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Beneficial Factors of Integrating Building Information Modelling (BIM) and Sustainability Practices in Construction Projects

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Abstract

The concepts of Building Information Modelling (BIM) and sustainability are relatively new concepts in the Architectural, Engineering, and Construction (AEC) industry. This paper aims to investigate the perceived benefits of integrating BIM and sustainable practices in construction projects. A quantitative approach was adopted, and data were collected from fourteen invited experts from both the academia and industry via a two-round Delphi survey. The data were analyzed to establish the ranking of each factor, and the Kendall's concordance test was used to determine the level of consensus among the respondents in each round. Most of the perceived benefits were ranked significant and important. More so, of the 36 beneficial factors, four factors were rated as highly important which are related to effective sharing and exchange of project data, better design of products, accurate geometrical representations of building models with embedded sustainability data, and ease of simulating building performance and energy usage. With these key benefits in mind and collaborative working in the AEC industry, the concepts and ideas of a sustainable urban city can be achieved in the built environment.

Keywords: BIM; Sustainability practices; Construction projects; Benefits; Delphi study

1.0 Introduction

In recent years, several innovative approaches, techniques, and concepts have been introduced in the AEC industry. Some of these approaches include BIM technologies, cloud-based project management, augmented reality and visual reality, sustainability, mobile technology, Radio Frequency Identification (RFID) and sensors for tracking and measurement and other collaborative solutions. These techniques and technologies are introduced to improve and reposition the construction industry as a collaborative environment (Olatunji *et al*., 2016; Olatunji *et al*., 2016; Olawumi & Ayegun, 2016) and combat profound challenges in the industry and provide prospects for the industry.

BIM per Olawumi *et al*. (2017) has continued to gain relevance and significance in the AEC industry and was described by extant literature (Mahalingam *et al*., 2015; Malekitabar *et al*., 2016; Olawumi *et al*. 2017; Succar & Kassem, 2015) as an innovative digital technology. More so, BIM can be used throughout various stages of project development from the planning and design stage, through the construction phase, facility management to demolition. BIM is of two parts – the process and the enabling technology (Gilkinson *et al*., 2015). Its capacity of easing the dissemination of project information could enhance the success of projects (Olawumi, 2016; Olawumi *et al*., 2016) as well as help the clients to derive good returns on their investment (Olatunji *et al*., 2017).

Sustainability involves improving and supporting existing (or ongoing) structures or conditions without recreating. It is a new wheel drive and focuses on project stakeholders in addition to the existing project management triangle which includes cost, time and quality (Olawumi *et al*., 2017). Several research studies (Ahmad & Thaheem, 2017; Akanmu *et al*., 2015; Alsayyar & Jrade, 2015; Jalaei & Jrade, 2015) have been conducted which utilized BIM technologies to amplify the adoption and implementation of sustainable practices in the construction industry. The adoption and execution of sustainability principles in the construction industry are concerned with project stakeholders incorporating environmental, social and economic indicators and measures in making project decisions to ensure the implementation of sustainable development. More so, several sustainability rating systems such as BEAM-Plus (Hong Kong), LEED (United States), BREEAM (United Kingdom), Green STAR (Australia), CASBEE (Japan) and G-SEED (South Korea), have been developed and at various level of utilization in some countries.

This paper attempts to bridge the gap between knowledge base of BIM and sustainability studies by exploring their advantages to the construction industry. The study aims to assess the perceptions of project stakeholders on the perceived benefits of integrating BIM technologies and sustainability principles in the AEC industry through a Delphi survey. Although there has been reported literature about the benefits of BIM in the construction industry, this study extends it further by investigating the benefits to be gained when BIM technologies are used to amplify the implementation of sustainable principles in construction projects towards achieving a holistic sustainable development. A bibliometric analysis conducted by Olawumi *et al*. (2017) revealed that out of 445 BIM research articles, only 17 journal articles dealt with the concepts of both BIM and sustainability together in such papers. This study, therefore, contributes to existing knowledge in the field of construction technology and environmentally friendly construction and development.

2.0 Research Methodology

This study assessed the benefits of integrating BIM and sustainability practices at the design stage of construction projects. A quantitative research approach which involved a two-round Delphi survey was used to elicit the necessary data for this study. Thangaratinam and Redman (2005) suggested a two-stage Delphi study and three-round if one-round is an open-ended survey. Delphi survey methodology is a technique that allows the use of a series of questionnaires together with feedback (written summaries) for each round (Chan *et al*., 2015; Russel, 1993). More so, it is defined as "*a systematic and interactive research technique to obtain the judgment of a group of experts on a specific topic*" (Chan & Chan, 2012; Hallowell & Gambatese, 2010). The approach has often been used in the field of construction management (Chan & Chan, 2012) and several other areas to reach consensus among the experts. It is also useful when it is necessary to investigate areas of disagreements among the experts (Chan *et al*., 2001).

Two-rounds of Delphi surveys were launched from May to September of 2017. The design of the survey form for the round 1 of the Delphi study was based on a review of extant literature on BIM and sustainability in the construction industry (Table 1). A total of 36 beneficial factors of integrating BIM and sustainability principles at the design stage of construction projects. In round 2, the 14 experts who responded in the first round were given individual feedbacks on the consolidated results obtained in the previous round and were invited again to review or alter their original choices given the mean rating for each factor. Also, we provided them with their initial scores for each factor to facilitate their reviews. Both round 1 and round 2 results were then analyzed statistically using the Kendall's coefficient of concordance, mean score comparison and standard deviation.

Meanwhile, the credibility of this approach depends on the selection of the right experts for the study (Goldstein, 1975; Chan & Chan, 2012; Chan *et al*., 2001). A purposive sampling technique was employed in selecting and inviting experts for this study (Chan *et al*., 2015; Chan & Chan, 2012; Edmunds 1999; Morgan 1998). A total of 27 experts were invited. However, only 14 experts (consisting of 7 academics and 7 practitioners) ultimately responded to our email invitations.

Extant literature suggested a minimum panel size of seven experts (Thangaratinam & Redman, 2005; Mullen, 2003; Linstone, 1978). The invited experts are those who have satisfied at least two of the following criteria: (1) experts with extensive experience in the construction industry; (2) experts who have participated in current/recent projects on both BIM and sustainability in the AEC industry; and (3) experts with sound knowledge and understanding of the concepts of BIM and sustainability practices.

3.0 Data Analysis and Results

This section discusses the results of the two-rounds of Delphi surveys conducted in this study.

3.1 Reliability Testing

The internal consistency for the questionnaire factors and its associated Likert scale of measurement were assessed to ensure that it measures the right constructs (Samuel O

Olatunji *et al*., 2017). Cronbach's α reliability value ranges from 0 to 1, and an α value of 0.70 is acceptable. The Cronbach's alpha value for the first round of the Delphi survey is 0.965 while we have an α value of 0.966 for the round 2. It reveals a very high level of internal consistency and reliability of measures.

3.2 Expert panel demographics

As earlier stated, twenty-seven (27) experts were invited for the Delphi survey. However, only fourteen experts accepted the invitations and constituted the expert panel. The experts are from 8 different countries across three continents which include four (4) experts from the United Kingdom, three (3) experts from Hong Kong, two (2) experts from the United States and one (1) expert each from Mainland China, South Korea, Australia, Sweden and Germany.

More than 60% of the experts have more than eleven (11) years working experience in the construction industry with seven experts each from both the academia and the industry. Also, all the respondents have practical knowledge and expertise in either BIM or sustainability, and we have the majority of experts with sound knowledge of both concepts. The experts' profiles also lend credence to the data collected in this study.

3.3 Ranking based on Mean score

In total, 36 factors were ranked based on their mean scores (MS) and standard deviations (SD) which are based on the data collated from the study's Delphi experts (Table 2). Meanwhile, per Olatunji *et al*. (2017) if "two or more factors have the same mean score, factors with a smaller standard deviation are assigned higher ranks". They further suggested that if the factors have the same MS and SD, they would have the same rank. More so, factors with a mean score of 4 or above on a 5-point Likert scale are regarded as important (Olatunji *et al*., 2017; Lu *et al*., 2008).

Noteworthy from the analysis reveals that the expert panel has refined their choices on some factors during the second round of the Delphi survey. For instance, there were some rankings of factors such as factor '1A' had changed from 2nd to 5th, factors '4H' and '5H' increased from 4th to 2nd each. However, factors such as '1C' (1st), '1E' (2nd), '1B' (35th) and '2B' (36th) among others retained their mean rankings. More so, the majority of the factors have a mean score of 4.00 or above. Therefore, we identified eight (8) factors with a mean score of 4.50 or above in the two rounds (Table 2).

Furthermore, the most significant factors of the eight factors are four (4) factors which include factor '1C' with values (4.79 ranked as 1st; 4.93 ranked as 1st)**; factor '1E' (4.64 ranked as 2nd; 4.71 ranked as 2nd). Also, factor '4H' (4.57 ranked as 4th; 4.71 ranked as 2nd), and factor '5H' (4.57 ranked as 4th; 4.71 ranked as 2nd).

*Note: ** means (MS in round 1, mean rank in round 1**;** MS in round 2, mean rank in round 2).*

3.4 Kendall's coefficient of concordance (W)

Kendall's concordance analysis is used to measure the level of agreement among the experts and to determine whether the respondents respond consistently or not (Chan &

Chan, 2012; Kvam & Vidakovic, 2011). The value of W ranges from 0 (perfect disagreement) to 1 (perfect disagreement). More so, the value of W is considered together with the p-value of the analysis. According to Chan and Chan (2012), if the p-value is less than 5% significance level, it implies that there is a considerable degree of consensus among the respondents.

More so, for this study's Delphi survey, the Kendall coefficient of concordance (W) increased from 0.255 ($p<0.005$) of the first round to 0.335 ($p<0.005$) in the second round. It can be concluded that there is a considerable level of consensus on the factors ranked by the experts in the second round.

Table 1: Beneficial factors of integrating BIM and sustainability practices at the design stage of construction projects

Code	Benefits of integrating BIM and sustainability practices at the design stage of construction projects	Sources of reference
1A	Enhance overall project quality, productivity, and efficiency	1, 2, 3
2A	Schedule compliance in the delivery of construction projects	1, 4, 5
3A	Predictive analysis of performance (energy analysis, code analysis)	6, 7
4A	Improve the operations and maintenance (facility management) of project infrastructure	1, 8
1B	Reduction in cost of construction works and improvement in project's cost performance	1, 8
2B	Improve financial and investment opportunities	9
3B	Reduction in the cost of as-built drawings	2
1C	Facilitate sharing, exchange, and management of project information and data	10, 1
2C	Facilitates resource planning and allocation	11
3C	Reduction in site-based conflicts	2, 12
1D	Ease the process to obtain building plan approvals and construction permits	13
2D	Support collaboration and ease procurement relationships	14
3D	Reduced claims or litigation risks	6
4D	Increase firms' capability to comply with prevailing statutory regulations	15
1E	Better design of products and facilitate multi-design alternatives	6, 8, 1
2E	Facilitate building layout flexibility and retrofitting	16
3E	Real-time sustainable design and analysis early in the design phase	17
1F	Facilitate, support and improve project-related decision-making	14, 8
2F	Improved organization brand image and competitive advantage	17, 9
3F	Enhance business performance and technical competence of professional practice	14
4F	Enhance innovation capabilities and encourage the use of new construction methods	14, 9, 4
1G	Prevent and reduce materials wastage through reuse & recycling and ensure materials efficiency	2, 9
2G	Reduce safety risks and enhance project safety & health performance	3
3G	Control of lifecycle costs and environmental data	1
4G	Facilitate the implementation of green building principles and practices	18
5G	Ease the integration of sustainability strategies with business planning	9, 19
6G	Minimize carbon risk and improve energy efficiency	9, 19

7G	Improve resource management and reduce environmental impact across the value chain	9, 19
8G	Facilitate the selection of sustainable materials, components, and systems for projects	19, 20
9G	Higher capacity for accommodating the three pillars of sustainability (social, economic & environmental sustainability)	20
1H	Enhance the accuracy of as-built drawings	21
2H	Facilitate integration with domain knowledge areas such as project management, safety, and sustainability	22
3H	Allow the checking of architectural design of buildings from the sustainability point of view	23
4H	Facilitate accurate geometrical representations of a building in an integrated data environment	1
5H	Ability to simulate building performances and energy usage	24
6H	Encourage the implementation of clean technologies that require less energy consumption	20, 9, 19

Notes: Digits in the '*sources of reference*' column are references from the past studies.
1 = Azhar (2011); 2 = Hanna *et al*. (2013); 3 = Akula *et al*. (2013); 4 = Phillip (2013); 5 = Al Hattab and Hamzeh (2015); 6 = Eastman *et al*. (2008); 7 = Sacks *et al*. (2010); 8 = CURT (2010); 9 = BSN (2007); Wong *et al*. (2014); 11 = Hua (2013); 12 = Boktor *et al*. (2014); 13 = McGraw-Hill Construction (2009); 14 = Aibunu and Venkatesh (2014); 15 = Silverstein (2016); 16 = Webster and Costello (2005); 17 = Autodesk (2011); 18 = Wu and Issa (2014); 19 = Autodesk (2010); 20 = Anton and Diaz (2014); 21 = Eastman *et al*. (2011); 22 = Kam *et al*. (2012); 23 = Abolghasemzadeh (2013); 24 = Akinade *et al*. (2015)

Table 2: Experts' mean score ranking for Round 1 and Round 2

S/N	Factors	Round 1 (All experts)			Round 2 (All experts)		
		Mean	SD	Rank	Mean	SD	Rank
1	1A	4.64	.497	2	4.64	.497	5
2	2A	4.14	.770	20	4.07	.730	26
3	3A	4.43	.514	9	4.57	.514	8
4	4A	4.57	.514	4	4.64	.497	5
5	1B	3.57	.938	35	3.50	.855	35
6	2B	3.43	.646	36	3.43	.646	36
7	3B	3.93	.616	29	3.86	.663	31
8	1C	4.79	.579	1	4.93	.267	1
9	2C	4.14	.770	20	4.14	.663	22
10	3C	4.36	.842	15	4.43	.756	12
11	1D	3.64	.745	34	3.71	.726	34
12	2D	3.93	.997	32	3.86	s.949	32
13	3D	3.79	.893	33	3.79	.893	33
14	4D	3.93	.829	30	3.93	.829	30
15	1E	4.64	.497	2	4.71	.469	2
16	2E	4.36	.745	13	4.43	.646	11
17	3E	4.57	.646	7	4.64	.633	7
18	1F	4.36	.497	11	4.36	.497	15
19	2F	4.07	.829	27	4.14	.770	23
20	3F	4.14	.770	20	4.29	.611	18
21	4F	4.36	.497	11	4.36	.497	15
22	1G	4.43	.852	10	4.50	.760	10
23	2G	4.14	.949	26	4.07	.917	27
24	3G	4.14	.864	23	4.29	.825	20
25	4G	4.21	.802	18	4.29	.825	20
26	5G	4.21	.802	18	4.14	.770	23
27	6G	4.36	.745	13	4.43	.756	12
28	7G	4.14	.864	23	4.14	.864	25
29	8G	4.29	.726	16	4.36	.745	17
30	9G	4.07	.997	28	4.07	.997	28
31	1H	4.50	.650	8	4.57	.514	8
32	2H	3.93	.917	31	4.00	.877	29
33	3H	4.29	.825	17	4.43	.756	12
34	4H	4.57	.514	4	4.71	.469	2
35	5H	4.57	.514	4	4.71	.469	2
36	6H	4.14	.864	23	4.29	.726	19

4.0 Conclusions and Future Research Directions

There have been increased in research in BIM and sustainability studies in recent years. However, only a few studies had attempted to investigate the integration of BIM technologies to amplify the implementation of sustainability practices in the construction industry. This study identified the perceived benefits of integrating BIM and sustainability principles in the construction projects using a two-round of Delphi survey. The study also identified 36 beneficial factors from the review of extant literature which were ranked by 14-member expert panel consisting of seven academics and practitioners each.

The four (4) most significant benefits are factor 1C "facilitate sharing, exchange, and management of project information and data" (MS = 4.93, SD = 0.267); factor 1E "better design of products and facilitate multi-design alternatives" (MS = 4.71, SD = 0.469). Also, factor 4H "facilitate accurate geometrical representations of a building in an integrated data environment" (MS = 4.71, SD = 0.469); and factor 5H "ability to simulate building performances and energy usage" (MS = 4.71, SD = 0.469). This study has contributed to existing knowledge by providing both academics and practitioners with an extensive list of key benefits to be derived when BIM technologies are adopted to amplify the implementation of sustainable practices. It also points out the salient benefits which relate to sharing of project data (models and sustainability data) among stakeholders which would facilitate a collaborative working in the construction industry.

Conclusively, further research works can dwell on using BIM and other innovative technologies (such as RFID, GIS, etc.) to amplify the execution of sustainable principles and the three pillars of sustainability – economic, social and environmental technologies in the built environment towards ensuring a sustainable urban development.

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