Development of a Benchmarking Model for BIM Implementation in Developing Countries

Abstract

Purpose– This paper explored BIM implementation and practices in developed economies into developing a benchmarking model that will enhance BIM adoption and implementation in developing countries.

Design/methodology/approach– The research design adopted a qualitative approach which includes the desktop review of the extant literature as well as case study reviews of 10 BIM projects using an explanatory case study technique to form the foundation upon which the study proposed the model. The Moving Basis Heuristics (MBH) technique was adopted to develop the scoring system.

Findings– The BIM benchmarking model and assessment template were developed which consisted of three-level concepts modeled to aid project organizations and project team in developing countries to assess and score the level of improvement and implementation of BIM in a project. A review of BIM projects in developed countries demonstrated the significant improvements and benefits possible through the implementation of the established BIM benchmarking model.

Practical implications– The assessment template in conjunction with the benchmarking model are useful for comparative evaluation of similar BIM projects and benchmarking purposes. The study also discussed how current findings compared to previous works in the literature.

Originality/value– The findings have provided policymakers, construction stakeholders and professional bodies in the construction industry in developing countries with valuable insights and counter-intuitive perspective that could facilitate the uptake of BIM in construction projects.

Keywords: BIM, innovative strategies, benchmarking model, assessment template, scoring system, developing countries.

1. Introduction

The development and integration of information technologies (IT) have helped improved construction processes and practices in the built environment (Aksamija, 2012; Chien & Mahdavi, 2009; Dawood, 2009; Thomassen, 2011; Wikforss & Löfgren, 2007). Thus, the construction industry been as a composite sector, made up of diverse stakeholders (Olatunji et al., 2016; Olawumi et al., 2016; Olawumi & Ayegun, 2016) need to be proactive in its adoption of IT in its operation. Buswell *et al.* (2007) noted that a construction project has traditionally relied on 2D drawings to convey project information and data. However, the advent and increasing importance of Building Information Modelling (BIM) have changed the working system in the industry with the development of 3D models of building structures, and its capacity to integrate other concepts such as sustainability, project scheduling, costing and facility management.

Tulubas-Gokuc and Arditi (2017) described BIM as a "trend of the future" with significant impacts on professional performances. One of the benefits of BIM implementation in projects is to facilitate effective communication among project stakeholders (Olatunji et al., 2017) and could enhance business operations (Ahankoob et al., 2018). Consequently, BIM has seen a dramatic increase in its application across the project phases in recent years (Dim et al., 2015; Patrick & Ii, 2010). According to Eastman et al. (2008), BIM is one of the several other technologies in the architecture, engineering, and construction (AEC) industries and per Autodesk (2010), BIM is a more sophisticated tool with better feedback mechanisms for its users. Also, according to Olawumi and Chan (2018c), BIM as a versatile technology can help advance the implementation of green buildings and innovations in the built environment. In contrast, some of the existing IT applications in the construction industry are constrained by their reliance on static methods of information delivery (Aziz et al., 2009; Buswell et al., 2007).

Olawumi and Chan (2018a) identified BIM as one of the recent innovative concepts in the country industry which per Olawumi and Chan (2018b) has improved the design and construction of building projects. Inyim et al. (2015) described BIM as "an advanced example of an ICT approach" and outlined ways in which the construction industry uses ICT: (1) information management and service; (2) communications; and (3) processing and computing. Pero et al. (2015) pointed out the usefulness of BIM as a veritable IT tool for data sharing and exchange. BIM is a process of generating and managing information of a building or infrastructure during its life cycle (Kuiper & Holzer, 2013). Eastman et al. (2011) also defined it to be "*a modeling technology and associated set of processes to produce,* *communicate, and analyze building models*." BIM allows for multi-disciplinary information to be superimposed on one model (Autodesk, 2008; Schlueter & Thesseling, 2008). Nevertheless, per Van Lith et al. (2015), the definition of BIM is still under debate with several interpretation depending on how it is deployed in a project. Meanwhile, Olawumi et al. (2018) categorize BIM implementation in two aspects such as (1) the BIM product or technology uses in creating building models and simulating the design parameters, and (2) the BIM process which affords the synthesis of relevant of information relating to a project within a central hub. However, according to Matthews et al. (2018), the inadequate knowledge and experience on how to adopt BIM in a project as resulted in stakeholders undertaking its implementation in a cluttering manner.

1.1 Knowledge gaps, research objectives and values

The construction industry needs to revamp its practices and systems for it to strive profitably like other sectors such as the automobiles; a viewpoint supported by Van Lith et al. (2015) who noted that the industry is plagued with issues of inefficiency, fragmentation, adversarial culture and lack of collaborative working environemnt. In a similar vein, a succession of reports on how to tackle construction related issues has emphasized this notion. These include: 'Reaching for the Skies' in 1934, the Simon Report in 1944 among others. Also, in 1997, a report by the Construction Task Force headed by Sir John Egan argued that the real value of a project would not be achievable unless the entire supply chain worked as a team, including the client; and other industry-sponsored initiatives.

Developed economies such as the US, the UK, Australia, etc. have attempted to a great level of success to implement concepts and technologies such as BIM and its associated add-ins to improve some of the salience issues (*like project information management*) in the construction industry. A study by Boktor et al. (2014) on the North American construction industry reveals that BIM has helped reduce conflict on the project, increased efficiency and enhance project coordination. Accordingly, they observed the increased use of BIM by contracting firms in the region. Pärn and Edwards (2017) developed a BIM plug-in (FinDD API) to facilitate the integration of BIM and facility management (FM) semantic data, the findings reduce costs and ease the updating of FM data in the as-built BIM.

More so, Zhang et al. (2013) developed an algorithm using a case study project that can automatically check building models and schedules for safety measures to prevent related site hazards. Also, Gelisen and Griffis (2014) developed an automated tool for predicting, managing and optimizing productivity issues associated with construction projects. A BIM-based integrated system that can improve the efficiency and collaboration among project stakeholders using a hospital project as a case study was developed by Oh et al. (2015). It shows improved design quality and work efficiency.

The above studies from the extant literature show some of the several ways BIM had been employed to solve construction-related problems in developed economies. A review of global BIM research and implementation in the built environment by (Olawumi et al., 2017) reveals a little or no level of BIM research in the developing countries. It revealed just seven BIM studies, one in Nigeria and six studies in Egypt (Olawumi et al., 2017); which is very insignificant compared to other regions and is also indicative of the low level of adoption of BIM in developing countries. In a similar vein, a previous study by Jung and Lee (2015) indicated an advanced level of BIM implementation in North America, Europe, Asia, and Oceania. Accordingly, the study described countries in the Middle East, Africa and South America to still being in the early adoption phase.

Some of these developing countries might have been using BIM in some forms, such as in the 3D design of building models. Although, there are no records of the subsequent application in the construction or facility management stages in the literature. For example, the first BIM conference that seeks to educate construction professionals on BIM and its processes was organized in Nigeria in the late year 2016. In contrast, the developed countries have implemented BIM to some reasonable degree across the project development phases (Jung and Lee, 2015; Olawumi et al., 2017). Matthews et al. (2018) stressed the importance of the development of a framework to enable professionals acquire a deep contextual understanding of BIM and how to apply it to the project. Also, Matthews et al. (2018) argued for the need to incorporate training, education and learning into such BIM strategy.

Given the above, the study aims to enhance the adoption of BIM and its implementation in the construction sectors of developing countries; using lessons drawn from extant literature and case study BIM projects in developed economies to develop a benchmarking model and an assessment template for developing countries (or countries still in the early development phase of BIM adoption).

The research objectives are: (1) to explore the strategies for improving BIM processes and products; (2) to develop a benchmarking model to ensure efficient management of project information using BIM; (3) to develop an assessment template to score the level of implementation of BIM practices in developing countries; and (4) to deduce lessons from case study BIM projects in developed economies to demonstrate possibilities in BIM adoption by developing countries. The findings of this study will help to advance BIM research in developing countries by highlighting the BIM best practices and strategies for improving BIM processes and products. The discussion of some case study BIM projects in advanced economies will further highlight the possibilities and benefits of BIM for project stakeholders in emerging economies.

2. Review of BIM maturity models in developed countries

A study by Jung and Lee (2015), and Olawumi et al. (2017) gave a breakdown and the illustration of BIM adoption in several countries and regions of the world. Key western countries such as the United States, Canada, the United Kingdom, Germany and Portugal as well as South Korea, China, Australia in Asia revealed a more substantial implementation of BIM in their construction sectors (Olawumi et al., 2017). However, regions such as Africa, southern America, and the Middle East are still at the BIM infant maturity stage (Jung & Lee, 2015; Olawumi et al., 2017).

BIM maturity index or model is a set of knowledge tools and conceptual models developed to evaluate the level (*maturity*) of BIM adoption and implementation in a project or an organization. Some BIM-related maturity indexes have been developed in the literature such Lainhart (2000) who developed a Control Objects for Information and related Technology (COBIT) to address issues related to IT risks and vulnerabilities in organizations. Meanwhile, Vaidyanathan and Howell (2007) advanced the Construction Supply Chain Maturity Model (CSCMM) to improve operational excellence at firm and project performance levels. The CSCMM matrix is proposed to help the management and flow of project information, funds.

More so, other developed maturity indices include I-CMM- “Interactive Capability Maturity Model” (Suermann et al., 2008); “Knowledge Retention Maturity Levels” (Arif et al., 2009); LESAT- “Lean Enterprise Self-Assessment Tool” (Nightingale & Mize, 2002). Others are P3M3- “Portfolio, Programme and Project Management Maturity Model” (OGC, 2008); BPO- “Business Process Orientation Maturity Model” (Lockamy & McCormack, 2004) and PM^2- “Project Management Process Maturity Model” (Kwak & Ibbs, 2002).

McCuen et al. (2012) evaluated some awarding winning BIM projects in the United States based on the Capability Maturity Model (CMM) produced by the National Building Information Model Standard (NBIMS). The findings indicated the use of BIM in areas such as visualization, designs. However, BIM is still less used for virtual analysis and other critical aspects lifecycle views, change management, data richness, etc. The study also listed some challenges faced by those BIM projects to include interoperability between software and maturity of BIM users in their roles and disciplines (McCuen et al., 2012).

More so, Succar et al. (2012) discussed the five metrics for assessing the competency and capacity of organization or project team, individuals in delivering a BIM project. The study also highlighted some BIM maturity indexes developed in the extant literature. Succar et al. (2012) argued for the establishment of an independent BIM certification organization to accredit individuals or corporate bodies towards improving BIM performance in construction projects. Meanwhile, Chen et al. (2014) utilized a survey method to measure key maturity areas developed in previous models. The findings revealed more emphasis should be placed on BIM process and information, as well as on technology and people.

Giel and Issa (2013) highlighted some key competencies or characteristics to be possessed by building clients or owners to be categorized as an experienced BIM user. More so, the study undertook some comparative analysis of existing BIM maturity index. In a similar vein, Giel and Issa (2016) utilized a Delphi technique to develop a BIM competency evaluation framework for building owners and facility managers. Also, BIM maturity indexes such as the Bew and Richards maturity model (Bew & Richard, 2008) and the Bilal Succar linear model (Succar, 2009) have been developed to enhance BIM efficiency in projects. Figure 1 depicts the Bew-Richards BIM maturity model.

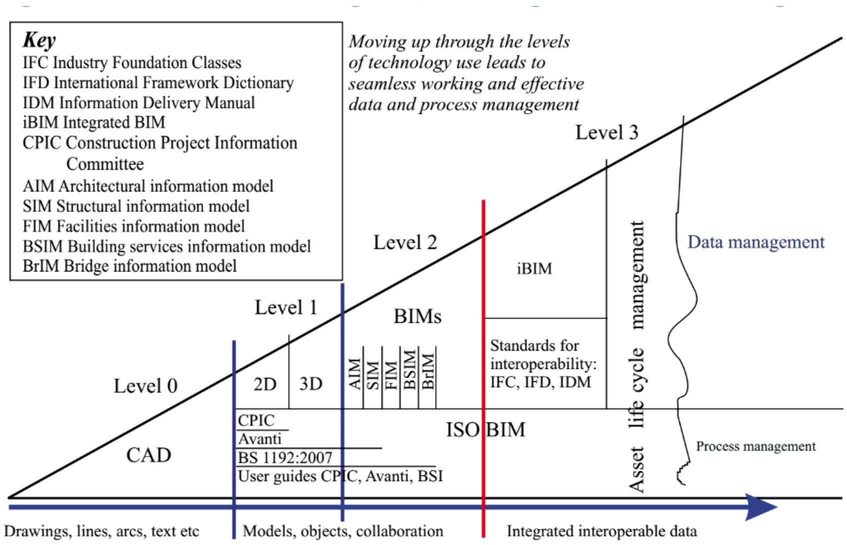

Figure 1: Bew-Richards Maturity Model (Bew & Richards, 2008)

3. Research methodology

The research design for this study included: (1) desktop literature review; and (2) case study review of ten (10) BIM projects. Firstly, the study carried out a review of extant literature on BIM studies undertaken in developed economies and regions categorized by Jung and Lee (2015) and Olawumi et al. (2017) with the matured level of BIM adoption and implementation to established strategies for improving BIM process and products in developing countries. More so, the comprehensive literature review was augmented with the authors' experiential knowledge which according to Maxwell (2005) is typical of conceptual research. The search article databases and search engines include Google Scholar, ISI Web of Science, and Scopus.

The developed benchmarking model is composed of three-level (3L) concepts: (1) innovative strategies at BIM process level; (2) innovative strategies at BIM product level; and (3) measures of good practices. These high-level concepts interact in such a way to enhance and improve the management of project information, amplify BIM implementation in developing countries, provide avenues for quantitative assessment of BIM performance and implementation in projects among others.

Secondly, the study uses an explanatory case study technique which involved both a review of the selected ten BIM projects in developed countries and generation of some cause-effect relationships to demonstrate ways wherein BIM have revolutionized the construction process and information management in such projects with an advanced level of BIM adoption. Explanatory case study research according to Chong et al. (2014) is used to "compare with a set of variables to reach a specific outcome." Blatter and Haverland (2012) noted that it starts with a specific aim, the interplay of the causal conditions, generation of data through perceptions and the proximity between cause and consequences and drawing of conclusion based on the identified mechanism that is sufficient and necessary for the research outcome. Lessons and the contributory benefits of BIM are drawn from these projects to ease BIM adoption and implementation in developing countries. A Moving Basis Heuristics (MBH) approach (Kamdjoug et al., 2007; Shah & Oppenheimer, 2008) was adopted to develop the scoring system for the BIM benchmarking model developed in this study.

4. 3-level (3L) Concepts and benchmarking model development

This section highlights and discusses the development of the three-level concepts (A-B-C) or strategies to enhance BIM uptake in developing countries, benchmarking model development, and the development of an assessment template to aid project organizations and project team in developing countries to assess and score the level of improvement and implementation of BIM in a project. Van Lith et al. (2015) and Succar (2009) described BIM as a set of "policies, processes and technologies aiming to manage building design and project data in a digital format throughout the building's life cycle."

A. BIM processes

BIM is not a thing or a type of software but a human activity that ultimately involves extensive process changes in construction; and it is used to describe an activity rather than an object (Eastman et al., 2008). The construction sector processes as considered by Kazi et al. (2009) is mainly by delivery of unique product and service delivery through competence and information sharing between different organizations. Therefore, this necessitates the idea that underpinned the fact that there is a need for improvement in the existing framework and processes for BIM-based information management.

Hence, to improve the BIM processes in construction projects in developing countries, the following strategies are recommended for implementation. It includes: (1) group support system (GSS) on BIM; (2) efficient online sharing of project data and simulation results; (3) specialized training workshops for BIM users; (4) improving accessibility of relevant BIM data; and (5) Extending BIM adoption to the facility management phase.

1. Group support system (GSS) on BIM: GSS is a set of techniques, and technology designed to focus on and enhance the communications, deliberations, and decision-making process of groups (Chung & Shen, 2004). It can take the form of an interactive computer-based system that can help facilitate the solution of unstructured problems by a group of people that must make decisions. Studies such as Katranuschkov et al. (2010) and Redmond et al. (2012) also pointed out the need for stakeholders to imbibe and encourage collaborative attitude in the construction industry. A survey by Scheer et al. (2007), observed the increasing adoption of IT by construction professionals. Hence, it is recommended for construction stakeholders and professional bodies in developing countries or regions still in the early BIM adoption phase to adopt GSS as part of their project management tool to increase the uptake of BIM in projects. Van Lith et al. (2015) stressed the importance of BIM in assisting project team in the management and flow of project information.

2. Efficient online sharing of project data and results: Studies (*see* Abolghasemzadeh, 2013; Akinade et al., 2016) have advocated the need for the development of a system or procedure to ease the exchange of BIM data. More so, some BIM software such as Autodesk GBS requires an internet connection and authorization for its use (Azhar et al., 2009); however, the limited penetration and speed of internet services in most developing countries will hamper its adoption, and there is the probable case of incurring extra cost of data bandwidth (Akanmu et al., 2015). Significant investment in IT by the government and corporate organization involved in construction projects will go a long way to enhance online information exchange and the development of a central BIM information hub in these countries.

3. Specialized training workshops for BIM users: BIM design and analysis software could be complicated and require specialized training to use them (Autodesk, 2010). Extant literature (Abubakar et al., 2014; Aibinu & Venkatesh, 2014; Chan, 2014; Olawumi et al., 2017) highlighted several benefits to organizations and in construction projects when consideration is given to enhancing the BIM competency of project staff. Given this, construction professional organizations and firms in developing countries should invest in the training of their members and staff on BIM technologies applicable to their operations. The training is expected to enhance the skill sets and development of in-house personnel on the use of BIM.

4. Improving accessibility of relevant BIM data: Watson (2011) argued that intensifying the sharing and reuse of relevant data during the planning/design, and construction phase will ease the reuse of project information at the facility management phase. These project data are process results (Cerovsek & Katranuschkov, 2006); and they include architectural and structural solutions, drawings, sustainability analysis results, etc., which are communicated through a BIM-based tool to facilitate the ease of information retrieval. Moreover, this study recommends the development of context databases which will allow for historical comparisons of BIM models and help to promote knowledge reuse, integration of innovations, and integration of captured data with contextual history. Van Lith et al. (2015) also pointed out that BIM acts as an interface between the main contractors and suppliers in aspect of design, communication and management of project data.

5. Extending BIM adoption to the facility management phase: Motamedi and Hammad (2009) proposed permanently attaching radio frequency identification (RFID) tags to building components where the memory of the cards is populated with accumulated life cycle from a standard BIM database. They proved through case studies that these tags provide a distributed database of BIM and allow data access for various users. Other studies such as Fang et al. (2016) and Motamedi et al. (2016) demonstrated the use of RFID and BIM for FM. Moreover, ontology matching can be used to integrate facility components with BIM. The above studies had shown the possibilities of BIM in the FM phase. Therefore, it is recommended for project stakeholders in countries during the early adoption phase of BIM to drive and develop indigenous tools to enhance the adoption of BIM at the FM phase.

B. BIM products

Benjaoran (2009) indicated that the construction industry could leverage on information and communication technology (ICT) such as BIM to enhance its business processes. More so, there is a need to improve BIM products on different functional levels (Wikforss & Löfgren, 2007) to ensure continuous improvement. Therefore, to improve the BIM products and associated technologies to ease and increase the uptake of BIM in developing countries, the following strategies are recommended. It includes (1) close collaboration with BIM software developers; (2) adoption of open source principles for software development; (3) user-friendly and well-structured program interface; (4) efficiency in interoperability between BIM software; and (5) proper management of BIM models and cloud-BIM.

1. Close collaboration with BIM software developers: Collaborative approaches should be employed by BIM software developers to overcome the limitations of physical and psychological factors (Benjaoran, 2009; Chen et al., 2010; Cidik et al., 2014; Lam et al., 2004). Benjaoran (2009) argued that it is imperative for a close working relationship and the development of a collaborative approach among the developers during the development stage of BIM applications. One of the benefits of such relationships is that issues such as interoperability among the BIM software will be easier to address. Also, BIM software developers in the developing countries can exchange knowledge with those in countries with matured BIM implementation, and this can also aid the transfer of technology and knowledge. Such transfer of technology and expertise can immensely improve BIM implementation and maturity in developing countries.

2. Adoption of open source principles for software development: A significant barrier to BIM adoption in the construction industry is the huge initial capital outlays to procure BIM software and the subsequent renewal of licenses (Bolpagni, 2013; Dedrick et al., 2003; Hergunsel, 2011). Also, most fully functional BIM authoring tools are only commercially available to its users and come with short-term licenses (*usually no more than one year of the authorized period*). Its attendant cost implications, when weighed with the consultancy fee, aggravates the pre-existing apathy of clients towards implementing BIM in their projects. Open source principles entail the sharing of software code collaboratively, and this system also enables construction organization to develop BIM software suited for their operations. This approach to software development, when adopted by developing countries, would aid BIM implementation and significantly improve BIM software and technologies.

3. User-friendly and well-structured program interface: The user-friendliness of BIM software's interface affect its usability and the level of user exploring its functionality for their project. Azhar et al. (2009) reported that the user interface of some software such as Autodesk Ecotect is hard to understand and that its analysis steps or procedures are ambiguous. In a similar vein, the Autodesk Green Building Studio have difficulties working with large datasets (Azhar et al., 2009). Studies (*see* Al-Hammad & Al-Hammad, 1996; Al-Hammad, 2000; Chen et al., 2010; Khanzode et al., 2000; Miles & Ballard, 2002) revealed two major issues with BIM software interfaces as inaccurate interface information; and inefficiencies in information exchange. Hence, to enhance its adoption in developing countries, the user interfaces should be made more user-friendly to ensure all a harmony search, computation, and analysis. Also, labels should be worded and visualized (Chien & Mahdavi, 2009).

4. Efficiency in interoperability between BIM software: The insufficient interoperability of BIM software is a significant barrier to BIM implementation in the construction industry (Cidik et al., 2014; Olawumi et al., 2017). Efficiency in interoperability would prevent the loss of information occasioned during the transfer of the building model from collaborative BIM tools to proprietary analysis tools. Also, interoperability between BIM software will improve the ability of sustainability tools to analyze BIM models (Adamus, 2013; Aksamija, 2012; Chen et al., 2010; Dim et al., 2015; Eastman et al., 2008). Moreover, the development of plug-ins using the Application Programming Interfaces (APIs) to communicate with the parent collaborative BIM software would be significant in improving the interoperability of BIM software.

5. Proper management of BIM models and cloud-BIM: BIM design models typically have extensive architectural and construction details, which may not be needed for performance or sustainability analysis of BIM models. Hence, it is imperative to understand the level of details required for the simulation models and manage the data essential for further analysis (Aksamija, 2012). More so, the advent of cloud-BIM technology which is a variance of the ICT cloud computing technology is still a long way to full adoption in the construction industry. The adoption and implementation of this technology will improve the management of BIM data and ease on-site BIM model visualization.

C. Measures of good practices

As discussed in this study, a significant improvement in the BIM products and processes is imperative in achieving a more efficient information management process regarding quality, customer satisfaction, timeliness in delivery and value for money. More so, there is a need for construction professionals and stakeholders in developing economies to imbibe some measures of good practices in their organizations and projects to facilitate and improve the management of project information.

These measures include: (1) increased investment in research and development; (2) greater collaboration between the academics and the industry; (3) standardization of project features for BIM manipulation; and (4) mutual trust and open communications. Others include: (5) enhancement of BIM software and integration of emerging technologies; (6) diverse support for BIM development and upgrade of ICT infrastructure; and (7) education and development of users' IT skills. These measures of good practices lie between the boundary of the suggested improvement to BIM processes and products.

1. Increased investment in research and development: The level of investment in research and development (R&D) in the construction industry is low compared to other sectors of the economy and the situation is even more worrisome in developing countries. Olawumi et al. (2017) analysis of funding of funding for BIM research reveals a significantly low level of funding in developing countries. It is observed from the literature that substantial financing of

BIM projects in South Korea had improved BIM adoption in the country (Olawumi et al., 2017). Studies (*see* Antón & Díaz, 2014; Dawood, 2009; Scheer et al., 2007) argued that low level of investment in R&D naturally hinders any form of improvement or evolution. Therefore, increased investment in R&D and capital outlay is encouraged as a good practice in the construction industry, most especially, in developing economies or early adopters to enhance BIM adoption and implementation.

2. Greater collaboration between the academia and the industry: The lack of convergence between academic interests and industrial productivity was identified by Scheer et al. (2007) as a weak link in the connectivity between the output of research and development. Therefore, to facilitate adequate information, skills and knowledge transfer between the research community and the AEC firms, a sound platform should be provided for the various parties to facilitate interaction, support, and collaboration within and among the contracting parties in developing economies. Collaboration per Matthews et al. (2018) harnesses the collective capacity, knowledge and resources of the parties involved which help to achieve an optimal result which is less costly and timely. Also, Pero et al. (2015) using a case study approach highlighted our BIM effectively served as an interface between the various parties with the construction supply chain management.

3. Standardization of project features for BIM manipulation: The distinct characteristics of each project and the diversity among the project stakeholders makes any form of standardization difficult (Khasreen et al., 2009). Therefore, concerted efforts should be galvanized to establish a benchmark for the development of BIM software and its associated libraries to ensure ease of use and interchange of data. Extant studies (Akanmu et al., 2015; Böhms et al., 2009; Chen et al., 2010) also argued in this direction.

4. Mutual trust and open communications: Inadequate or lack of cooperation and collaboration among the project stakeholders need to be addressed (Olawumi et al., 2017). Antón and Díaz (2014) reported lack of mutual trust and open communications as a significant challenge in the construction industry. Hence, to enhance BIM efficiency in managing project information, a culture of trust and cooperation should be embraced by construction professionals in developing countries. It would also help solve the problem of inadequacy of relevant data for subsequent simulation analysis of BIM models.

5. Enhancement of BIM software and integration of emerging technologies: It is imperative for the development of dynamic and intelligent BIM software user interfaces that are optimized for efficient performance, and can enhance user. More so, it will ensure that the developed BIM models are adaptable to user skill levels and preferences (Autodesk, 2011; Aziz et al., 2009; Dawood, 2009). In a similar vein, the integration of BIM adaptive plug-ins will ensure BIM-generated designs and analysis results can be transferred and utilized across various platforms. Aziz et al. (2009) argued for an information delivery roadmap that uses emerging technologies to accelerate and optimize the collaboration process in a dynamic project environment.

6. Diverse support for BIM development and upgrade of ICT infrastructure: Existing BIM infrastructure needs to be improved to ensure it is enabling its users in their projects. Suggested improvements include diverse languages, integration of cultural aspects in designs, use of technologies such as VoiceXML to give multi-language capabilities (*voice-enabled interfaces*) among others. More so, BIM software should be improved to enhance data security and trust of project stakeholders. Scheer et al. (2007) reported that Brazilian construction companies still use old versions of CAD/BIM software, due to prohibitive costs of upgrading such facilities. It is recommended for construction firms to upgrade their ICT infrastructure (both hardware & software) on a regular basis to receive security patches and fixes. Chien and Mahdavi (2009) stressed that the possibility to technologically upgrade software without replacing the hardware might decrease the cost of rapid obsolescence of technology protocols.

7. Education and development of users' IT skills: It is essential for the provision of relevant teaching and training opportunities for construction industry practitioners in BIM. Also, BIM modules should be recommended in the curriculum of construction-related departments for both graduate and undergraduate degrees. More so, best practice guidance notes should be formulated and shared across the industry (Dawood, 2009) and technology transfer programs should be developed within the industry. Benefits include the increased capacity of deployed BIM infrastructure to facilitate efficiency and effectiveness in information delivery within and among construction organizations.

Therefore, bringing these perspectives together, the study proposes a BIM benchmarking model (Figure 2) for BIM deployment and implementation in developing countries and its application for project information management. The benchmarking model is to serve as a guide for the project team and other stakeholders in the implementation of BIM in their projects. It can also form a consultative tool for policymakers in developing countries in their quest for BIM adoption in public and private capital projects.

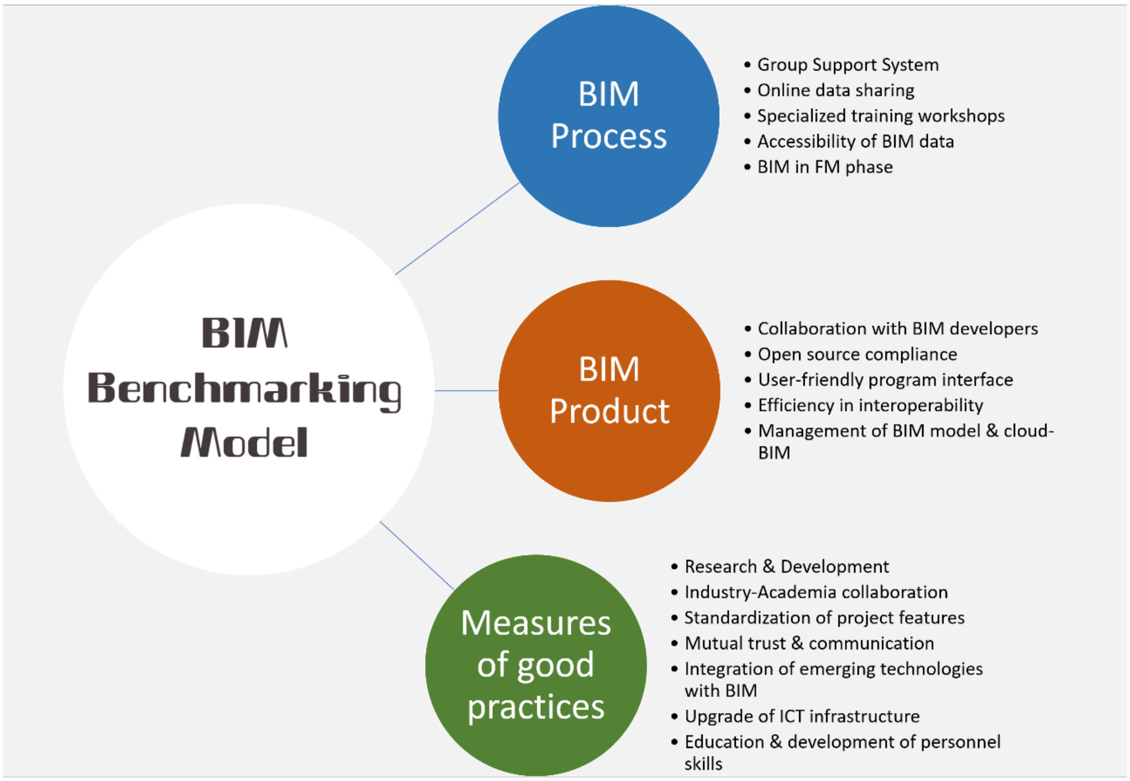

Figure 2: Proposed benchmarking model for BIM implementation in developing countries

More so, the developed conceptual framework can serve as a metric to gauge the capacity of the project BIM users to foster a collaborative working system and ensure efficient management of project information. It is a form of good practice to be observed by project stakeholders.

5. Benchmarking model's assessment template and scoring system

This section features the development of an assessment template and its associated scoring system which are based on the 3L concepts and benchmarking model discussed in the previous section. It aims to aid construction organizations and project teams or any appointed personnel to assess the level of BIM innovation and validate the level of implementation of the BIM benchmarking model in a construction project. In the evaluation of the sets of key indicators (A, B & C) as shown in Table 1, the study proposes that the assessment of the BIM benchmarking model be carried out by a team of experts not less than three (3) experts who have broad experience of BIM implementation.

As observed by Kamdjoug et al. (2007), expert decision-makers are rational beings, and they usually utilize a set of criteria threshold to accept or reject a given action. Hence, the assessment template (Table 1) uses a 5-point Likert scale (1=*very low/none, 2=low; 3= average, 4= high, and 5=very high*) to evaluate the sets of key indicators A, B and C of the benchmarking model. More so, in order to arrive at a consensus among the group of expert decision-makers, the study adopted the Moving Basis Heuristics (MBH) model discussed in Kamdjoug et al. (2007). A Heuristics approach to problem-solving enables the expert decision-makers to arrive at an answer, solve a problem, and conduct a judgment task more efficiently and quickly. Also, per Shah and Oppenheimer (2008), heuristics serve "*the purpose of reducing the effort associated with a task*" as well as reduce its redundancy. According to Kamdjoug et al. (2007), to arrive at an acceptable decision for each criterion, each expert decision-maker must (1) not be motivated by selfish interest or evaluate with a preconceived outcome in mind. (2) be willing to support the consensus decision of the expert panel members even if his perception of the criteria is at variance to the final group decision.

Table 1: Assessment template

#	Description	Φ(α)	Expert Conclusion
A	***Innovative strategies at BIM process level***		
A1	Group Support System (GSS) on BIM		
A2	Efficient online sharing of project data & simulation results		
A3	Specialized training workshops for BIM users		
A4	Improving the accessibility of relevant BIM data		
A5	Extending BIM adoption to the facility management phase		
B	***Innovative strategies at BIM product level***		
B1	Close collaboration with BIM software developers		
B2	Adoption of open source principles for software development		
B3	User-friendly & well-structured program interface		
B4	Efficiency in interoperability between BIM software		
B5	Proper management of BIM models & cloud-BIM		
C	***Measures of good practices***		
C1	Increased investment in research and development		
C2	Greater collaboration between the academics and the industry		
C3	Standardization of project features for BIM manipulation		
C4	Mutual trust and open communications		
C5	Enhancement of BIM software and integration of emerging technologies		
C6	Diverse support for BIM development and upgrade of ICT infrastructure		
C7	Education and development of users' IT skills		

Note: Φ(α) is the aggregate numerical values derived in equation (3)

As suggested by Shah and Oppenheimer (2008) who argued that the heuristics model must (1) examine fewer cues; (2) simplify the weighting principles (3) integrate less information, among others. Hence, the study modified the MBH approach adopted by Kamdjoug et al.

(2007) to ease the decision-making task of the expert decision-makers. The following algorithms explain the working principles of the study's modified heuristics approach.

5.1 Decision space for each expert decision-maker

At this stage, each expert evaluates the importance level of each sub-indicators as it relates to the key indicators. Considering Ꝃ as the sets of key indicators where each sub-indicator, α ∈ Ꝃ as evaluated by a set of *L* criteria, each criterion g_j, j ∈ {1, 2, …, *L*} which is defined on a 5-point Likert scale as mentioned earlier in the study. As shown in Table 1, the key indicators, Ꝃ are A, B, and C; and each sub-indicator (α ∈ Ꝃ) is described as α = {α_1, α_2, …, α_n} such that key indicator 'B' = {B_1, B_2, …, B_5}. As the evaluation of each sub-indicator attempt to quantify the level of implementation for each set of key indicators, it is necessary to assigned values to the set of criteria to ease the measurement of each expert and the final aggregation of the judgment reached by the expert decision-makers.

Hence, each sub-indicator α ∈ Ꝃ is measured by an element y = (g_1(y), g_2(y), …, g_n(y)) ∈ *L*; where g_k(y) indicates the value of y on the criterion g_k. Also, according to Kamdjoug et al. (2007), it is essential to provide a sort of numerical values for each criterion g_j. Therefore, points are assigned to each criteria (g_k), g_j(1) = 20 points; g_j(2) = 40 points; g_j(3) = 60 points; g_j(4) = 80 points; and g_j(5) = 100 points). The numerical values attempt to measure the magnitude of the criterion (g_k) that defines each sub-indicator (α).

5.2 Extracting and aggregating each expert decision

According to Kamdjoug et al. (2007), each expert arrives at a decision base on a set of individual decision rules, such that if a <condition> is met, then a <conclusion> can be derived. Likewise, it is expected for the condition thresholds to vary from expert to another. The values of the set of criteria (*L*) is based on the value of y in g_j(y) = {20, 40, 60, 80, 100}. As noted by Kamdjoug (2003), the study added a constraint called 'domination' to eliminate problems caused when the conclusions reached by the experts differ widely. Such that p_j(α) assesses the likelihood of the contribution of the criterion g_j when α is accepted.

The study develops two linear functions to define the notions of:

(1) a *weakly accepted sub-indicator* (α)

$$y_j(\alpha)^- = \frac{g_j(y)}{100n} - 1 \qquad ------------\text{equation 1}$$

where $y_j(\alpha) < 0$, for $0 < g_j(y) < 50$; and

(2) a *strongly accepted sub-indicator* (α)

$$y_j(\alpha)^+ = 1 - \frac{g_j(y)}{100n} \qquad ------------\text{equation 2}$$

where $y_j(\alpha) \geq 0$, for $50 \leq g_j(y) \leq 100$.

Equation (1) and (2) is applied to each expert decision, and the aggregate or conclusion for each sub-indicator is derived using equation (3) while Table 2 provides the linguistic description for the numerical values aggregated from the discussions of the expert decision-makers. The linguistic description ranges from 'very poor' (<0.244) to 'excellent' (>0.804).

$$\Phi(\alpha) = \sum_{i=1}^{n} y_j(\alpha) \text{ ------ ------------- equation 3}$$

Where n= number of experts; $\Phi(\alpha)$ = aggregate conclusion reached by the expert decision-makers on each sub-indicator.

More so, to arrive at an aggregate decision for the top-level key indicator 'A', equation (4) can be applied and the resulting value can be interpreted using Table 2 also.

$$\Phi(\text{₭}) = \sum_{i=1}^{n} \frac{\Phi(\alpha)}{m} \text{ ------ ------------- equation 4}$$

Where m= number of sub-indicators within the set ₭; Φ(₭) = aggregate conclusion reached by the expert decision-makers on each key indicator.

Table 2: Scoring system metrics

Points	Measurement
> 0.804	Excellent
0.705 – 0.804	Very good
0.645 – 0.704	Good
0.445 – 0.644	Average
0.245 – 0.444	Poor
< 0.244	Very poor

5.3 Sample assessment of a project based on the model's assessment template

This section provides a sample case study assessment of a project based on the heuristics approach and equations provided in section 5.1 and 5.2 above. The first set of key indicators (₭) which is 'A' will be used to illustrate the study's benchmarking model to assess a project's BIM level implementation (see Table 3 and Table 4). Key indicator 'A' has five sub-indicators ($\alpha \in$ ₭), such that 'A' = {A_1, A_2, …, A_5} and five expert decision-makers, n= {n_1, n_2, …, n_5} are invited to provide their values (gj(y) = {20, 40, 60, 80, 100}) for each sub-indicator of 'A'.

Table 3: Experts' decision and aggregation of their decisions (for sub-indicators A1 - A5)

#	A1		A2		A3		A4		A5	
	$g_j(y)$	Eqn. (1) *or* Eqn. (2)	$g_j(y)$	Eqn. (1) *or* Eqn. (2)	$g_j(y)$	Eqn. (1) *or* Eqn. (2)	$g_j(y)$	Eqn. (1) *or* Eqn. (2)	$g_j(y)$	Eqn. (1) *or* Eqn. (2)
Expert 1	40	-0.92	80	0.84	80	0.84	100	0.80	20	-0.96
Expert 2	60	0.88	80	0.84	40	-0.92	60	0.88	80	0.84
Expert 3	80	0.84	40	-0.92	60	0.88	40	-0.92	40	-0.92
Expert 4	40	-0.92	40	-0.92	80	0.84	40	-0.92	60	0.88
Expert 5	100	0.80	40	-0.92	40	-0.92	60	0.88	80	0.84
Eqn. (3)		**0.68**		**-1.08**		**0.72**		**0.72**		**0.68**
Eqn. (4)										**0.344**

Note: Eqn. (1) implies Equation (1) etc.

The values (Φ(α)) of A1 – A5 is then expressed in Table 4 along with the linguistic descriptions. The overall conclusion of the expert decision-makers on the first key indicator (A) was 'Poor' with a numerical value of 0.344 which implies that the level of *innovative strategies at BIM process level* for the sample project is still very low; although, on individual sub-indicators basis, some of the criteria was scored 'good' or 'very good'.

Table 4: A typical assessment of a project using the assessment template for key indicator 'A.'

#	Description	Φ(α)	Expert Conclusion
A	***Innovative strategies at BIM process level***		**Poor**
A1	Group Support System (GSS) on BIM	0.68	Good
A2	Efficient online sharing of project data & simulation results	-1.08	Very poor
A3	Specialized training workshops for BIM users	0.72	Very good
A4	Improving the accessibility of relevant BIM data	0.72	Very good
A5	Extending BIM adoption to the facility management phase	0.68	Good

5.4 Comparison between current BIM benchmarking model and previous findings

Table 5 shows the comparison between the study's benchmarking model and the previous BIM models developed in the literature. Five aspects such as (1) intended use; (2) unit of analyses; (3) categories; (4) certification levels; and (5) approach to metrics, were examined to express how current findings extends and contradicts previous findings. As observed by Van Lith et al. (2015), most construction organizations are developing their internal BIM maturity strategies although unstructured and unstandardized. More so, previous studies as shown in Table 5 revealed that the existing BIM models utilized a subjective approach in their assessment of BIM adoption in a project.

However, this study builds on existing models to develop a benchmarking model for developing countries which is a more objective and quantitative approach to evaluate the key indicators and parameters that constitute the 3-level of the BIM concept with the use of a heuristics methodology to develop the model's scoring system.

Table 5: Comparison between the study's benchmarking model and previous BIM models

Paper	Intended use	Unit of analyses	Categories	Certification levels	Approach to metrics
Succar et al. (2013)	BIM competency model	Individual stakeholders & construction firms	3 tiers of competencies	5-levels (*0- none; 1-basic; 2-intermediate; 3-advanced; 4-expert*)	Subjective methods
Mccuen et al. (2012)	Capacity Maturity Model (CMM)	Construction firms	11 categories	6-levels (*Not certified; minimum BIM; certified; silver; gold; platinum*)	Subjective methods *supplemented with objective metrics*
Lainhart (2000)	COBIT model (managing technology risks and vulnerabilities)	Construction firms (*business orientation*)	4 domains	6-levels (*non-existent; ad-hoc; repeatable but intuitive; defined process; managed and measurable; optimized*)	Very subjective methods
Mccuen (2008)	Interactive Capacity Maturity Model (I-CMM)	Individual BIM maturity (*not useful for comparison purpose*)	11 categories	5-levels (*minimum BIM; certified; silver; gold; platinum*)	Very subjective methods
Bew et al. (2008)	Integrated Building Information Modelling (i-BIM)	Construction firms	4 areas	4 maturity level (*poorly defined*)	Very subjective methods
Current Study	**BIM benchmarking model**	Construction firms, project teams & construction project	3 areas (*17 sub-parameters*)	6 levels (*Excellent, Very good, Good, Average, Poor, Very poor*)	Objective metrics *with expatiation on the sub-parameters*

6. Lessons from case study BIM projects in developed countries

The study undertook some reviews of successful BIM projects in developed countries to demonstrate the significant improvements and benefits possible through the implementation of BIM benchmarking model. Olawumi et al. (2017) classified areas of BIM application based on project sectors to include building and housing, transportation, environment, energy infrastructure, urban regeneration, etc. Lessons from these case study projects are drawn from projects such as two (2) commercial buildings, one sports center, four (4) hospitals complexes, two (2) school projects and one automobile production plant. The projects are drawn from five (5) countries namely the United State, Sweden, the United Kingdom, China, and Finland. Aspects considered in these BIM projects include (1) cost savings and added value gained using BIM; (2) the reduction in project schedule; (3) ease of achieving green buildings using BIM tools; and (4) the attendant innovation in construction.

1. Cost savings and added value: Maine Hospital in the United States used BIM at its design and construction stages with a cost savings of about US$ 20 million and completion of the project ahead of schedule (Autodesk, 2014). Donahue (2015) study shows the application of BIM in the construction of a large school building project in Delaware, the US with a reported reduction in change orders and significant savings. More so, the project team who handled the St. Barts Hospital complex (746 beds) and the Royal London Hospital complex (290 beds) used BIM to facilitate spatial coordination (Throssell, 2016). Accordingly, the project team was able to improve the quality of the project, reduce its costs and waste; save time and improve the health and safety of end users; and meet the ten (10) percent waste target proposed by the environmental team.

3. Reduction in project schedule: BIM was used for a Healthcare building project (New Karolinska Solna) in Solna, Sweden. The use of BIM by the design and project team members helped to “save about 1,000 hours of double work” (Udd, 2014). More so, BIM was used to support processes such as procurements, detection of hard and soft clashes, development of asset code for facility managers among others. In a similar vein, Eastman et al. (2008) reported that BIM was utilized to shorten the design-construction cycle of General Motors production plant project, using lean construction methods. Also, the use of BIM reduces the installation time for the installation of HVAC system and hangers of the central utility plant at the University of Massachusetts (Autodesk, 2014).

3. Green buildings: Olawumi et al. (2017) stressed that sustainability issues is currently a salient concept in the built environment as well as other sectors of the economy and highlighted several studies that show how the use of BIM technologies have helped achieved green and sustainable buildings and infrastructure. Also, BIM was employed in several ways to manage two commercial building projects (Kathy & Neptun of 15,458m^2 and 12,770m^2 gross areas respectively) in Helsinki, Finland and to achieve a very ambitious green energy goal in these projects (Oikari, 2016).

4. Innovation in construction: BIM can help to facilitate innovation in construction projects. For example, the Beijing National Aquatics Centre, Beijing, China is a unique building with innovative conceptual designs and structural engineering made possible using BIM (Eastman et al., 2008). Also, the design team engaged for the James Hunt Library, North Carolina, United States faced a significant challenge in the modeling of a custom unitized curtainwall system (Stouthamer, 2017). The project team developed a barcoding protocol (plug-in) which was linked with the BIM model which enabled the team to visualize the sequential fabrications and installation works.

7. Practical implications of the study's findings

The developed benchmarking model and the associated scoring system are poised to assist BIM managers and construction project teams in developing countries to increase their knowledge of BIM and evaluate the level of its implementation in their projects. As argued by Jayasena and Weddikkara (2013), the implementation of innovative concepts such as BIM usually poses multitudinous challenges to an infant BIM industry of which most developing countries can be classified (Olawumi et al., 2017). The findings and the developed BIM benchmarking model will be of great benefits to those countries in Africa, Middle East and South America which according to Jung and Lee (2015) who are still in the early stages of BIM adoption.

The first practical implication of this study's findings is the development of the BIM benchmarking model to measure BIM uptake in developing countries. According to Jayasena and Weddikkara (2013), previous BIM models such as the Bew-Richards BIM Maturity Model and Succar's BIM Maturity Stages Model earlier discussed in this study are less reliable in developing countries' context and more suitable to developed countries. Also, the benchmarking model captures the three broad aspects of BIM which are the processes, products, and information. The adoption of the study's model by local authorities, policy makers, and other key stakeholders in the construction industry will help improve the maturity and implementation of BIM in the construction sector of developing countries. More so, as advocated by Van Lith et al. (2015), construction firms needs to develop their BIM capabilities towards a holistic implementation from "internal towards external orientation."

Secondly, the study has provided and illustrated a more objective and quantitative approach to evaluate the key indicators and parameters that constitute the benchmarking model with the use of a heuristics methodology to develop the model's scoring system. The scoring system integrated an in-depth assessment technique as well as balancing the rational perspective of the expert decision-makers so as to give an objective assessment of the uptake of BIM in a construction project. The method adopted in this study has brought a significant improvement of previous model evaluation models which are mostly qualitative in nature and only allow for a narrow scope assessment. Also, as Matthews et al. (2018) argued for a rigorous strategy and framework to enable BIM implementation; this study has build on existing work and provided a systematic approach toward improving BIM adoption in developing countries. Also, there are some qualitative attributes of BIM implementation in previous studies that have been strengthened in this study by the providing a quantitative basis for its assessment.

More so, the established BIM benchmarking tool and its associated scoring system will provide a valuable tool for developing countries with low or infant BIM industry, and will assist both client organizations and project consultants in gauging the level of BIM implementation in their projects. The government can utilize it as an ad-hoc tool in its administrative assignments as well as in its decision to award subsidies or credits for innovative performance to deserving construction organizations. More so, the study aligns with the recommendation of Van Lith et al. (2015) that construction firms, local authorities as well as other key stakeholders to synergize their collective efforts towards ensuring innovative strategies and frameworks (such as the benchmarking model developed in this study) can have the expected impact on construction projects. The benchmarking model can also be useful in a firm's quest for comparing the growth and level of BIM implementation between their previous and currently undertaken projects.

8. Conclusions

BIM is a repository of digital information which facilitates the efficient management of project information from conception by way of simplifying and presenting a real-world simulation of a pre-conceived project facility. The study reviewed the current practice and implementation of BIM using lessons drawn from the literature and case study BIM projects in developed economies to developing a BIM benchmarking model and assessment template for developing countries or countries still in the early development phase of BIM adoption.

Extant studies reveal little or no progress in BIM adoption and implementation in developing countries as compared to the strides achieved in developed countries. Hence, a BIM benchmarking model was proposed to amplify BIM implementation and provide modules for quantitative assessment of BIM performance and application in projects in countries still in the early development phase of BIM adoption. The benchmarking model is made up of three high-level concepts namely innovative strategies at the BIM process level, innovative strategies at the BIM product level, and measures of good practices.

Two of the concepts “innovative strategies at BIM process level” and “innovative strategies at BIM product level” have five blueprints each that can improve the BIM products and processes as well as its associated technologies to facilitate and ensure increased adoption and implementation in developing countries. The third concept “measures of good practices” contains seven (7) blueprints that construction professionals and stakeholders in developing economies can imbibe in their organizations and projects to facilitate and improve the management of project information.

Furthermore, an assessment template and scoring system were produced to support the benchmarking model by providing a quantitative metric system for the proposed model. Construction organizations and project teams can use the template and the associated scoring system to assess the level of BIM innovation and validate the implementation of the best practice framework in a project and enhance the management of project information across the building lifecycle. Also, it can facilitate comparisons of similar BIM projects for benchmarking purposes.

Moreover, an in-depth review of selected successful BIM projects in developed economies was undertaken to substantiate the significant improvements and benefits possible through the implementation of BIM best practices and measures. Lessons are drawn from a total 10 BIM projects which include commercial buildings, a sports center, hospital complexes, school projects and an automobile production plant, and the projects are drawn from five countries namely the United States, Sweden, the United Kingdom, Mainland China, and Finland. Lessons and the contributory benefits of BIM are collated from these projects to help facilitate BIM adoption and implementation in developing countries.

Future research will focus on developing a maturity matrix based on the conceptual framework and testing the framework and assessment template on real-world case study projects in developing countries. Also, future works can report on how various organizations and project teams use the developed benchmarking model’s assessment template to advance BIM adoption and implementation in construction projects.

References

Abolghasemzadeh, P. (2013). A comprehensive method for environmentally sensitive and behavioral microscopic egress analysis in case of fire in buildings. *Safety Science*, 59, 1–9. https://doi.org/10.1016/j.ssci.2013.04.008

Abubakar, M., Ibrahim, Y. M., Kado, D., & Bala, K. (2014). Contractors Perception of the Factors Affecting Building Information Modelling (BIM) Adoption in the Nigerian Construction Industry. *Computing in Civil and Building Engineering-ASCE*, 167–178.

Adamus, L. W. (2013). BIM: Interoperability for Sustainability Analysis in Construction. *In Central Europe towards Sustainable Building 2013: Integrated building design BIM* (pp. 1–4).

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

Aibinu, A., & Venkatesh, S. (2014). Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia. *Journal of Professional Issues in Engineering Education and Practice*, 140(3), 1–10. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000193

Akanmu, A., Asfari, B., & Olatunji, O. (2015). BIM-Based Decision Support System for Material Selection Based on Supplier Rating. *Buildings*, 5, 1321–1345. https://doi.org/10.3390/buildings5041321

Akinade, O. O., Oyedele, L. O., Ajayi, S. O., Bilal, M., Alaka, H. A., Owolabi, H. A., … Kadiri, K. O. (2016). Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills. Waste Management. https://doi.org/10.1016/j.wasman.2016.08.017

Aksamija, A. (2012). BIM-Based Building Performance Analysis: Evaluation and Simulation of Design Decisions Integration of BIM-Based Performance Analysis with Design. *In ACEEE Summer Study on Energy Efficiency in Buildings* (pp. 1–12).

Al-Hammad, A. (2000). “Common interface problems among various construction parties.” *Journal of Performance of Constructed Facilities*, 14(2), 71–74.

Al-Hammad, A., & Al-Hammad, I. (1996). “Interface problems between building owners and designers.” *Journal of Performance of Constructed Facilities*, 10(3), 123–126.

Antón, L. Á., & Díaz, J. (2014). Integration of LCA and BIM for Sustainable Construction. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, 8(5), 1378–1382.

Arif, M., Egbu, C., Alom, O., & Khalfan, M. M. A. (2009). Measuring knowledge retention: a case study of a construction consultancy in the UAE. *Engineering, Construction and Architectural Management*, 16(1), 92–108. https://doi.org/10.1108/09699980910927912

Autodesk (2014). The Value of BIM for Owners: Save Time and Money During the Building Lifecycle. https://goo.gl/dLTaY3

Autodesk, Inc. (2008). Improving Building Industry Results through Integrated Project Delivery and Building Information Modeling. White Paper, Available online at www.autodesk.com.

Autodesk. (2010). Sustainable Design Analysis and Building Information Modeling. Autodesk Revisk, Http://www.autodesk.com/revit.

Autodesk. (2011). Building Information Modelling for Sustainable Design Building Information Modelling for Sustainable Design Conceptual Building Performance Analysis Overview.

Azhar, S., Brown, J., & Farooqui, R. (2009). BIM-based Sustainability Analysis: An Evaluation of Building Performance Analysis Software. *Alabama, Auburn University*. http://goo.gl/MbQqwk, 1–9.

Aziz, Z., Anumba, C., & Peña-mora, F. (2009). A Road-map to Personalized Context-aware services delivery in construction. *Journal of Information Technology in Construction, 14(Special Issue)*, 461–472. Retrieved from http://www.itcon.org/2009/30

Benjaoran, V. (2009). A cost control system development: A collaborative approach for small and medium-sized contractors. *International Journal of Project Management*, 27(3), 270–277. https://doi.org/10.1016/j.ijproman.2008.02.004

Bew, M., & Richards, M., (2008). Bew-Richards BIM Maturity Model.

Bew, M., Underwood, J., Wix, J., & Storer, G. (2008). Going BIM in a commercial world. Paper presented at the EWork and EBusiness in Architecture, Engineering and Construction: European Conferences on Product and Process Modeling (ECCPM 2008), Sophia Antipolis, France. BIMserver.

Blatter, J., & Haverland, M. (2012). Two or three approaches to explanatory case study research? Paper Prepared for Presentation at the Annual Meeting of the *American Political Science Association*, (September), 1–18.

Böhms, M., Bonsma, P., Bourdeau, M., & Samad, A. (2009). Semantic product modelling and configuration: Challenges and opportunities. Electronic *Journal of Information Technology in Construction*, 14(August), 507–525.

Boktor, J., Hanna, A., & Menassa, C. C. (2014). State of Practice of Building Information Modeling in the Mechanical Construction Industry. *Journal of Management in Engineering*, 30(1), 78–85. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000176

Bolpagni, M. (2013). “The implementation of BIM within the public procurement: A model based approach for the construction industry.” VTT Technology, Finland, 130

Buswell, R. A., Gibb, A. G. F., Soar, R. C., Austin, S. A., & Thorpe, A. (2007). Applying Future Industrialised Processes to Construction. *CIB World Building Congress*, 2536–2547.

Cerovsek, T., & Katranuschkov, P. (2006). Active process reuse model for collaboration. *Journal of Information Technology in Construction* (ITcon), 11, 467–488. Retrieved from http://www.itcon.org/2006/35/

Chan, C. T. W. (2014). Barriers of Implementing BIM in Construction Industry from the Designers’ Perspective: A Hong Kong Experience, *Journal of System and Management Sciences*, 4(2), 24-40

Chen, Q., Reichard, G., & Beliveau, Y. (2010). Object Model Framework for Interface Modeling and IT-Oriented Interface Management. *Journal of Construction Engineering and Management ASCE*, 136(2), 187–199. https://doi.org/10.1061/_ASCE_CO.1943-7862.0000120

Chen, Y., Dib, H., & F. Cox, R. (2014). A measurement model of building information modelling maturity. *Construction Innovation*, 14(2), 186–209. https://doi.org/10.1108/CI-11-2012-0060

Chien, S.-C., & Mahdavi, A. (2009). Requirement Specification and Prototyping for User Interfaces of Buildings' Environmental Controls. Special Issue Building Information Modeling Applications, Challenges and Future Directions, *Journal of Information Technology in Construction* (ITcon), 14, 642–653. Retrieved from http://www.itcon.org/2009/42

Chong, H.-Y., Wong, J. S., & Wang, X. (2014). An explanatory case study on cloud computing applications in the built environment. *Automation in Construction*, 44, 152–162. https://doi.org/10.1016/j.autcon.2014.04.010

Chung, J. K. H. & Shen Q. (2004). A group supports system for improving value management studies in construction. *Automation in Construction*, pp.209-212.

Cidik, M. S., Boyd, D., Thurairajah, N., & Hill, S. (2014). BIM and Conceptual Design Sustainability Analysis: An Information Categorization Framework. In 50th *ASC Annual International Conference Proceedings* (pp. 1–8). Associated Schools of Construction.

Dawood, N. (2009). VR-Roadmap: A Vision for 2030 in the Built Environment. Journal of Information Technology in Construction (ITcon), Vol. 14, *Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning*, 14, 489–506. Retrieved from http://www.itcon.org/2009/32

Dedrick, J., Gurbaxani, V., & Kraemer, K. L. (2003). "Information technology and economic performance: A critical review of the empirical evidence." *ACM Computing Surveys*, 35(1), 1–28

Dim, N. U., Ezeabasili, A. C. C., & Okoro, B. U. (2015). Managing the Change Process Associated with Building Information Modeling (BIM) Implementation by the Public and Private Investors in the Nigerian Building Industry. *Donnish Journal of Engineering and Manufacturing Technology*, 2(1), 1–6.

Donahue, C. (2015). The BIM Revolution: The Top 3 Benefits of Using BIM in Construction. Accessed June 13, 2017. https://goo.gl/lnQWVX

Eastman, C., Teicholz, P., Sacks, R. & Liston, K., (2011). *BIM Handbook: a guide to building information modeling for owners, managers, designers*. 2nd ed. Hoboken, New Jersey: John Wiley & Sons, Inc.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). *A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. Hoboken, New Jersey: Wiley, Hoboken, NJ.

Fang, Y., Cho, Y. K., Zhang, S., & Perez, E. (2016). Case Study of BIM and Cloud-Enabled Real-Time RFID Indoor Localization for Construction Management Applications. *Journal of Construction Engineering and Management*, 142(7). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001125

Gelisen, G., & Griffis, F. H. (Bud). (2014). Automated Productivity-Based Schedule Animation: Simulation-Based Approach to Time-Cost Trade-Off Analysis. *Journal of*

Construction Engineering and Management ASCE, 140(4), 1–10. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000674

Giel, B., & Issa, R. R. A. (2013). Synthesis of Existing BIM Maturity Toolsets to Evaluate Building Owners. *Computing in Civil Engineering,* 451–458.

Giel, B., & Issa, R. R. A. (2016). Framework for Evaluating the BIM Competencies of Facility Owners. *Journal of Management in Engineering*, 32(1), 4015024. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000378

Hergunsel, M. F. (2011). “Benefits of building information modeling for construction managers.” *M.S. thesis, Worcester Polytechnic Institute*, Worcester, MA

Inyim, P., Rivera, J., & Zhu, Y. (2015). Integration of Building Information Modeling and Economic and Environmental Impact Analysis to Support Sustainable Building Design, *Journal of Management in Engineering*, 31(1), 1–10. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000308.

Jayasena, H. S., & Weddikkara, C. (2013). Assessing the BIM Maturity in a BIM Infant Industry. In The Second World Construction Symposium 2013: *Socio-Economic Sustainability in Construction* (pp. 62–69). Retrieved from http://www.suranga.net/publications/2013_bim_maturity.pdf

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

Kamdjoug, J.R.K. (2003). Aide à la décision pour la gestion demicro-crédits en Afrique : application à la sélection des CVECA au refinancement. *Ph.D. thesis, ENST Bretagne, Ecole des Hautes Etudes en Sciences Sociales*.

Kamdjoug, J.R.K., Lenca, P., & Barthélemy, J.P. (2007). Assessment of actions in a multi-actor and multicriteria framework: Application to the refunding of microfinance institutions. *Computational Economics*, 29(2), 213–227. https://doi.org/10.1007/s10614-006-9079-6

Kazi, A. S. (Sami), Aouad, G., & Baldwin, A. (2009). Editorial- Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping and Scenario Planning. Journal of Information Technology in Construction *in Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning*, 14, 123–128. Retrieved from http://www.itcon.org/2009/12

Khanzode, A., Fischer, M., & Hamburg, S. (2000). “Effect of information standards on the design-construction interface: Case examples from the steel industry.” *Proc., Computing in Civil and Building Engineering, ASCE*, Reston, Va., 804–811.

Khasreen, M. M., Banfill, P. F., & Menzies, G. F. (2009) “Life-Cycle Assessment and the Environmental Impact of Buildings: A Review.” *Sustainability*, 1(3), pp. 674 – 701

Kuiper, I., & Holzer, D. (2013). Rethinking the Contractual Context for Building Information Modelling (BIM) in the Australian Built Environment Industry. *Australasian Journal of Construction Economics and Building*, 13(4), 1–17.

Kwak, Y. H., & Ibbs, C. W. (2002). Project management process maturity (PM) 2 model. *Journal of Management in Engineering*, 18(3), 150–155. https://doi.org/10.1061/(ASCE)0742-597X(2002)18:3(150)

Lainhart, J. W. (2000). COBITTM: A Methodology for Managing and Controlling Information and Information Technology Risks and Vulnerabilities. *Journal of Information Systems*, 14, 21–25. https://doi.org/10.2308/jis.2000.14.s-1.21

Lam, K. P., Wong, N. H., Mahdavi, A., Chan, K. K., Kang, Z. & Gupta, S. (2004). SEMPER-II: an internet-based multi-domain building performance simulation environment for early design support. *Automation in Construction*, 13 (5), 651-663.

Lockamy, A., & McCormack, K. (2004). The development of a supply chain management process maturity model using the concepts of business process orientation. *Supply Chain Management: An International Journal*, 9(4), 272–278. https://doi.org/10.1108/13598540410550019

Matthews, J., Love, P. E. D., Mewburn, J., Stobaus, C., & Ramanayaka, C. (2018). Building information modelling in construction: insights from collaboration and change management perspectives. *Production Planning and Control*, 29(3), 202–216. https://doi.org/10.1080/09537287.2017.1407005

Maxwell, J.A. (2005). Qualitative research design: An interactive approach. Thousand Oaks, CA: *Sage Publications,* Inc.

Mccuen, T. L. (2008). Building Information Modeling and the Interactive Capability Maturity Model. In Associated Schools of Construction International Proceedings of the 44th Annual Conference. Auburn, Alabama.

McCuen, T. L., Suermann, P. C., & Krogulecki, M. J. (2012). Evaluating Award-Winning BIM Projects Using the National Building Information Model Standard Capability Maturity Model. *Journal of Management in Engineering*, 28(2), 224–230. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000062

Miles, R. S., & Ballard, G. (2002). “Problems in the interfaces between mechanical design and construction: A research proposal.” *Journal of Construction Research*, 3(1) , 83–95.

Motamedi A, & Hammad A., (2009) Lifecycle management of facilities components using radio frequency identification and building information model, ITcon Vol. 14, *Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning*, pg. 238-262, http://www.itcon.org/2009/18

Motamedi, A., Soltani, M. M., Setayeshgar, S., Hammad, A., Mostafa, M., Setayeshgar, S., & Hammad, A. (2016). Extending IFC to incorporate information of RFID tags attached to building elements. *Advanced Engineering Informatics*, 30(1), 39–53. https://doi.org/10.1016/j.aei.2015.11.004

Nightingale, D. J., & Mize, J. H. (2002). Development of a Lean Enterprise Transformation Maturity Model. *Information, Knowledge, Systems Management*, 3(1), 15–30.

OGC. (2008). Portfolio, Programme, and Project Management Maturity Model (P3M3): Office of Government Commerce - England. https://goo.gl/k6OcnV

Oh, M., Lee, J., Hong, S. W., Jeong, Y., Wan, S., & Jeong, Y. (2015). Integrated system for BIM-based collaborative design. *Automation in Construction*, 58, 196–206. https://doi.org/10.1016/j.autcon.2015.07.015

Oikari, V. (2016). Manskun Rasti- Commercial development project in Helsinki, Finland. Accessed June 13, 2017. https://goo.gl/h7sjwg

Olatunji, S. O., Olawumi, T. O., & Awodele, O. A. (2017). Achieving Value for Money (VFM) in Construction Projects. *Journal of Civil and Environmental Research- The International Institute for Science, Technology and Education (IISTE)*, 9(2), 54–64.

Olatunji, S. O., Olawumi, T. O., & Ogunsemi, D. R. (2016). Demystifying Issues Regarding Public Private Partnerships (PPP). *Journal of Economics and Sustainable Development- The International Institute for Science, Technology and Education (IISTE)*, 7(11), 1–22.

Olawumi, T. O., & Ayegun, O. A. (2016). Are Quantity Surveyors competent to value for Civil Engineering Works? Evaluating QSs' competencies and militating factors. *Journal of Education and Practice- The International Institute for Science, Technology and Education (IISTE)*, 7(16), 1–16.

Olawumi, T. O., Akinrata, E. B., & Arijeloye, B. T. (2016). Value Management – Creating Functional Value for Construction Project: An Exploratory Study. *World Scientific News*, 54, 40–59.

Olawumi, T. O., Chan, D. W. M., & Wong, J. K. W. (2017). Evolution in the Intellectual Structure of BIM Research: A Bibliometric Analysis. *Journal of Civil Engineering and Management*, 23(8), 1060–1081. https://doi.org/10.3846/13923730.2017.1374301

Olawumi, T. O., Chan, D. W. M., Wong, J. K. W., & Chan, A. P. C. (2018). Barriers to the Integration of BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts. *Journal of Building Engineering*, 20, 60–71. https://doi.org/10.1016/j.jobe.2018.06.017

Olawumi, T.O., & Chan, D.W.M. (2018a). Beneficial Factors of Integrating Building Information Modelling (BIM) and Sustainability Practices in Construction Projects. In *Hong Kong International Conference on Engineering and Applied Science* (HKICEAS) (pp. 141–152). Hong Kong: Higher Education Forum.

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

Olawumi, T.O., & Chan, D.W.M. (2018c). Identifying and prioritizing the benefits of integrating BIM and sustainability practices in construction projects: A Delphi survey of international experts. *Sustainable Cities and Society*, 40, 16–27. https://doi.org/10.1016/j.scs.2018.03.033

Pärn, E. A., & Edwards, D. J. (2017). Conceptualising the FinDD API plug-in: A study of BIM-FM integration. *Automation in Construction*, 80, 11–21. https://doi.org/10.1016/j.autcon.2017.03.015

Patrick, W., & Ii, B. (2010). Building Information Modeling in Support of Sustainable Design and Construction. University of Florida.

Pero, M., Stößlein, M., & Cigolini, R. (2015). Linking product modularity to supply chain integration in the construction and shipbuilding industries. *International Journal of Production Economics*, 170, 602–615. https://doi.org/10.1016/j.ijpe.2015.05.011

Redmond, A., Hore, A., Alshawi, M., & West, R. (2012). Exploring how information exchanges can be enhanced through Cloud BIM. *Automation in Construction*, 24, 175–183. https://doi.org/10.1016/j.autcon.2012.02.003

Scheer, S., Amorim, S. R. L. de, Santos, E. T., Ferreira, R. C., & Caron, A. M. (2007). The Scenario and Trends in the Brazilian Construction Applications' Experience, 12(December), 193–206. Retrieved from http://itcon.org/2007/13/

Schlueter, A., & Thesseling, F. (2008). "Building Information Model-Based Energy/Exergy Performance Assessment in Early Design Stages." *Automation in Construction*. 18(2), 153-163.

Shah, A.K., & Oppenheimer, D.M. (2008). Heuristics Made Easy: An Effort-Reduction Framework. *Psychological Bulletin*, 134(2), 207–222. https://doi.org/10.1037/0033-2909.134.2.207

Stouthamer, S. (2017). James B. Hunt Library- Raleigh, North Carolina, United States. https://goo.gl/H9aJFg

Succar, B., (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357-375.

Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. *Architectural Engineering and Design Management*, 8(2), 120–142. https://doi.org/10.1080/17452007.2012.659506

Succar, B., Sher, W., & Williams, A. (2013). An integrated approach to BIM competency assessment, acquisition and application. *Automation in Construction*, 35, 174–189. https://doi.org/10.1016/j.autcon.2013.05.016

Suermann, P. C., Issa, R. R. A., & McCuen, T. L. (2008). Validation of the US national building information modeling standard interactive capability maturity model. In *12th International Conference on Computing in Civil and Building Engineering*, Beijing, China.

Thomassen, M. (2011). BIM & Collaboration in the AEC Industry. Aalborg University.

Throssell, D. (2016). Barts & London Hospital- BIM projects. Accessed June 12, 2017. https://goo.gl/8xVu5Y

Tulubas Gokuc, Y., & Arditi, D. (2017). Adoption of BIM in architectural design firms. *Architectural Science Review,* 60(6), 483-492. https://doi.org/10.1080/00038628.2017.1383228

Udd, A. (2014). New Karolinska Solna - Skanska BIM projects. Accessed June 12, 2017. https://goo.gl/NhkH5u

Vaidyanathan, K., & Howell, G. (2007). Construction Supply Chain Maturity Model – Conceptual Framework. In International Group for Lean Construction, (IGLC-15). Michigan, USA. (pp. 170–180).

Van Lith, J., Voordijk, H., Castano, J. M., & Vos, B. (2015). Assessing maturity development of purchasing management in construction. *Benchmarking: An International Journal*, 22(6), 1033–1057. https://doi.org/10.1108/BIJ-07-2014-0071

Watson, A. (2011) "Digital building- Challenges and Opportunities" *Advanced Engineering Informatics*, 25 573-581

Wikforss, Ö., & Löfgren, A. (2007). Rethinking communication in construction. *Journal of Information Technology in Construction (ITcon)*, 12(May), 337–345. Retrieved from http://itcon.org/2007/23/

Zhang, S., Teizer, J., Lee, J., Eastman, C. M., & Venugopal, M. (2013). Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Automation in Construction*, 29, 183–195. https://doi.org/10.1016/j.autcon.2012.05.006