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AN INVESTIGATION INTO THE USE OF BUILDING INFORMATION MODELLING AND ITS IMPACT ON CONSTRUCTION PERFORMANCE WITHIN GHANAIAN CONSTRUCTION INDUSTRY

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Building Information Modelling (BIM) is a key computer aided technology that can facilitate construction productivity enhancements through the removal of numerous construction inefficiencies. This study investigates the use of BIM and its impact on construction project performance in Ghanaian architecture, engineering and construction industry. A cross-sectional survey design was adopted for the study. Self-administered questionnaires were used for data collection from architects, structural and civil engineers, project managers, quantity surveyors, contractors and general foremen in Greater Accra, Ashanti and Western Regions. Purposive sampling technique was used to elicit information from 300 participants. Data was analysed through the use of multiple response analysis, relative importance index (RII), principal component analysis and descriptively analysis. The results indicated that experts in the construction industry obviously agreed that the use of BIM has a great impact on construction project performance. Increase productivity, improve product quality and create customer value, help in removing barriers and constraints, reduce time of project design and shop drawings, improve communication effectiveness, provide accurate cost estimation and take off materials, reduce conflicts and number of claims, reduce defects in the construction phase, increase collaboration in project design were considered by the respondents as the most important factors for project performance improvement. It is recommended that experts and stakeholders should encourage the use of BIM technology in Ghanaian construction industry to improve construction project performance to meet customer satisfaction and also boost the infrastructural development.

Keywords: building information modelling (BIM), construction performance, Ghana

INTRODUCTION

Information technology (IT) is one of the promising tools which have been constantly deemed as a solution to save construction projects. Among those,

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computer-aided design (CAD) software applications have been playing the leading role for more than three decades in the construction industry (CI). BIM-supported software applications are the new generation of CAD software applications (Parvan, 2012). Building Information Model (BIM) is known as a shared digital representation of the physical and functional characteristics of the facility in the Architectural, Engineering and Construction (AEC) industry. The basic premise of BIM is to improve collaboration and interoperability among the stakeholders of the facility during its lifecycle. The 3D visualization is the basic essential feature of BIM. However, BIM is not just a 3D CAD. It is more than the elaborated 3D renderings. Also, it is more than delivering the project documentation in the electronic version. It is about information use, reuse, and exchange, of which the digital format is just one part (Parvan, 2012).

General Services Administration (GSA, 2007) BIM guide defines BIM as the development and use of a multi-faceted computer software data model not to only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. BIM is the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way (Vanlande, Nicolle & Cruz, 2008). BIM is a revolutionary technology and process that has quickly transformed the way buildings are conceived, designed, constructed and operated (Hardin, 2009). BIM can also be referred to as a computer-integrated project due to its process and technology application in project delivery (Azhar et al., 2012).

The building industry is under great pressure to provide value for money, sustainable infrastructure, visual and analytical checks to enable better code compliance and this has boosted the implementation of BIM technology (Mihindu & Arayici, 2008). According to Ahadzie and Amoa-Mensah (2010) and Laryea (2010), the Ghanaian construction industry faces challenges that include inadequacy of finance and credit services for contractors, design constraints and variation of works, poor preparation and supervision as well as low computerization. A further challenge of construction management is the poor estimation of project cost (Agele, 2012; cited in Akwaah, 2015). The industry is changing and adopting new ways of working which include an increased digitalization and implementation of BIM (Crotty, 2013, Bryde et al. 2013), supply chain integration (Briscoe & Dainty, 2005) and productivity enhancement (Dubois & Gadde, 2002). Stakeholders in the construction industry use variety of scheduling methods, study as well as its application; however, they are not sufficiently competent to fulfil the need of building parties. Thus, parties in AEC industries make use of scheduling methods such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), Gantt Charts, Task List, Simulation and others but yet have short comings in project delivery. There exists a huge discrepancy among the implementation as well as plan (Allen & Smallwood, 2008).

Studies conducted on BIM in Ghana include Akwaah (2015), on the guideline for building the capacity of contractors for adoption and implementation of BIM in Ghana. Nani (2015) studied the guidelines for capacity building of construction firms for BIM adoption in Ghana. Acquah, Eyiah and Oteng (2018) investigated the acceptance of BIM, which was a survey of professionals in the construction industry in Ghana. Akwaah and Nani (2015) investigated the fundamental requirements for the adoption and implementation BIM of by contractors, the state of BIM implementation, the relevance of BIM implementation, and the challenges of BIM implementation to construction firms in Ghana. Armah (2015) considered the areas of implementing BIM in the construction industry, the benefits that come with the adoption of BIM, and the barriers to BIM implementation in the construction industry in Ghana.

All the above researches on BIM in Ghana did not consider the use of building information modelling and its impact on construction project performance. This gap necessitated the need to conduct a study on the use of building information modelling and its impact on construction performance in the Ghanaian construction industry since that aspect is lacking in BIM literature in Ghana. The purpose of the study is to investigate the use of building information modelling and its impact on construction performance within the Ghanaian construction industry.

LITERATURE REVIEW

Building Information Modelling (BIM)

Alvarez-Romero (2014), described Building Information Modelling (BIM) as one of the most promising technologies for the Architecture, Engineering, and Construction industries. Building information models encapsulate and represent the three-dimensional geometry of building objects and the corresponding attributes of a physical facility. By its very nature, it promotes collaboration from design and construction participants around the digital model of a facility. The core of BIM is the building geometry, but also is a structured information base of non-graphical data that provides detailed information about the identity of building components and their properties, for example a wall element in a model exists as a wall and is no longer represented by a set of drawn lines (Alvarez-Romero, 2014). The National Building Information Model Standards (NBIMS) vision for BIM is an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by throughout its lifecycle (NIBS 2008). This definition implies a collaborative and integrated approach (see Figure 1). BIM is a tool used by designers, engineers, and contractors to present the graphics and database of a construction project to enhance the communication between all project stockholders (Krygiel & Nies, 2008).

Katez and Gerald (2010) define BIM as a "multi-faceted computer software data model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalized facility" (p. 26). Meanwhile, Krygiel and Nies (2008) define BIM as "the creation and use of coordinated, consistent, computable information about a building project in design-parametric information used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, and construction planning" (p. 27). The BIM model presents the actual building construction and assemblies and two-dimensional drawings (Azhar, 2011).

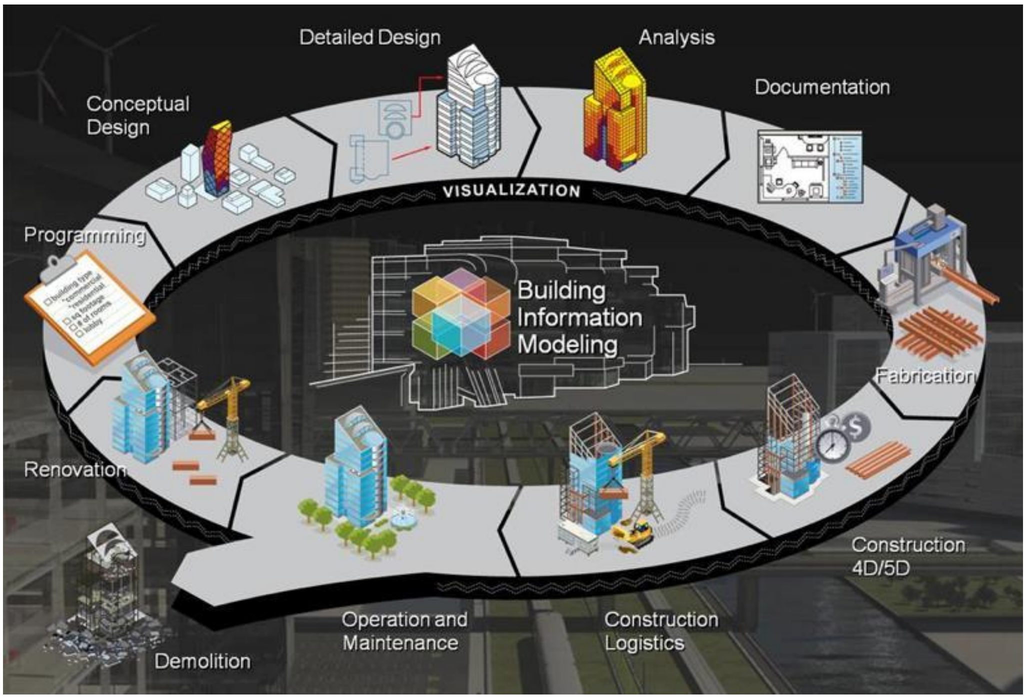

Figure 1: Collaborative and Integrated view of BIM through the project lifecycle, Image Source: Alvarez-Romero (2014).

Figure 2 shows a 3D external model for a commercial building design in Iraq presenting the final design concept and the finishing materials of the building.


Figure 2: A 3D BIM model for a commercial building design in Babylon city- Iraq
Source: Hussein and Zaid (2016).

BIM has created a new development revolution in the design and construction industry. It is causing a major paradigm shift in the Architectural, Engineering and construction industry while creating wider and newer opportunities for young professionals (Uddin & Atul, 2014). While this creates a positive drive and focuses on this industry, it is also important to fully understand what BIM encompasses. BIM is expansive (Turk, 2016). Turk's study discusses the structural, functional and behavioural attributes of BIM which indicate its complex nature. Roles such as BIM managers, BIM coordinators and BIM specialists are becoming increasingly popular and sought after for BIM assisted construction projects. The complex nature of BIM can be seen in a study that identified the motivations for adopting BIM were multi-dimensional (Dongping, 2016). BIM consists of several dimensions, 3D BIM models, 4D BIM adds time-related information to 3D to enable detailed scheduling of the construction process. 5D BIM adds costs to BIM components to assist the calculation of total project costs. 6D BIM includes lifecycle properties to enable optimised asset management. This makes the entire process complex in nature

Therefore, a limited understanding of its capability and resultant impacts would mean that the industry would not be maximizing the benefits of BIM and in some instances could harm the progress and expansion of BIM.

The pursuit to better understand and define BIM has prompted studies to establish a standard for effectively measuring and understanding Building Information Modelling Maturity (BIMM). Chen (2013) explores BIMM and investigated the indicators and related factors that would capture a more comprehensive understanding of BIM as it relates to its maturity (Chen, Hazar Mark, & Mihaela, 2016). The study by Chen proposes that BIMM can be grouped under Technology, Information, Process and People. Succar identifies the factors proposed by Chen but also includes Policy as a factor of BIM (Succar, Sher, & Williams, 2012). Therefore, the literature review indicated that the comprehensiveness of BIMM can be measured through Information, Technology, Process, People and Policy Management. Maturity is synonymous for effectiveness and performance as the Building Information Modelling is composed of dimensions such as Technology, information, process and people. The application of software's, information delivery methods, Process & Technology Innovation as well as competency profile of teams in the AEC industries determines the output of work.

Chen (2013), presented a table listing the dimensions/factors and grouped indicators under the relevant dimensions as seen in Table 1. Collaboration among project participants is important for aspects of Productivity. However, it seems that software interoperability has been a significant issue in the application of BIM (Bynum, 2013). Project delivery is a team work which includes the client's team, construction team, statutory personals and designers. BIM usage brings on board all the various stakeholders or persons together and as such, each of the team performs a unique function to realize an effective delivery of project amounting to its general performance. A critical success factor for the successful implementation of BIM is the willingness of participants to share information (Won et al, 2013). BIM can be used as an effective platform for collaboration by changing the way construction is performed and documented (James & Meadati, 2008). For collaboration in practice, a case study showed that there was an expectation for participants on BIM projects to drive collaboration, as opposed to having an expectation of a collaborative organizational structure (Dossick & Neff, 2010). These studies refer to BIM being a platform for collaboration and as a result a means of achieving productivity. However, the studies indicate a necessity to improve elements such as software interoperability of BIM, while also improving leadership from the participants to share information and collaborate.

Table 1: BIMM Dimensions and Indicators

BIMM Dimension	BIMM Indicator
Technology (Chen, 2013; Jung and Joo, 2011; Succar 2010)	Software Applications Interoperability Hardware Equipment Hardware Upgrade
Information (Chen et al. 2014; CIC 2011; NIBS 2007)	Information Delivery Method (IDM) Information Assurance Data Richness Real-Time Data Information Accuracy Graphics Geospatial Capability Work Flow Documentation and Modeling Standards (DMS)
Process (Giel & Issa 2013; Gu	Process & Tech Innovation (PTI)
& London 2010; Mom et al. 2011)	Strategic Planning
	Lifecycle Process
	Change Management
	Risk Management
	Standard Operating Process (SOP)
	Quality Control
People (Chen, 2013; Computer Integrated	Senior Leadership
Construction, 2013; Gu & London, 2010; Gu, Singh,	Role
& London, 2014)	Reward System
	Competency Profile
	Training Delivery Method (TDM)

Source: Chen (2013)

Understanding BIM

From a technology perspective, a building information model is a project simulation consisting of the 3D models of the project components with links to all the required information connected with the project planning, design, construction or operation as depicted in Figure 3 (Kymmell, 2008). The BIM technology hailed from the object-oriented parametric modelling technique (Azhar et al., 2008). The term "parametric" describes a process by which an element is modified and an adjacent element or assembly (e.g. a door attached to a wall) is automatically adjusted to maintain a previously established relationship (Stine, 2011).

BIM as technology

From a technology perspective, a building information model is a project simulation consisting of the 3D models of the project components with links to all the required information connected with the project planning, design, construction or operation as depicted (Kymmell, 2008). The BIM technology hailed from the object-oriented parametric modelling technique (Azhar et al., 2008). The term "parametric" describes a process by which an element is modified and an adjacent element or assembly (e.g. a door attached to a wall) is automatically adjusted to maintain a previously established relationship (Stine, 2011).

BIM as a process

BIM can be viewed as a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all team members (Owners, architects, engineers, contractors, subcontractors and suppliers) to collaborate more accurately and efficiently than traditional processes. As the model is being created, team members are constantly refining and adjusting their portions according to project specifications and design changes to ensure the model is as accurate as possible before the project physically breaks ground (Carmona & Irwin, 2007).

BIM as people

Competencies may be expressed as "behaviour that an individual need to demonstrate", or they may be expressed as "minimum standards of performance". BIM competency represents the ability of users to fulfil all the important areas of an effective BIM implementation to deliver value and achieve the expected BIM product/service. BIM implementation process can produce valuable benefits to BIM users by having the ability to introduce and implement changes effectively (Giel and Issa, 2013c; Nepal et al., 2014; Succar, 2010a). The skills, knowledge and behaviour of people leads to successful performance. These skills, knowledge and behaviour are required to deliver certain activities for successful performance.

RESEARCH METHODOLOGY

A cross-sectional survey was employed for the research design as it permitted the researchers to study the participants once and therefore not necessitating follow-ups (Shuttleworth, 2010). In turn, this design was used to determine the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, explore the most important factors of improvement in performance on construction projects as a result of adoption and implementation of BIM in the construction industry in Ghana. Creswell and Plano (2011) defined the research population as a large well-defined collection of individuals having similar features. The target population for this study consisted of experienced professionals from the architectural consultancy firms, quantity surveying firms, and structural engineering firms operating within the Kumasi, Accra, and Sekondi-Takoradi metropolises in Ghana.

The sampling frame used for the study was well-established firms registered by the Architectural Registration Council-Ghana, Ghana Institute of Surveyors and Ghana Chamber of Construction. Bryman (2004) opined that sampling techniques tell us how part of the population used in data collected is carefully chosen. The study, therefore, employed purposive sampling to select the firms from the sampling frame as well as the respondents engaged in the study. This technique was chosen specifically because the number of construction projects who had adopted BIM technology greatly overshadowed the number of projects not into this technology, so it facilitated the ease in reaching such firms. Again, this technique ensured participants selection was based on the participant's organization's knowledge on BIM (Saunders et al, 2012). In effect, the survey sample consisted of professionals such as architects, engineers, quantity surveyors, contractors and general foremen drawn from 300 participants sampled from the study population.

A close-ended questionnaire was used for collecting data. This is essentially because this tool has the track record as the most reliable technique that helps collect important and valid data (Easterby-Smith et al., 2002). In the design, the questionnaire was supported by literature and thereafter categorized into five main broad headings. The process equally permitted respondents to either rate responses on a seven-point Likert scale and also make multiple choices when it was necessitated. The first part constituted the demographic characteristics of the respondents. The second part was composed of determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. Exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of BIM in the construction industry in Ghana made the third part as the fourth part highlighted on measuring the relevance of BIM maturity in the Ghanaian construction industry. The fifth and final part focused on determining the various softwares available for BIM essential.

Conca et al. (2004) contended that validity explains the extent to which a test item or an instrument measures what it is purposed to measure. To ensure that the instrument captured all the relevant areas of using BIM technology and the whole proposed survey instrument was well worded and understood; thus, content validity, the questionnaire was sent to two lecturers well versed in BIM technology to check the comprehensiveness of the items under each construct. This helped to improve the content, thereby eliminating ambiguity and ensuring its ease of understanding. To maximize the reliability of the questionnaire, the items generated were pretested on a sample of 20 professionals sharing similar characteristics as the study sample and also in the construction industry at Obuasi Municipal. Reliability refers to the extent to which an instrument measures the same way each time it is used under the same conditions with the same subjects (Naoum, 2007). This sample is consistent with a study by Patton (2002) that suggests that the sample size for a pilot study should be at least 20 respondents. This pre-test aimed to ensure that quantitative measurements corresponded with expected results from interaction with construction consultants. The Cronbach's alpha values of the measurement used met the threshold of 0.7 (Hair et al., 2003; Pallant, 2007) as shown in Table 2.

Table 2: Reliability Analysis

Objective	Cronbach's Alpha	No. of variables
Key drivers for acceptance and implementation of BIM in the construction industries in Ghana.	0.878	36
Most important factors of improvement in performance on construction projects.	0.821	13
Measuring the relevance of BIM maturity in the Ghanaian construction industry.	0.871	28
Various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.	0.846	23

The questionnaire was self-administered over a period of about six months in the towns of Kumasi, Accra and Sunyani respectively to the targeted respondents to seek the necessary information in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. This was preceded by previewing respondents on the necessary arrangements regarding the date, time and place where applicable. Respondents were also informed about the confidentiality of their responses. The quantitative data collected from the field survey through the use of closed-ended questionnaire items were analysed on the Statistical Package for Social Sciences (SPSS) version 25 and Microsoft excel software.

RESULTS AND DISCUSSION

Descriptive statistics were used to analyse the data subsequently. 214 well-answered questionnaire items were received from a total of 300 items self-administered. This thus approximates the response rate to about 71%.

Key drivers for acceptance and implementation of BIM in the construction industries in Ghana.

Aimed at determining the key drivers for acceptance and implementation of BIM in the construction industry, the respondent's views were subjected to multiple response analysis and ranked subsequently. This was established based on the fact that respondents were presented with items that demanded more than a single response and had the option to select any that they deemed appropriate. The items were tabulated as a dichotomy group at a value of 1 (Yes), a threshold set as the selected item of preference with value 2 (No) as otherwise. The number of "Yes" responses were only tabulated and ranked consequently against the "No" responses from the participants. Again, the key drivers as stated earlier in the objective explained the need and urge as well as the benefits accrued in the use of BIM in the construction industry. They were classified in terms of their advantages, stakeholder's involvement, capabilities and functions and types of buildings affected as shown in Table 3.

In dealing with a data set that offers respondents the liberty to select more than a response at the same time, multiple response analyses stand significant (Simon, 2013). In this respect, the technique was used in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. Six main drivers were identified in this effect. These are; capability and function to create drawings, the involvement of architect/engineers as stakeholders, advantage gained as a result of enhanced productivity, capability and function in providing quality take-off, the involvement of construction managers as stakeholders and its usage in commercial building projects. The capability and function to create drawings came up as a key driver in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. According to Azhar (2011), building proposals can be rigorously analysed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions to generate a better design.

Inevitably, stakeholders like architects as well as engineers form a core component in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. This assessment was clarified by Azhar et al, (2012), who claimed that the project architects and engineers can take advantage of BIM in schematic and detailed design; and construction detailing phases.

Table 3: Key drivers for the acceptance and implementation of BIM in the construction industries in Ghana.

Drivers	Responses		Ranking by category	Overall ranking
	N	Percent		
Advantages				
Enhance productivity	167	30.5%	1	3
Competitive Advantage	140	25.6%	2	8
Exploring and adopting new trends	91	16.6%	3	14
Required by owners or contracts	75	13.7%	4	19
Success stories of others using BIM	74	13.5%	5	20
Total	547	100.0%		
Stakeholders				
Architect/Engineers	183	35.9%	1	2
Construction Managers	155	30.4%	2	5
General Contractors	77	15.1%	3	17
Owner/Developers	43	8.4%	4	25
Consultants	31	6.1%	5	28
Subcontractors	18	3.5%	6	33
Software Vendors	3	0.6%	7	36
Total	510	100.0%		
Capabilities and Functions				
Create drawings	191	15.9%	1	1
Quantity Take-off	159	13.2%	2	4
Site Planning	120	10.0%	3	9
Clash Detection	119	9.9%	4	10
Scheduling and sequencing	83	6.9%	5	15
Costing and Budgeting	80	6.7%	6	16
Improve project controls	74	6.2%	7	20
Communication	69	5.7%	8	21
Facility management	55	4.6%	9	22
Facilitate decision making	48	4.0%	10	23
Equipment management	46	3.8%	11	24
Waste management	41	3.4%	12	26
Labour resource allocations	35	2.9%	13	27
Collaboration with stakeholders	30	2.5%	14	30
Energy analysis	21	1.7%	15	31
Code compliance	19	1.6%	16	32
Virtual meeting capabilities	11	0.9%	17	34
Total	1201	100.0%		
Types of Building Projects				
Commercial	153	22.3%	1	6
Industrial	148	21.6%	2	7
Residential	118	17.2%	3	11
Educational	93	13.6%	4	12
Institutional	93	13.6%	5	12
Healthcare	77	11.2%	6	17
Transportation	4	0.6%	7	35
Total	686	100.0%		

The construction industry in developed countries is experiencing a major move from the traditional methods of intensive manual Laboure towards the utilization of automation that has been made possible through the use of information technology. This trend results in enhanced construction efficiency leading to improved productivity in terms of reduction in wastage, errors, and rework Nath et al. (2015). Provision of quantity take-off as a function and capability of BIM greatly impacts the essence for the acceptance and implementation of BIM in the construction industries in Ghana. Efficient and accurate quantity take-off and cost estimation are pivotal to a project's success (Staub-French, 2003). Aram et al. (2014) emphasized the conditions for successful BIM use in ensuring quality take-off.

The involvement of construction managers as stakeholders forms a major element as a key driver for the acceptance and implementation of BIM in the construction industries in Ghana. Construction managers or general contractors can use BIM to extract quantities of work to prepare cost estimates (Hergunsel, 2011). Complex construction projects require inter-organizational associations (Maurer, 2010). To ensure success in inter-organizational project ventures, trust between the different project partners is acknowledged as a key success factor (Kadefors, 2004; Maurer, 2010). Because of the nature of work in these inter-organizational ventures, there is a well-recognized need for better integration, cooperation, and coordination of construction project teams (Cicmil & Marshall, 2005, cited in Maunula, 2008).

Most important factors of improvement in performance on construction projects as a result of the adoption and implementation of BIM in the construction industry in Ghana.

In exploring the level of improvement in performance on construction projects as a result of adoption and implementation of BIM in the Ghanaian construction industry, opinions of respondents were analysed using the Relative Importance Index (RII) and subsequently ranked according to their relative importance. This was based on a seven-point Likert scale from strongly important (=7) to strongly unimportant (=1). According to Akadiri (2011), the criticality of RII is defined as follows; strongly unimportant (≥ 0.14), very unimportant (0.15 – 0.29), unimportant (0.30 – 0.44), moderately important (0.45 – 0.59), important (0.60 – 0.74), very important (0.75 – 0.89) and strongly important (≥ 0.90). Data obtained from respondents therefore were used to calculate the importance of each level of improvement in performance as the basis of the ranking (Table 5). This may be calculated using the formula;

$$RII = \sum \frac{W}{AN}$$

Where RII (Relative index) is used for ranking indicators (degree of importance), W is the weight given to each item by respondents on a scale of one to seven with one implying the least and seven the highest, A is the highest weight (7 in our case) and N is the number of respondents (Akadiri 2011). Table 4 displays the Relative Importance Index (RII) of the level of improvement in performance on construction projects as a result of adoption and implementation of BIM in the Ghanaian construction industry with their associate rankings concerning their mean values. The threshold for the key levels of performance improvement was set at a range of 0.75 – 0.89 and any level below this range was not deemed prime. It was evident per the criticality of the RII that ten levels of performance improvement (falling within the range 0.75 – 0.89) were identified as "very important" which are interpreted as key levels regarding the level of improvement in performance on construction projects as a result of adoption and implementation of BIM in the Ghanaian construction industry. These levels with their corresponding RII accordingly are; increases productivity (0.81), improves product quality and creates customer value (0.81), helps in removing barriers and constraints (0.80), reduces conflicts and number of claims (0.79), reduces the time of project design and shop drawings (0.79), improves communication effectiveness (0.79), provides accurate cost estimation and take off materials (0.77), reduces conflicts and number of claims (0.77), reduces defects in the construction phase (0.76) and increases collaboration in project design (0.75).

Table 4: Level of improvement in performance of construction projects as a result of adopting and implementation of BIM

Level of improvement in performance	RESPONSES (RANKING)							TOTAL	∑W	MEAN	RII	DESCRIPTION
	1	2	3	4	5	6	7					
Increases productivity	2	0	12	15	50	79	56	214	1214	5.67	0.81	Very important
Improves product quality and creates customer value	0	1	1	20	80	61	51	214	1208	5.64	0.81	Very important
Helps in removing barriers and constraints	1	2	1	24	67	80	39	214	1192	5.57	0.80	Very important
Reduces the time of project design and shop drawings	2	1	0	23	69	73	44	214	1187	5.55	0.79	Very important
Reduces the time of project design and shop drawings	0	1	0	19	87	76	31	214	1186	5.54	0.79	Very important
Improves communication effectiveness	0	1	14	31	56	54	58	214	1178	5.50	0.79	Very important
Provides accurate cost estimation and take off materials	0	0	1	33	87	67	26	214	1154	5.39	0.77	Very important
Reduces conflicts and number of claims	1	1	1	16	112	61	22	214	1150	5.37	0.77	Very important
Reduces defects in the construction phase	2	3	1	52	38	100	18	214	1135	5.30	0.76	Very important
Increases collaboration in project design	3	1	0	62	41	77	30	214	1130	5.28	0.75	Very important
Reduces uncertainty inherent in the construction phase	1	15	2	27	84	78	7	214	1082	5.06	0.72	Important
Generates and evaluates alternative construction plans	1	1	26	43	69	44	30	214	1072	5.01	0.72	Important
Aids in just in time delivery of materials and parts	0	1	8	57	96	41	11	214	1057	4.94	0.71	Important

An increase in productivity came up as an important factor in the improvement in performance on construction projects as a result of the adoption and implementation of BIM in the construction industry of Ghana. It is perceived to have the potential to significantly change and improve performance and documentation in the AEC industry by reducing inefficiencies, enhancing productivity, and increasing collaboration and communication (Campbell 2007;

Goedert & Meadati 2008). Improvement of product quality and creation of customer value emerged also as one of the important factors in performance on construction projects as a result of adoption and implementation of BIM. This is advocated by Jylhä and Junnila (2012) who claim that customers are the nursing companies and their nursing staff; special focus is given to the value potentials that BIM, as well as improved environmental performance, might offer to the customers. From this perspective, it could be said that, to improve product quality and customer value by using processes and systems which aim to fulfil the customer's requirements, enhance customer satisfaction, monitor against applicable quality standards have a great impact on the performance on a construction project.

Another factor obtained is the improvement in product quality and creating of customer value. Czmoch and Pękala (2014) attested that the construction process enforces the final and accurate decision to be taken. They emphasized further that the BIM model requires accuracy in modelling from the very beginning and that strict standards and rules have to be set within the team to work according to BIM standards as this affects the whole designing teamwork and its efficiency. BIM technology requires the members of the design team to abandon the individual working schemes, so characteristic for each person and specific for discipline or design office.

Reduction of time of project design and shop drawings found itself among the most important factors geared towards improvement in performance on construction projects as a result of adoption and implementation of BIM. Azhar (2011) postulates that BIM can do faster drafting without compromising quality. Linderoth (2010) maintains that the result of using BIM is improved project coordination, minimised errors, as well as reduced delays and conflicts, which could lead to a potential saving in construction cost.

Measuring the relevance of BIM maturity in the Ghanaian construction industry.
To ascertain the suitability of the data for factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and a Bartlett's Test of Sphericity were performed (Table 5). As a rule of thumb, a KMO value of 0.5 or higher necessitates the need to proceed with factor analysis. Therefore, obtaining (Chi-square = 6434.809, df = 231, $p < 0.000$) signifies that it is worth continuing with factor analysis as there is a relationship to investigate.

Table 5: KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.856
Bartlett's Test of Sphericity	Approx. Chi-Square	6434.809
	df	231
	Sig.	0.000

To better appreciate the opinions of respondents in measuring the relevance of BIM maturity in the Ghanaian construction industry, their views were subjected to factor analysis (Table 6). In effect, five main factors came up regarding the precepts underlying the use of this statistical tool. Again, an accumulated value of about

80% emanating from five factors met the criteria of explaining variance of 5%. Further, these five had considerable theoretical backing thus making them interpretable. However, two factors fell outside the scope of this bracket and were eliminated eventually. Concerning their variance explained, their percentages were 53. 625%, 15.409%, 6.281% and 5.266% and subsequently ascribed to component 1, component 2, component 3 and component 4 respectively (Table 6).

Table 6: Total Variance explained

Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11.797	53.625	53.625	6.262	28.466	28.466
2	3.390	15.409	69.033	5.266	23.937	52.403
3	1.382	6.281	75.315	3.555	16.160	68.563
4	1.163	5.285	80.600	2.648	12.036	80.600

Extraction Method: Principal Component Analysis

Varimax rotation method was used to obtain the factor loadings with their corresponding components in measuring the relevance of BIM maturity in the Ghanaian construction industry (Table 7).

Table 7: The relevance of BIM maturity in the Ghanaian construction industry

Relevance	Component			
	1	2	3	4
Interoperability			**0.847**	
Software Applications			**0.697**	
Hardware Equipment			**0.693**	
Information delivery method			**0.578**	
Information Accuracy	**0.874**			
Graphics	**0.865**			
Real-time Data	**0.834**			
Senior Leadership	**0.790**			
Process and Technology Innovation	**0.780**			
Data Richness	**0.700**			
Information Assurance	**0.689**			
Strategic Planning	**0.688**			
Geo-spatial Capability	**0.660**			
Specification		**0.904**		
Quality Control		**0.889**		
Documentation and Modeling Standards		**0.811**		
Standard Operating Process		**0.801**		
Work Flow		**0.765**		
Life Cycle Process		**0.737**		
Training Program				**0.844**
Competency Profile				**0.777**
Training Delivery Method				**0.771**

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser

Component one: information related factors
The principal component explained 53.625 % of the total variance with nine factors loading unto it. These factors were; information accuracy, graphics, real-time data, senior leadership, process and technology innovation, data richness, information assurance, strategic planning and geo-spatial capability. According to Eastman et al. 2008, BIM provides information on the ability to evaluate the impact of design changes on construction in a visual manner that is not possible with traditional 2D drawings. Regarding information accuracy, they reiterated further that automated quantity take-off which is linked to the BIM model is more accurate as there are fewer chances of human error; hence, it improves flow by reducing variability. Making information from the BIM especially with the increasing complexity of projects denotes such an improvement beneficial to better control its related complexity issues (Hamdi et al., 2012). Upon the submissions churned out, information related factors are very essential as it prevents doubts, clients and other parties in the Architecture, Construction, Engineering industry rely on requisite information in decision making on projects.

Component two: process-related factors
Process related factors had their principal component explaining 15.409 % of the total variance with six factors loading unto it. These included, specification, quality control, documentation and modeling standards, standard operating process, work flow and life cycle process. Pas (2013) hints that and BIM defines how the information modelling aspects of a project will be carried out and clarifies roles and their responsibilities, standards to be applied and procedures to be followed. Giel et al. (2013) attested that, in terms of the BIM specification process, it has specific metrics well defined and serve industry-specific assessment purposes. Quality control, an inevitable process in BIM was clearly explained by Aranda-Mena et al. (2009) who advocates that with building information modelling implementation, quality control ensures that the activities conducted, the mechanisms or techniques used for a project meet the requirements for the product or service are used.

Component three: Technology-Related Factors
The principal component defined 6.281 % of the total variance as four factors loaded unto it. The factors were interoperability, software applications, hardware equipment and information delivery method. NIBS (2007) advanced that BIM serves as an eminent technology with its interoperability properties. Expanding further, they explained that software interoperability is seamless data exchange among diverse applications which each may have its internal data structure. Data usage, storage and exchange are well defined within organisations and project teams therefore signifying that interoperable data exchanges are defined and prioritized (Succar, 2010). This in effect affirms that technology field BIM representing the availability, accessibility and affordability of hardware, software and network systems; also, the availability, usability, connectivity and openness of information systems have an impact on the construction project performance.

Component four: People Related Factors
People related factors under this principle component explained 5.285 % of the total variance. Three main factors were loaded unto it which were, training program, competency profile and training delivery method. Gu and London (2010)

suggested that, in reaching the level of BIM maturity to better understand and facilitate its adoption in the AEC industry, training should be organized for its users 'overtime. They directed that this training should be dedicated to the use of BIM software tools and the workflows associated with them to be competent in its usage in project delivery. In defining this competency involved through training of the people concerned Dakhil et al. (2019).

4.4 Various software available for BIM essential for the Ghanaian AEC companies

Pursuance to determining the various software's available for BIM essential for the Ghanaian AEC companies, respondent's views were descriptively examined. The outcome of the analysis was based on the precept that mean values of (≥ 3.5) were tagged as " Most available", those within the range (3 – 3.49) as "Available", so as those within (2.5 – 2.99) as " Somewhat available" and those falling under (≤ 2.0) also classified as "Rarely available (Table 8).

Table 8: Software's available for BIM essential

Software's	Mean	SD	Description
Revit Architectural	4.02	1.138	Most available
AutoCAD Architectural	3.88	1.293	Most available
SketchUp	3.81	1.028	Most available
ArchiCAD	3.72	1.153	Most available
AutoCAD Civil 3D	3.52	1.244	Most available
AutoCAD	3.52	1.244	Most available
AutoCAD Design Suite Premium	3.36	1.146	Available
Bentley Systems	3.23	1.127	Available
Revit Structure	3.21	0.722	Available
ARCHline	3.18	0.988	Available
Revit MEP	3.18	1.099	Available
Chief Architect	3.11	1.445	Available
Edificius 3D Architectural	3.04	0.978	Available
3D Ultimate	3.00	1.179	Available
Tekla	2.92	1.221	Somewhat available
Autodesk Navisworks	2.91	1.600	Somewhat available
AutoCAD MEP	2.91	1.436	Somewhat available
Vector Works	2.78	1.246	Somewhat available
Autodesk Navisworks	2.64	1.149	Somewhat available
Twinmotion	2.53	1.741	Somewhat available
Lumion	2.12	1.252	Rarely available

With over twenty variables opened to participant's opinion specifically on deducing the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies, six of these software's came up as the most available softwares. Interesting, Revit architecture emerged as the most available software for BIM essential for the Ghanaian AEC companies. Revit architecture software is used used for 3D architectural modelling and parametric design (Reinhardt, 2009). Guan-Pei, (2010) accentuated that, Revit architecture assumes this enormous patronage because it contains a set of tools, techniques and concepts that allow realizing the BIM approach toward general construction design. AutoCAD architecture similarly surfaced as one of the most available software for BIM essential. Confirming this assertion is AutoCAD (2009), which reckoned that AutoCAD Architecture is the version of AutoCAD software for architects. Drafting and documentation are much more efficient with the software's intuitive environment and purpose-built tools for architects. Another significant software that fell within the bracket of the most available software for BIM essential was SketchUp. According to Ying et al. (2011), SketchUp is used to automatically construct 3D models with attributes and thematic information from 2D survey plans. They stressed that spatial topologic relationships and operations are analysed with the programming and development of the Ruby language.

ArchiCAD similarly remained as another most available software for BIM essential. ArchiCAD allows its users to create 3-D structures with "smart objects" such as walls, slabs, roofs, doors, windows and furniture. 2-D drawings (plan and elevation views) can be created from 3-D creations (KIA 2013). Jiang, (2011) indicated that ArchiCAD is the Virtual Building Explorer, a real-time 3D navigation that is enhanced with gravity, layer control, fly-mode, egress recognition and pre-saved walkthroughs. AutoCAD Civil 3D equally emerged as one of the most available software for BIM essential. Varela-González (2013) suggests that AutoCAD Civil 3D software is a BIM solution for design and documentation in the civil engineering field from Autodesk. AutoCAD Civil 3D supports BIM and helps reduce the time it takes to design, analyse, and implement changes (Autodesk, 2017). Convincingly, AutoCAD was one of the most available software for BIM essential. Autodesk (2017) hints that AutoCAD software provides the power and flexibility to help drive your projects from concept through creation quickly and efficiently; visualize design concepts within a 3D environment, quickly and accurately document designs, and collaborate with clients and contractors to save time and money. The study conducted by Danso (2012) found that the most known general CAD software program in the Universities in Ghana offering civil engineering and related programs is AutoCAD.

CONCLUSION

The study sought to investigate the use of BIM and its impact on construction performance within the Ghanaian construction industry. With regards to the levels of importance of improvement in performance on construction projects as a result of adopting and implementation of BIM in the construction industries in Ghana, nine of the levels considered to be very important were: increases productivity, improves product quality and creates customer value, helps in removing barriers and constraints, reduces the time of project design and shop drawings, improves communication effectiveness, provides accurate cost estimation and take off materials, reduces conflicts and number of claims, reduces defects in the construction phase, and increases collaboration in project design. The study, therefore, concludes that stakeholders in the Ghanaian construction industry have a competitive advantage over other non-BIM users as the BIM application in construction projects reduces. The study recommends that experts and stakeholders should encourage the use of BIM technology in Ghanaian construction industry to improve construction project performance to meet customer satisfaction and also boost the infrastructural development.

REFERENCES

Acquah, R., Eyiah, A. K., & Oteng, D. (2018). Acceptance of Building InformationModelling: a survey of professionals in the construction industry in Ghana. ITcon, 23, pp.75-91.

Agele, J. A. (2012). Adoption of Building Information Modeling and Nigerian's Quest for Project Management.

Ahadzie, D. K., & Amoa-Mensah, K. (2010). Management practices in the Ghanaian house building Industry. Journal of Science and Technology (Ghana), 30(2).

Akadiri, P. O., & Olomolaiye, P. O. (2012). Development of sustainable assessment criteria for building materials selection. Engineering, Construction and Architectural Management.

Akwaah, G. (2015). Guideline for building the capacity of contractors for adoption and implementation of building information modelling (BIM) in Ghana (Doctoral dissertation).

Allen, C., & Smallwood, J. (2008). Improving construction planning through 4D planning. Journal of Engineering, Design and Technology.

Alvarez-Romero, S. O. (2014). Use of building information modeling technology in the integration of the handover process and facilities management (Doctoral dissertation, Worcester Polytechnic Institute).

Aram, S., Eastman, C., & Sacks, R. (2014), January. A knowledge-based framework for quantity takeoff and cost estimation in the AEC industry using BIM. In The 31st International Symposium on Automation and Robotics in Construction and Mining.

Aranda-Mena, G., Crawford, J., Chevez, A., & Froese, T. (2009). Building information modelling demystified: does it make business sense to adopt BIM? International Journal of managing projects in business.

Armah, N. N. O. (2015). Assessing the Benefits and Barriers of the use of BIM in the Ghanaian Construction Industry. Unpublished Thesis in Construction Management. Kwame Nkrumah University of Science and Technology, Kumasi.

AutoCAD, L. T. (2009). Autodesk®.

Autodesk, (2017). Autodesk®.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), pp.241-252.

Azhar, S., Hein, M. & Sketo, B. (2008), April. Building information modeling (BIM): Benefits, risks and challenges. In Proceedings of the 44th ASC Annual Conference (pp. 2-5).

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modelling (BIM): now and beyond. Construction Economics and Building, 12(4), pp.15-28.

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modelling (BIM): now and beyond. Construction Economics and Building, 12(4), pp.15-28.

Bryman, A. (2004). Qualitative research on leadership: A critical but appreciative review. The leadership quarterly, 15(6), pp.729-769.

Bynum, P., Issa, R. R., & Olbina, S. (2013). Building information modeling in support of sustainable design and construction. Journal of construction engineering and management, 139(1), pp.24-34.

Campbell, D. A. (2007), April. Building information modeling: the Web 3D application for AEC. In Proceedings of the twelfth international conference on 3D web technology (pp. 173-176).

Carmona, J., & Irwin, K. (2007). BIM: Who, what, how and why. Building Operating Management, 54(10), pp.37-39.

Chen, L., & Luo, H. (2014). A BIM-based construction quality management model and its applications. Automation in construction, 46, pp.64-73.

Chen, Y. (2013). Measurement Models of Building Information Modeling Maturity. (Ph.D), Purdue University, Ann Arbor

Cicmil, S., & Marshall, D. (2005). Insights into collaboration at the project level: complexity, social interaction and procurement mechanisms. Building Research & Information, 33(6), pp.523-535.

Computer Integrated Construction, C. (2013). BIM Planning Guide for Facility Owners: The Pennsylvania State University, University Park, PA, USA.

Computer Integrated Construction, CIC. (2011). BIM Project ExecutionPlanning Guide (pp. 125): Pennsylvania State University.

Conca, F. J., Llopis, J., & Tarı□, J. J. (2004). Development of a measure to assess quality management in certified firms. European journal of operational research, 156(3), pp.683-697.

Creswell, J. W., Klassen, A. C., Plano Clark, V. L., & Smith, K. C. (2011). Bestpractices for mixed methods research in the health sciences. Bethesda (Maryland): National Institutes of Health, 2013, pp.541-545.

Crotty, R. (2013). The impact of building information modelling: transforming construction. Routledge.

Czmoch, I., & Pękala, A. (2014). Traditional design versus BIM based design. Procedia Engineering, 91, pp.210-215.

Dakhil, A. J., Underwood, J., & Alshawi, M. (2019). Critical success competencies for the BIM implementation process: UK construction clients. Journal of information technology in construction (ITcon), 24, pp.80-94.

Danso, H. (2012). Assessment of the awareness of structural computer aided design programs of universities in Ghana. European Journal of Social Sciences, 30(1), pp.41-47.

Dongping, C., Heng, L., Guangbin, W., & Ting, H. (2016). Identifying and contextualizing the motivations for BIM implementation in Construction projects: An empirical study in China. International Journal of Project Management, 12.

Dossick, C. S., & Neff, G. (2010). Organizational divisions in BIM-enabled commercial construction. Journal of construction engineering and management, 136(4), pp.459-467.

Dubois, A., & Gadde, L. E. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. Construction management & economics, 20(7), pp.621-631.

Easterby-Smith, M., Thorpe, R., & Lowe, A. (2002). Management research: An introduction. London, Sage Publications.

Giel, B. K., & Issa, R. R. (2013). Return on investment analysis of using building information modeling in construction. Journal of computing in civil engineering, 27(5), pp.511-521.

Goedert, J. D. and Meadati, P. (2008). Integrating construction process documentation into building information modeling. Journal of construction engineering and management, 134(7), pp.509-516.Gu & London 2010

GSA, B. (2007). Guide for spatial program validation—GSA BIM guide series 02., US General Services Administration, Washington, DC.

Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. Automation in construction, 19(8), pp.988-999.

Gu, N., Singh, V., & London, K. (2014). BIM ecosystem: the coevolution of products, processes, and people. Building information modeling: BIM in current and future practice, pp.197-210.

Guan-pei, H. (2010). BIM and BIM software. Journal of Information Technology in Civil Engineering and Architecture, 4, 110-117. Taking from: A

Hair, A. R. (2003). U.S. Patent No. 6,615,349. Washington, DC: U.S. Patent and Trademark Office.

Hamdi, O., & Leite, F. (2012, July). BIM and Lean interactions from the bim capability maturity model perspective: A case study. In Proceedings for the 20th Annual Conference of the International Group for Lean Construction. The International Group for Lean Construction.

Hardin, B. (2009). BIM and construction management, proven tools, methods, and workflows. Indianapolis: Wiley Publishing.

Hergunsel, M. F. (2011). Benefits of building information modeling for construction managers and BIM based scheduling.AI Hussein, Z.K., 2016. Using Building Information Modeling (BIM) and the Last Planner System (LPS) to Reduce Construction Process Delay.

Jiang, X. (2011). Developments in cost estimating and scheduling in BIM technology.

Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation. Automation in construction, 20(2), pp.126-133.

Jylhä, T., & Junnila, S. (2012, July). Using the Kano model to identify customer value. In 20th Annual Conference of the International Group for Lean Construction.

Kadefors, A. (2004). Trust in project relationships—inside the black box. International Journal of Project Management 22 (3), 175–182.

Katz, G. I., & Crandall, J. C. (2010). Building information modeling: The present the construction industry. Construction Accounting & Taxation, 20(1), pp.26-32.

Krygiel, E., & Nies, B. (2008). Green BIM: successful sustainable design with building information modeling. John Wiley & Sons.

Kymmell, W. (2008). Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations (McGraw-Hill Construction Series). McGraw-Hill Education.

Linderoth, H. C. (2010). Understanding adoption and use of BIM as the creation of actor networks. Automation in construction, 19(1), pp.66-72.

Maunula, A., & Smeds, R. (2008). The implementation of building information modeling (BIM): A process perspective. Teknillinen korkeakoulu.

Maurer, I. (2010). How to build trust in inter-organizational projects: The impact of project staffing and project rewards on the formation of trust, knowledge acquisition and product innovation. International journal of project management, 28(7), pp.629-637.

Mihindu, S., & Arayici, Y. (2008, July). Digital construction through BIM systems will drive the re-engineering of construction business practices. In 2008 international conference visualisation (pp. 29-34). IEEE.

Mom, M., Tsai, M. H., & Hsieh, S. H. (2011, November). On decision-making and technology-implementing factors for BIM adoption. In International Conference on Construction Applications of Virtual Reality (pp. 86-92).

Nani, G., & Akwaah, G. (2015). Guidelines for Capacity Building of Construction Firms for Building Information Modeling (BIM) Adoption in Ghana. ARCA, p.468.

Naoum, S. G. (1998). Dissertation Research and Writing for Construction Students, Oxford: Bultermouth-Heinemom.

Nath, T., Attarzadeh, M., Tiong, R. L., Chidambaram, C., & Yu, Z. (2015). Productivity improvement of precast shop drawings generation through BIM-based process re-engineering. Automation in Construction, 54, pp.54-68.

National Institute of Building Science (NIBS) 2007, United States National Building Information Modelling Standard™ Version 1 - Part 1: Overview, Principles, and Methodologies.

Parvan, K. (2012). Estimating the impact of building information modeling (BIM) utilization on building project performance (Doctoral dissertation).

Patton, M. Q. (2002.) Two decades of developments in qualitative inquiry: A personal, experiential perspective. Qualitative social work, 1(3), pp.261-283.

Reinhardt, J., & Klancnik, D. (2009). The Contractor's Guide to BIM—. Appendix C: BIM Tools Matrix." AGC of America.

Saeed, K. I. A. (2013). Review of Building Information Modeling (BIM) Software Packages Based on Assets Management. Amirkabir University of Technology, Department of Civil and Environmental Engineering, 27.

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2012). Research methods for business students (6th ended.) Harlow. England: Pearson Education.

Shuttleworth, R., Russell, C., Weerakoon, P., & Dune, T. (2010). Sexuality in residential aged care: A survey of perceptions and policies in Australian nursing homes. Sexuality and Disability, 28(3), pp.187-194.

Staub-French, S., Fischer, M., Kunz, J., & Paulson, B. (2003). A generic feature-driven activity-based cost estimation process. Advanced Engineering Informatics, 17(1), pp.23-39.

Stine, D. J. (2012). Design Integration Using Autodesk Revit 2013. SDC Publications.

Succar, B. (2010). Building information modelling maturity matrix. In Handbook of research on building information modeling and construction informatics: Concepts and technologies (pp. 65-103). IGI Global.

Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. Architectural Engineering and Design Management, 8(2), pp.120-142.

Turk, Ž. (2016). Ten questions concerning building information modelling. Building and Environment, 107, pp.274-284.

Uddin, M. M., & Khanzode, A. R. (2014). Examples of How Building Information Modeling can enhance career paths in construction. Practice Periodical on Structural Design and Construction, 19(1), pp.95-102.

Vanlande, R., Nicolle, C., & Cruz, C. (2008). IFC and building lifecycle management. Automation in construction, 18(1), pp.70-78.

Varela-González, M., González-Jorge, H., Riveiro, B., & Arias, P. (2013). Performance testing of LiDAR exploitation software. Computers & Geosciences, 54, pp.122-129.

Won, J., Lee, G., Dossick, C., & Messner, J. (2013). Where to focus for successful adoption of building information modeling within organization. Journal of construction engineering and management, 139(11), p.04013014.

Ying, S., Li, L., & Guo, R. (2011). Building 3D cadastral system based on 2D survey plans with SketchUp. Geo-spatial Information Science, 14(2), pp.129-136.