construction projects. Also, the varying degree of difference between the perceptions of the academics and practitioners as well as distinctions between the adoption of BIM and sustainability practices between countries in the west and east have been discussed. However, beyond presenting these benefits for construction stakeholders; this section identifies some research gaps that need to be bridged and recommends strategies to enable the actualization of these benefits in construction projects or a country.

1) The first research gap is the difficulty in measuring some of the identified benefits which are qualitative. For instance, it might be difficult for a client organization to evaluate factor A11- "*ease the process to obtain building plan approvals and construction permits*" and how the adoption of the two concepts in their projects have helped in securing necessary regulatory approvals. Also, factor A20- "*enhance business performance and technical competence of professional practice*," there is not yet a clear-cut approach to measure its achievement. However, previous studies (Akintoye et al., 2003; Loû, 2012) have demonstrated how metrics or theories in other disciplines such as accounting, management, etc. can be used in construction management to get a quantitative measurement for a somewhat qualitative parameter. To this end, future studies can focus on developing metrics for these 'qualitative' benefits and, aim to investigate other measures or indicators that might be contributory to the realization of the benefits.
2) The lack or inadequacy of comprehensive BIM standards and model for sustainability practices in a sizable number of countries is the second research gap. Implementing these concepts without a standard or guideline in a nation would only result in untraceable development and impact of BIM and sustainability practices in such

projects since there won't be a benchmark to measure it. Olawumi and Chan (2018) argued that each country needs to develop its policies and standards but with a global perspective. Therefore, it is advocated for countries (mostly developing countries) who have neither BIM or sustainability standards to set up machinery in place to establish policies to ensure the benefits in this study can be gained in their projects. Similarly, this recommendation can be extended to countries who have BIM standards but haven't commenced processes for sustainability. The formulation of policies and guideline is a crucial requirement and stage to begin the implementation of BIM and sustainability practices.

3) The last research gap lies in the unwillingness of project stakeholders to implement BIM and sustainability practices in their projects due to various reasons. Lu et al. (2017) revealed that despite the extensive BIM studies undertaken in the literature, there is still a 'low industrial acceptance' of green BIM. Hence, it is recommended for future research to examine the reasons behind the low application of green BIM in construction projects. More so, it advocated for experts and knowledgeable project team members who have utilized BIM and sustainability practices to advocate for the implementation of these two concepts in their future projects; and encourage clients by providing clear evidences of the successes achieved in their past projects when green BIM was adopted as well as potential possibilities in the new project.

Worthwhile and coordinated attempts to investigate and address these gaps in literature and practice can help furtherance the adoption of BIM and the implementation of sustainability practices in the built environment.

## 6.0 Conclusions

The recent innovations and development in the built environment have led to calls for academics and practitioners alike to use innovative technologies such as BIM to drive the implementation of the sustainable smart city. The study explored and analyzed the benefits derivable by various components of the construction industry such as the project itself, stakeholders and organizations when BIM and sustainability practices are fully integrated into construction projects.

The first approach in this study was the systematic content analysis of extant literature for benefits of BIM and sustainability practices implementation and categorization of these factors under eight (8) categories. A Delphi survey technique was adopted which involved fourteen experts from eight countries who formed the expert panel and provided the data for this study across two rounds of Delphi survey. A series of statistical methods such mean score ranking, Kendall's coefficient of concordance, inter-rater agreement (IRA) statistics, Spearman's rank correlation coefficient and Mann-Whitney analysis were used in analyzing the responses solicited from the expert panel.

The expert panel achieved reasonable levels of consensus after the second round of Delphi survey and likewise among the respondents' groups such as the academics, practitioners, etc. Moreover, the expert panel, as well as the experts' groups, were significantly improved in their levels of the agreement after the second round with both Kendall's coefficient values and the chi-square values higher than the values obtained in the first round of Delphi survey. More so, some factors have increased ranking after the second-round while some retained the same rank and a few reduced in the ranking.

Meanwhile, the IRA statistic was used to validate the consensus reached by the expert panel on each factor, and the factors' significance levels were incorporated to rank each benefit in descending order. Utilizing the significance level and IRA values, we identified the three most significant benefits of BIM and sustainability practices integration in construction projects. These include "enhance overall project quality, productivity, and efficiency," "ability to simulate building performances and energy usage," and "better design products and facilitate multi-design alternatives." More so, the most salient categories were identified based on the ranking of the composite factors, and these include "efficiency and productivity," "technology-related issues," and "planning and design."

Moreover, there was a significant and positive correlation between the rankings of the academics and practitioners' groups as well as for the respondents from the east and west regions. The findings have demonstrated a satisfactory level of agreement and consensus among the expert panel on the identified benefits of BIM initiatives and sustainability practices implementation in construction projects. In a similar vein, an analysis of significant divergence in the perceptions of the respondents' groups as regards the identified factors indicated there were no statistically significant differences in the ranking of the factors. Hence, this further strengthens that the expert panel reached a strong consensus on each of the beneficial factors, although the study is subjected to the limitation of the number of respondents involved due to the uniqueness of the cross-field research.

The study also identified prevalent research gaps emanating from this research and in practice and provided salient recommendations and strategies to mitigate the challenges faced in the implementation of BIM and sustainability practices in the industry. Future research works can consider an in-depth case study of these benefits on specific construction projects or an extensive collection of data through empirical questionnaire surveys to extend and substantiate the key findings derived in this study. The findings of this study have contributed to the existing body of knowledge on BIM and sustainability by presenting academics and industry experts alike with comprehensive benefits achievable via the implementation of sustainable construction practices. The results are expected to assist the project team in encouraging construction clients and other stakeholders alike to allow the full implementation of BIM innovations and sustainable strategies in their projects to enhance the optimal goal of sustainable smart city initiatives.

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