BUILDING INFORMATION MODELLING AND PROJECT INFORMATION MANAGEMENT FRAMEWORK FOR CONSTRUCTION PROJECTS

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Abstract. The study aims to develop an effective BIM-project information management framework (BIM-PIMF) and associated assessment model for construction projects with a view to enhancing the functional management of project information. An explanatory case study technique and case study evidence from four BIM construction projects form the study's research design. The study identified and established the three sub-criteria of the BIM-PIMF model which are the BIM process level factors, BIM product level factors, and the key indicators for a successful BIM deployment on construction project sites. These criterias were semantically linked to the development of the BIM-PIMF framework on a five-point metric scale. The deliverables of this study include the development of the BIM-PIMF framework, together with its analytical scoring system. The findings of the study will improve the information channels of and ease the integration of technological innovations in construction processes while improving the technical competencies of project staff. The study highlighted a basket of effective recommendations and strategies to enhance the deployment of BIM throughout a project lifecycle. Policymakers and government departments can utilize the model in assessing the level of usage of BIM in a construction project as one of the useful measures in gauging which construction firms to be provided subsidies.

Keywords: assessment model, Building information modelling (BIM), BIM process, BIM products, construction projects, information management.

Introduction

Building Information Modelling (BIM) is a repository of digital information which eases the management of information in a project. Abanda, Vidalakis, Oti, and Tah (2015) depict BIM as a "global digital technology" with the capacity to ease the construction process, facilitate coordination and enhance the efficient delivery of project information. Also, Sampaio (2015) described BIM as an "innovative technology" which can support project activities throughout the project lifecycle. Moreover, Eastman, Teicholz, Sacks, and Liston (2008) defined it as a "modeling technology and associated set of processes to produce, communicate, and analyze building models". More so, Zhao (2017) noted that BIM had transformed the construction industry in such a way that construction stakeholders have developed an interest in its implementation for their diverse job nature (Olatunji, Olawumi, & Ogunsemi, 2016; Olawumi, Akinrata, & Arijeloye, 2016; Olawumi & Ayegun, 2016). McCuen (2008) advocated that BIM provide "single, non-redundant, interoperable

information repository" capable of supporting every stage, process and functional units in a construction project.

Demian and Walters (2014) highlighted the use of BIM to manage project information management in construction projects and stressed that the adoption of BIM in the construction industry has helped bring solutions to the sector's problems. Fisher and Yin (1992) dated the utilization of Information Technology (IT) in the United Kingdom to early 1970s and further opined that the globalization of construction works such as the pre-fabrication and assembly of building components will greatly increase the usefulness of IT in construction projects. The prediction of Fisher and Yin (1992) is a current reality in the construction industry as evidenced in some construction projects (Bansal, 2011; Davies & Harty, 2013). Moreover, Olawumi, Chan, and Wong (2017), and Olawumi and Chan (2018b) argued that for the construction industry to strive and be competitive, it needs to be innovative and improve the ways, methods, and techniques of delivering its products.

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Given the above, the current study intends to develop a BIM framework that will enhance the use of BIM for managing project information in construction projects. Previously developed BIM frameworks have focused on different aspects ranging from (i) supply chain management, (ii) lean construction, (iii) knowledge retention, (iv) organizational growth, and (v) renewable energy as discussed in the Section 2. Majority of the existing BIM framework according to Olawumi and Chan (2019) have a subjective approach to quantifying the achievement of the framework's parameters in a project. The current study intends to bridge this gap as well by developing a more quantitative metric as well as using the experiential knowledge of experts. Giel and Issa (2016) noted that the development of BIM framework is significant in the overall process of integrating BIM in construction process to improve the various project activities and processes. It is hoped that the development of the study's BIM-project information management framework (BIM-PIMF) will further help to bridge the gap in both knowledge and practice, and enhance the capacity of project teams to guage the level of BIM adoption for information management process in construction projects.

Bringing these perspectives together, the study's research objectives are to: (i) identify and describe the key parameters and indicators that constitute the BIM-PIMF; (ii) develop the BIM-PIMF model based on documentary evidence from four BIM case study projects; and (iii) provide an analytical solution to calculate the BIM-PIMF model using a scoring system. The research findings will improve the capacity of the deployed BIM system in construction projects and enhance the skills and technical competencies of project teams and construction organizations towards improving project information management. It would help the project team to enhance the ability to achieve the desired performance level and fulfill the BIM-PIMF key indicators, and ensure technological innovations to be integrated to enhance the project information process. The framework will enable project team and stakeholders to evaluate the capacity of the deployed BIM to deliver a functional information management system in a construction project with a view to improving it via innovation in products and processes.

1. BIM adoption for construction project management

In recent years, several research studies have been conducted on the impact of BIM implementation in the Architectural, Engineering, and Construction (AEC) industry. extant literature such as Bradley, Li, Lark, and Dunn (2016) outlined the benefits of BIM in infrastructural projects while Fan, Skibniewski, and Hung (2014) using a case study project examined the influence of BIM during the construction phase. The case study's findings reveal a significant reduction in change orders, requests for information (RFI) and a better compliance to project schedule. Also, a study by Johansson, Roupe, and Bosch-

Sijtsema (2015) pointed out the capacity of BIM to facilitate large projects by providing visualization and real-time rendering of the projects while Karan and Irizarry (2015) argued that extending BIM capacity using tools such as Geographical Information System (GIS) can enhance its efficiency at the preconstruction stage.

Moreover, Inyim, Rivera, and Zhu (2015) highlighted areas in which BIM has been of benefit to the construction industry to include information management and service, communications. Studies (see Kim, Jung, Fischer, & Orr, 2015; Kim et al., 2016; Matthews et al., 2015; Morlhon, Pellerin, & Bourgault, 2014; Neto, Cruz, Rodrigues, & Silva, 2016; Oti, Tizani, Abanda, Jaly-Zada, & Tah, 2016; Olatunji, Olawumi, & Awodele, 2017) also revealed the significant advantages gained in project information management through the implementation of BIM to include: (1) compliance to project's delivery schedule; (2) resource planning and management; (3) faciltate collaboration among key stakeholders; and (4) real-time simulation and analysis of building performance among others. Extant literature (see Kang & Hong, 2015; Pärn & Edwards, 2017; Park & Cai, 2017) also examined the influence of BIM at the facility management stage of the building lifecycle. Also, some empirical studies (see Ham & Golparvar-Fard, 2015; Ilhan & Yaman, 2016; H. Kim et al., 2015; Kim, Jeong, Clayton, Haberl, & Yan, 2015; J. I. Kim et al., 2015) argued for the enrichment of BIM to aid sustainable development. Table 1 shows the summary of the selected literature on the current practices and benefits of BIM in the AEC industry as well as issues related to its implementation in construction projects.

2. Review of existing BIM frameworks

BIM frameworks or indexes are a metric tool which can be modelled to diagnose and measure the level of BIM implementation in an organization or a project. Succar, Sher, and Williams (2012) described it as a "hierarchical collection of individual competencies identified for the purposes of implementing and assessing BIM". The assessment and development of BIM maturity is quite widely discussed in extant literature (see Gupta, Cemesova, Hopfe, Rezgui, & Sweet, 2014; Haron, Marshall-Ponting, & Aouad, 2010; Jayasena & Weddikkara, 2013; McCuen, Suermann, & Krogulecki, 2012; Morlhon et al., 2014; Poirier, Staub-French, & Forgues, 2015; Salah, 2015; Succar & Kassem, 2015; Succar, Sher, & Williams, 2013; Khosrowshahi & Arayici, 2012; Laakso & Kiviniemi, 2012; Owen et al., 2010; Succar, 2009; Suermann & Issa, 2007). More so, BSI (2010) pointed out the influence of BIM in revolutionizing the "way of working" in the construction sector and its ability to foster a collaborative environment. Key stakeholders such as the clients, architects or designers, structural engineers, building services engineers, cost consultants, manufacturers, and contractors can benefit from BIM implementation in their projects. BIM has undergone some stages of development known as maturity index since its introduction to the construction industry (Gupta et al., 2014).

Table 1. BIM in the AEC industry

BIM in the AEC industry	References
Current BIM practices and benefits	
BIM for coordination and communication among project stakeholders.	Moldan, Jannouskova, and Hak (2012); Abanda et al. (2015); Wong, Wang, H. Li, Chan, and H. Li (2014); Espinal and Saluja (2010); Ahn, Y.-J. Kim, Park, I. Kim, and Lee (2014); Adamus (2013); Aibinu and Venkatesh (2014); McCuen (2009); Ajam, Alshawi, and Mezher (2010); Aksamija (2012); Azhar (2011)
Major BIM-energy simulation software: Ecotect and eQuest	Adamus (2013); Bynum, Issa, and Olbina (2013); Jeong, Kim, Clayton, Haberl, and Yan (2016); Kim and Yu (2016); Rahmani, Zarrinmehr, Bergin, and Yan (2015); Ryu and Park (2016); Shiau, YuChi, ChiHong, and PoYen (2012); Wong and Kuan (2014)
BIM to analyze and monitor projects during construction	Autodesk (2010); Khanzode, Fischer, and Reed (2008); Li et al. (2009); McGraw-Hill Construction (2009); Sacks, Koskela, Dave, and Owen (2010); Samuelson (2011); Suermann and Issa (2009); Akula et al. (2013); Al Hattab and Hamzeh (2015)
BIM to aid sustainable design decisions	Autodesk (2010); Abolghasemzadeh (2013); Wu and Issa (2015); Antón and Díaz (2014); Jalaei and Jrade (2014); Alsayyar and Jrade (2015); Olawumi and Chan (2018a, 2018c)
Major BIM data schema: IFC, gbXML	Basbagill, Fischer, and Flager (2012); Eastman et al. (2008); Adamus (2013); Aksamija (2012); Autodesk (2010)
Issues and challenges	
Parametric change technology	Azhar, Brown, and Farooqui (2009); Azhar, Carlton, Olsen, and Ahmad (2011); McGuire, Atadero, Clevenger, & Ozbek (2016); Rahmani et. al. (2015); Sacks and Pikas (2013)
Low adoption and implementation in several countries	Bansal (2011); Gu and London (2010); Redmond, Hore, Alshawi, and West (2012); Antón and Díaz (2014); Kivits and Furneaux (2013)
Issues with BIM software: visual interface	Issa, Flood, and O'Brien (2003)
Some BIM models have a single level of detail which hinders the collaboration among stakeholders	Poku and Arditi (2006); Katranuschkov, Weise, Windisch, Fuchs, and Scherer (2010); Redmond et al. (2012)
Interoperability issues	Nanajkar and Gao (2014); Rogers, Heap-Yih, Preece, McCaffer, and Thomson (2015); Abanda et al. (2015); Aranda-Mena, Crawford, Chevez, and Froese (2009); Bolpagni (2013); Saxon (2013); Antón and Díaz (2014); Kivits and Furneaux (2013)

One of the notable BIM frameworks in the literature is the Bew-Richards model (see Figure 1) which considers BIM maturity for an organization based on the convention of BIM technology adopted (Bew & Richards, 2008). For instance, an organization utilizing computer-aided design (CAD) drawings is classified as entry-level (phase 0) user. Also, the Bilal Succar linear model (see Figure 2) is another BIM framework which provides more stringent criteria at the lower end of BIM adoption as it requires object-based modeling at the entry-level stage (Succar, 2009). Gupta et al. (2014) also extended the Bew-Richards model by integrating it with Renewable Energy Systems (RES) tools. The National Institute of Building Science (NIBS) (2007) also developed an "Interactive Capability Maturity Model" which assesses 11 areas of BIM on a ten-point scale of maturity.

Lainhart (2000) developed COBIT^{TM} (Control Objects for Information and Related Technology), a system useful in managing information and its associated technologies which are described as an organization' most valuable assets. It aims to provide a clear policy guideline for the use of IT for information management in organizations. More so, Vaidyanathan and Howell (2007) advanced a Construction Supply Chain Maturity Model (CSCMM) with the purpose of removing inefficiencies in the construction supply chain and enhancing its overall performance. The model is more suitable for organizations involved in multiple projects works at the same time, and it helps to

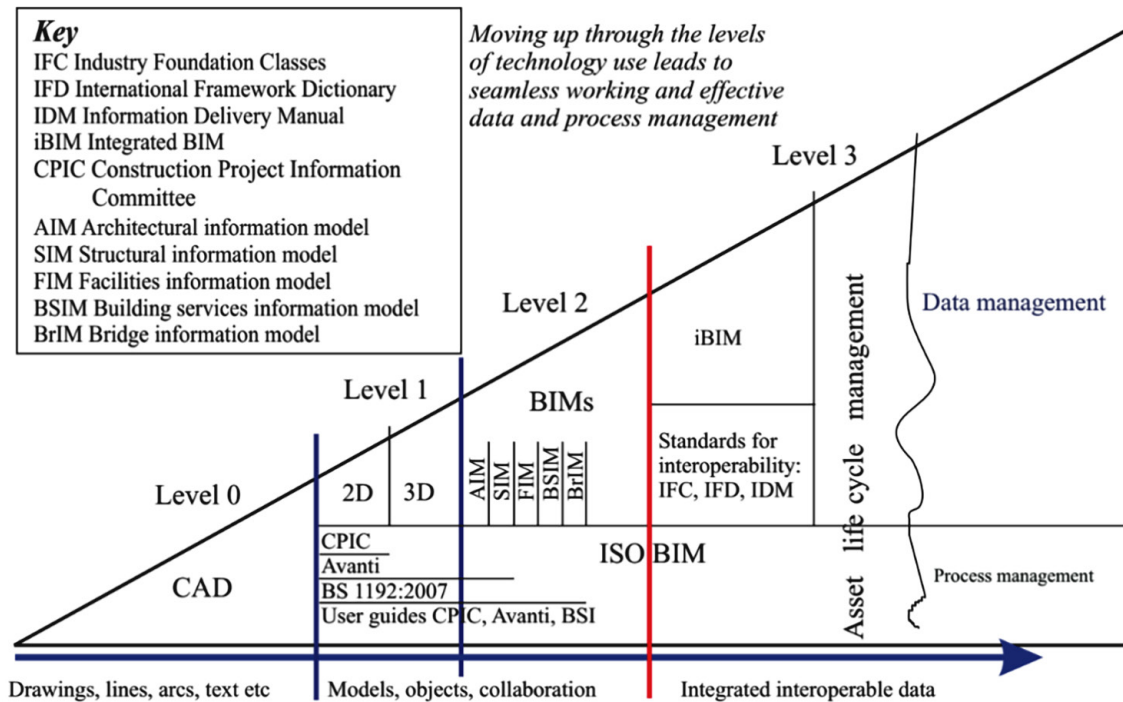Figure 1. Bew-Richards BIM Model (Bew & Richards, 2008; BSI, 2010)

Figure 2. Bilal Succar linear model (Succar, 2009)

optimize and streamline such firms' operations and prevents information lag.

Meanwhile, McCuen (2008) proposed an Interactive Capability Maturity Model (I-CMM) which is closely related to the NIBS capacity maturity model. McCuen (2008) utilized a case study project to present a scoring system for the study's maturity model. The tool is intended to help construction professionals to establish a starting point in BIM and improve the performance of BIM. Arif, Egbu, Alom, and Khalfan (2009) developed a Knowledge Retention Maturity model to evaluate the knowledge retentions capacities of construction firms. They proposed a four-stage knowledge retention process, which is "socialization, codification, knowledge construction, and knowledge retrieval" and presents ways or indicators in documenting an organization's knowledge retention process. Meanwhile, other studies on the development of BIM construction-related models in the literature include Kwak and Ibbs (2002) who developed the project management process maturity (PM)^2 model. Also, we have the development of a Lean Enterprise Transformation Maturity Model by Nightingale and Mize (2002) and Lockamy and McCormack (2004) which proposed and advanced the Supply Chain Management Process Maturity Model and the Business Process Orientation (BPO) Maturity Model.

3. Research methodology

The study aims at developing a BIM-Project information management framework (BIM-PIMF) and key indicators for use by the project team in construction projects. An Explanatory Case Study (ECS) approach which involved

both a "desktop literature review and pattern-matching using causal-process tracing (CPT) mechanism" (Blatter & Haverland, 2012) helped to elicit necessary data for the study augmented with four (4) case study BIM projects. A knowledge retention model advanced by Arif et al. (2009) also utilized desktop literature review to develop the model and augmented with a case study project. Other studies (see Kwak & Ibbs, 2002; Lainhart, 2000; Lockamy & McCormack, 2004; McCuen, 2008; Nightingale & Mize, 2002; Vaidyanathan & Howell, 2007) also developed their maturity models utilizing the same approach.

Explanatory case study approach is a variant of case study research methodology; the other types of case study research are the exploratory, descriptive case studies (Rhee, 2004; Yin, 1994) and confirmatory case study (Milliot, 2014). More so, per Milliot (2014) another word for the explanatory case study is "causal" case study. Chong, Wong, and Wang (2014) opined that ECS is used to compare with a set of variables to reach a specific outcome. The research approach (ECS) is suitable for this study because per DME (2013) descriptive and explanatory case studies are the most likely designs for evaluation purposes. Meanwhile, ECS research design enables the assessment of "cause-effect relationships" (Chong et al., 2014; DME, 2013). Yin (2014) stated the goal of an explanatory case study as that which attempts to provide possible explanations for a set of events; by searching for causes, for influences, for preconditions, for correspondences (Stake, 2010).

Simons, Ziviani, and Copley (2011) noted that ECS offers a way to address complex research issues. Blatter and Haverland (2012) further highlighted the three approaches to ECS which include Co-Variational Analysis (COV),

Causal-Process Tracing (CPT) and Congruence Analysis (CON). The CPT approach as adopted in this study start 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.

Meanwhile, the data collection for ECS relies on some techniques which are "documentation, interviews, direct observations and archival records" (Fisher & Ziviani, 2004). Explanatory case study method starts by retrieval of information, theories from a review of extant literature and archives to enable the "identification of the characteristics of what is termed the case" (Yin, 2003). Previous researchers (see Capraro, 2016; Chong et al., 2014; Simons et al., 2011; Rhee, 2004) have utilized explanatory case study research methodology in their research. Moreover, in this study, two data collection techniques (documentation and archival records) were used as detailed in this study's research design (Figure 3). The dashed lines as

shown in Figure 3 reveals that the specific action or algorithm step (within dashed frames) was iterated as many times as possible until the objectives of the respective actions/step (within solid frames) are achieved. The solid lines show a one-way movement between one algorithm step and another.

The current study uses multiple case studies to validate the developed maturity index. A total of four (4) case study construction projects were evaluated based on the published BIM implementation report in those projects. Simons and Ziviani (2011) considered multiple case study evaluation an "equivalent of multiple experiments." More so, according to Simons and Ziviani (2011), and Yin (2003) when two or more case studies are used to support a model development; such results can be considered to be potent, vigorous and robust.

Demian and Walters (2014) also did use four (4) case study BIM projects to document the benefits and challenges of information management in a BIM-based workflow.
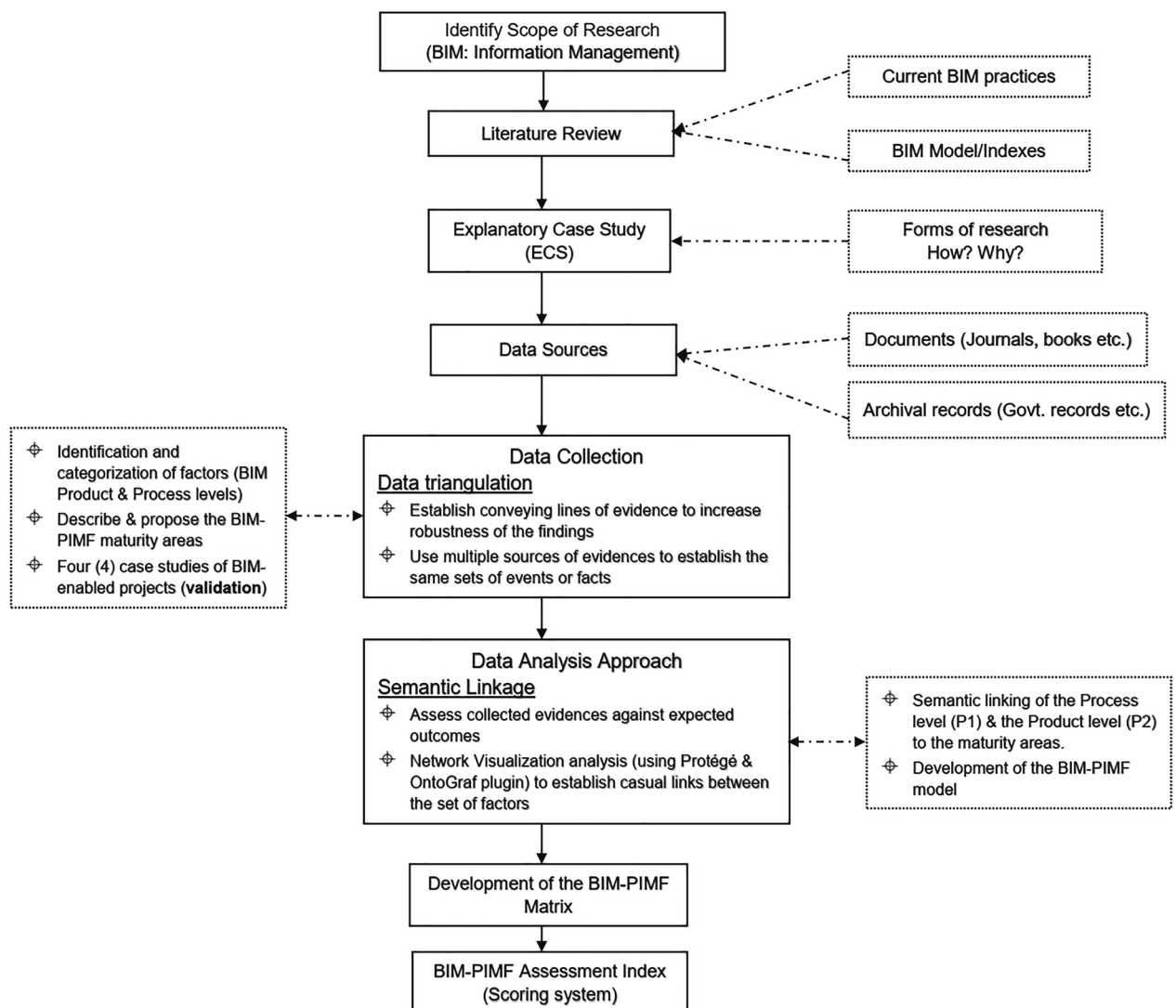

Figure 3. Outline of research design

Meanwhile, McCuen (2008) and Arif et al. (2009) adopted just one case study project in developing their models.

4. Development of BIM-Project Information Management Framework (BIM-PIMF)

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 according to Kazi, Aouad, and Baldwin (2009) delivers unique product and service through competence and information sharing between different organizations. BIM as an innovative technology as the potential to foster competitiveness in construction operations and aid the stakeholders' capacity to turn new ideas to practice (Rampersad, Plewa, & Troshani, 2012), thus, necessitated the need for improvement in the existing framework and processes for BIM-based information management.

This section elaborates on the steps taken in the development of a BIM information management framework which aims to assess the capacity of the deployed BIM system in a project and the capability of the project stakeholders to manage and coordinate project information. Key indicators (for project information management) were also developed to evaluate the capacity of BIM and its users to manage project information at both the (1) BIM Process level and (2) the BIM Product level. BIM capacity per Succar (2009) is "basic ability to perform a task, deliver a service or generate a product." Stakeholders' capability refers to the innate or acquired ability, qualities, experience to carry out a specific task. More so, the study carried out pattern matching for the process and product levels (including their respective sub-levels and parameters) to match the collected evidence or data with the expected outcomes based on a set of a five-point measurement scale.

Step 1: Identification and categorization of factors

In recent years, the construction industry has encountered an increasing compulsion to implement techniques that can ensure projects to be delivered on schedule and within budget while improving productivity and performance. A review of the extant literature (see Figure 3) was carried out to identify and establish key evidence or patterns (factors and sub-factors) and best practices (maturity areas) that could enhance information management using BIM system in construction projects at both the BIM process level and the BIM product level. Table 2 elicits the identified factors contributing to the improvement in BIM information management at the process level. The factors were rephrased in terms that could be easily understood by AEC stakeholders. Table 3 lists the identified factors contributing to the improvement in BIM information management at the product level.

The construction industry can leverage on Information and Communication Technology (ICT) to enhance its business processes (Benjaoran, 2009). Also, the improvement of project communication processes and technologies on different functional levels will ensure changes in future planning and execution of project activities (Wikforss & Löfgren, 2007). Therefore, the development of new systems should agree with research findings and be adaptable in integrating domain areas (in the form of plug-ins) to the system.

Step 2: Establishing key evidence (best practices with case studies) that enhance BIM-Project Information Management

A radical improvement in the BIM products and processes is considered necessary to achieve a more efficient information management process regarding quality, customer satisfaction, timeliness in delivery and value for money. Improvement in IT is quite indispensable because design firms and construction companies regardless of their sizes have been seeing IT as their opportunity for improvement in future (Jaafar, Abdul Aziz, Ramayah, & Saad, 2007).

The next step in the development of the BIM-PIMF model is to identify and establish sets of assessment criteria or best practices that could serve as a benchmark towards accessing the categorized factors at the process level (P1.1–P1.5) and product level (P2.1–P2.5). The established key indicators were augmented with relevant case studies of selected construction and infrastructural projects in Hong Kong.

Meanwhile, nine (9) best practices were established based on documentary evidence backed up with case studies of BIM-enabled projects. The best practices or key indicators for evaluating improvement in projects' information management are portrayed in Table 4. More so, Table 5 and Table 6 outline four (4) case studies of BIM-enabled projects which achieved some or all the identified BIM-PIMF best practices as elaborated in Table 4. The rationale for the selection of the four case study projects for this study was based on their relevance (well-known projects) and they been a representative of a group of projects and/or country of origin.

The data used in Table 5 to show how each of the four case study projects (#1–#4) aligns with some of the key indicators (best practices) outlined in Table 4, was extracted (using a content analysis approach) from published BIM implementation project reports compiled by the project team or client of the respective BIM projects under this study's case study review. Afterward, an explanatory case study approach as explained under the "research methodology" section and illustrated in Figure 3 was used to link the BIM best practices attained in each project with the study's BIM-PIMF key indicators.

The case #1 and #2 projects are both situated in Hong Kong. More so, for the case #1 project (One Island East), it is one of the first private commercial building projects on which BIM was employed in Hong Kong; while case #2 project (Public Rental Housing) is selected as a representative of BIM projects from the Hong Kong Housing Authority. Case #3 is a multi-purpose high-rise building project (BIM-enabled) in China, and the case #4 project is that of a hospital project located in the United States.

Table 2. Categorized factors contributing to improvement in information management at Process level

Code	BIM Process Level factors	Sub-levels	Description	References
P1.1	Exchange of BIM model or data	Offline BIM data exchange Online BIM data exchange	A functional means or system to exchange BIM data or project information either online (Internet) or offline would facilitate faster dissemination and processing of project information. A project team should choose which platform (offline/online) would be most suitable to their project. Meanwhile, a mix of both may be required especially when doing an energy analysis of buildings.	1, 5, 6, 9, 31
P1.2	Training for BIM users	Seminars and workshops Discipline specific in-house training Curriculum development	Users are to be equipped with the required skill and knowledge on BIM design and analysis software. Hence, there should be concerted efforts towards investing in staff training on BIM technologies as applicable to their operations.	2, 4, 8, 10, 11, 13, 17, 18, 23, 26, 28
P1.3	Group Support System (GSS)	Research or expert discussion forum Software developers Q&A platform FAQ Professional bodies	GSS is a set of "techniques, and technology designed to focus on and enhance the communications, deliberations, and decision-making process of groups." It can also 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. The imbibing of a collaborative attitude would enhance information management in projects.	14, 16, 24, 25
P1.4	Accessibility of BIM data	Sharing Reuse Integration of innovative concepts into BIM Digital Archives	The ease of sharing and reuse of knowledge during project phases facilitate information management. More so, integrating knowledge areas such as safety, sustainability into BIM and development and retrieval of process files from digital archives would allow for historical comparisons, promote efficiency and efficient BIM information management.	3, 7, 12, 27, 30, 31
P1.5	BIM integration into Lifecycle management of facility	RFID Ontology matching	The effectiveness of attaching radio frequency identification (RFID) tags to facility components and mapping with user-defined ontology classes would enhance information management at the facility management where its use is still quite low. It will also allow data access for users.	15, 19, 20, 21, 22, 29

Notes: Digits in the last column represent the references from the past studies, as: 1 = Abolghasemzadeh (2013); 2 = Abubakar, Ibrahim, Kado, and Bala (2014); 3 = Ahn et al. (2014); 4 = Aibinu and Venkatesh (2014); 5 = Akanmu, Asfari, and Olatunji (2015); 6 = Akinade et al. (2017); 7 = Aksamija (2012); 8 = Autodesk (2010); 9 = Azhar et al. (2009); 10 = Bin Zakaria, Mohamed Ali, Tarmizi Haron, Marshall- and Abd Hamid (2013); 11 = BuildingSMART (2011); 12 = Cerovsek and Katranuschkov (2006); 13 = Chan (2014); 14 = Chung and Shen (2004); 15 = Fang, Cho, Zhang, and Perez (2016); 16 = Katranuschkov et al. (2010); 17 = Ku and Taiebat (2011); 18 = McGraw-Hill Construction (2009); 19 = Motamedi and Hammad (2009); 20 = Motamedi, Saini, Hammad, and Zhu (2011); 21 = Motamedi, Soltani, and Hammad (2013); 22 = Motamedi, Soltani, Setayeshgar, and Hammad (2016); 23 = Nanajkar and Gao (2014); 24 = Redmond et al. (2012); 25 = Scheer, de Amorim, Santos, Ferreira, and Caron (2007); 26 = Specialist Engineering Contractors Group (2013); 27 = Watson (2011); 28 = Wu and Handziuk (2013); 29 = Zhang and Xiao (2013); 30 = Zhang and Bai (2015); 31 = Olawumi and Chan (2018c)

Table 3. Categorized factors contributing to improvement in information management at Product level

Code	BIM Product Level factors	Sub-levels	Description	References
P2.1	BIM models	Cloud-BIM BIM models Databases Archives	The adoption and integration of data management systems to ease the storage, sharing and reuse of BIM data and facilitate project visualization is essential to successful project information management.	1, 2, 3, 4, 6, 20, 26, 29
P2.2	Efficiency in interoperability	Data schema Information exchange Processing large files	Poor interoperability results in loss of information in many instances during the transfer of the building model from collaborative BIM tools to proprietary analysis tools. Interoperability between BIM software will improve the ability of sustainability tools to analyze BIM models and also enhance management of project information.	2, 6, 9, 14, 16, 17, 19, 29
P2.3	Well-structured interface and user-friendliness	Analysis procedure or steps Interface information Labels (clear and visual) Context filtering mechanism	Enhancement of the user interface of BIM software would improve its user-friendliness and enhance the ease to understand the software, enhance computation and analysis. It will also improve the efficiency of information exchange and its usability.	5, 7, 8, 10, 11, 14, 15, 23, 25
P2.4	Close collaboration and coordination	Software developers Project stakeholders Collaborative platforms Tools and technologies	Adoption of a collaborative approach by project stakeholders and software developers to manage and develops software and tools to enhance information management.	12, 14, 16, 24, 29
P2.5	Open source compliance	Design or authoring tools Simulation or energy analysis software Licenses	The cost implication of BIM software is attributed as one of the factors to its low usage in construction projects. Open source principles entail the sharing of software source code in a collaborative way and give rooms for the personification of the software for company use and enhance its functions.	13, 18, 21, 22, 27, 28, 29

Notes: Digits in the last column represent the references from the past studies, as: 1 = Abanda et al. (2015); 2 = Adamus (2013); 3 = Ahn et al. (2014); 4 = Aibinu and Venkatesh (2014); 5 = Akanmu et al. (2015); 6 = Aksamija (2012); 7 = Al-Hammad (2000); 8 = A. Al-Hammad and I. Al-Hammad (1996); 9 = Autodesk (2010); 10 = Azhar et al. (2009); 11 = Aziz, Anumba, and Peña-mora (2009); 12 = Benjaoran (2009); 13 = Bolpagni (2013); 14 = Chen, Reichard, and Beliveau (2010); 15 = Chien and Mahdavi (2009); 16= Cidik, Boyd, Thurairajah, and Hill (2014); 17 = Dawood (2009); 18 = Dedrick, Gurbaxani, and Kraemer (2003); 19 = Dim, Ezeabasili, and Okoro (2015); 20 = Espinal and Saluja (2010); 21 = Hergunsel (2011); 22 = Hope and Alwan (2012); 23 = Khanzode, Fischer, and Hamburg (2000); 24 = Lam et al. (2004); 25 = Miles and Ballard (2002); 26 = Wong et al. (2014); 27 = Yan and Damian (2008); 28 = Young, Jones, and Bernstein (2008); 29 = Olawumi and Chan (2018c)

Table 4. BIM-PIMF Key Indicators

Code	Key Indicators (best practices)	Description
AC1	Knowledge transfer	For a successful project, a sound platform should be provided to encourage and facilitate interaction, support, and collaboration among the project stakeholders and between the project team and academic BIM experts. Scheer et al. (2007) argued for a greater linkage between research output and ICT development efforts of construction firms.
AC2	Support and improvement	Information management in projects can be enhanced when project team members which include the designers provide support to improve or resolve design conflicts or to boost project parameters (time, cost & quality). The case studies in Table 5 give examples of how this practice could be exemplified in construction projects.
AC3	Regular facility upgrade	Clients, consultants, and contracting organization should endeavor to have installed in their firms and offices the latest BIM and associated software and the supporting operating systems and hardware for efficient performance. More so, they should promote uniformity in the deployed BIM software for a project as much as possible to reduce the incidence of interoperability which may lead to loss of details during file or data exchange. Scheer et al. (2007) reported that most firms still utilizes old versions of CAD/BIM software.
AC4	Standardization of project features	The standardization of project features for BIM manipulation would ease the use and interchange of BIM data at every stage of the project. Although Khasreen, Banfill, and Menzies (2009) noted the distinct characteristics of projects and the diverse set of stakeholders could make this form of standardization difficult. Nevertheless, previous authors (see Akanmu et al., 2015; Böhms, Bonsma, Bourdeau, & Kazi, 2009; Chen et al., 2010; Dawood, 2009) resolved that the establishment of a benchmark for the development of BIM software and its deployment to projects would ease this concern.
AC5	Trust and open communication	Cooperation, trust, and open communication should be foster among project stakeholders. Antón and Díaz (2014) described insufficient collaboration and cooperation as one of the barriers to information management in the construction industry; hence, construction stakeholders need to avoid such isolated efforts to achieve a more collaborative working environment.
AC6	Increased investment in research and development (R&D)	The key stakeholders in construction projects, as well as their organizations, should cultivate the attitude of investing resources in R & D. Lack of investment in R & D hinders growth or evolution in the building sector (Antón & Díaz, 2014; Dawood, 2009; Scheer et al., 2007). Chong et al. (2009) noted that the construction sector would profit in knowledge and technology from such investment because as of recent, the construction industry still lags due to inadequate resource allocation and funding as compared to other sectors. Investing in R & D would ensure value for money, timely and quality information and overall, the satisfaction of end-user's needs (Olawumi & Chan, 2018c).
AC7	Education and skill development	The development of the capacity and competencies of project stakeholders should be in the front-burner of every firms or organization through platforms such as construction-related symposium, conferences or seminars to equipped them on latest and innovate development in the construction industry. Dawood (2009) noted that best practice guidance notes should be formulated and shared across the industry. Meanwhile, there should be continuity and proactiveness in educating and improving the skills of project personnel especially those involved in the deployment and management of BIM in projects.
AC8	Enhancement of BIM technologies and integration with other technologies	The ease of integration of BIM software with other emerging technologies will improve and optimize the performance and user's understanding of their work context. However, the project team should ensure that project stakeholders have familiarized themselves with the technologies before its deployment and use in a project (Autodesk, 2011; Aziz et al., 2009; Chen et al., 2010; Dawood, 2009). More so, the integration should ensure the cross-compatibility of BIM models and analysis results across devices. BIM software could be enhanced with technologies such as VoiceXML to give multi-language capabilities (voice-enabled interfaces); hence, emerging BIM technologies must improve security, trust, safety, and construction planning.
AC9	Accessibility and availability of information	The essence of information management in any given project is to facilitate the construction project in such a way to aid its success, hence per Garza and Howitt (1998) the "quality, quantity, and timing" such information is important. Kondratova (2003) highlighted "poor access to the right information" as one of the challenges confronted by the project team in their bid to make timely decisions in a project. It is being suggested to the industry to establish a platform and hub to facilitate information dissemination and gathering on the project site.

Table 5. Case studies of achievement of the BIM-PIMF Key Indicators (AC1–AC4)

S/N	BIM-enabled projects	Achievement of the BIM-IMF Maturity Areas (best practices)			
		AC1	AC2	AC3	AC4
Case 1	One Island East (70-storey, Grade A private commercial building) Location: North Point, Hong Kong	The prospective contractors sought supports from academics in preparing their tenders. The successful contractor is to keep comprehensive details about the project and updated BIM model for the use of the facility manager after project completion.	The design team identified and resolved more than 200 design clashes and errors which improve the overall BIM model. A team of architects, structural engineers and other consultants from various firms provide support to improve the design. There was 20 percent cost savings and 20 days saved in the project schedule.	The BIM software – Gehry Technologies Digital Project® used for the project was up to date with associated software and hardware.	CAD was used for schematic design and BIM for detailed design stage onward. The Gehry BIM software is made up of CATIA® (for product modeling) and DEMIA (for process modeling).
Case 2	Public Rental Housing (PRH) Location: Tai Pak Tin Street, Kwai Chung Area 9H, Hong Kong	Knowledge and ideas interchange between the project team and the Hong Kong Housing Authority help in the decision-making process. Adequate record was kept for future use in operation and maintenance phase.	The prompt identification and resolution of site issues and challenges by the key stakeholders improve the project.	–	The use of 3D models eases the project team and contractors understanding of the construction than what 2D drawings and written method statements could have achieved.
Case 3	Tianjin Goldin Metropolitan (117-storey building) Location: Haitai South-North Street, Huayuan Industry Park, Central Business District (CBD) Phase 1, China	The BIM model designed by a team of designers help the landscape designers to visualize the project and makes it possible for them to create optimal landscape features.	The engineering consultants assist in fine tuning the design. The deployed BIM ease the design stage and serve as a boost to managing the project.	Regular upgrade and installation of required BIM software and tools facilitate the analysis of construction processes.	–
Case 4	Good Samaritan Hospital Location: Puyall, Washington, United States	The design team further separated the floors into 2D with the 3D background for the contractor use.	A regular check of the impact changes in the updated model has on the project. Quality control and design collision detection to improve the overall design.	BIM software such as Revit-3D and Navisworks was used for the project and efforts were made to ensure they are up-to-date and functioning properly.	The design team and other consultant agreed on the use of Revit-3D BIM software for their modeling.

Note: Case 1: Baldwin and Bordoli (2014); Case 2: Fung (2011), Garr (2017); Case 3: Autodesk (2012); and Case 4: Garr (2017).

Table 6. Case studies of achievement of the BIM-PIMF Key Indicators (AC5–AC9)

BIM-enabled projects	Achievement of the BIM-IMF Maturity Areas (best practices)				
	AC5	AC6	AC7	AC8	AC9
Case 1	Close to 50 design team members from different firms worked assiduously and collaboratively on the project design.	The contractor and the five (5) key firms that made up the design team made a considerable investment in R & D.	The bidding contractors were required as part of their tenders to submit simulation model of how they intend to undertake the project. Supplementary training and guidance were provided to the bidders on how to extract and use the BIM data by a team of BIM experts at the Hong Kong Polytechnic University.	The use of BIM with visualization enhances the design and construction processes. BIM was integrated with MS Project and Primavera to facilitate the project planning and scheduling. Construction visualization techniques were used to check site safety and analyze the construction process.	BIM was used as a central management tool to synthesize, identify and solve the construction problem before they impact construction on site. The completeness of the BIM model facilitates accurate project budget estimates.
Case 2	Deliberations and consultations between the project staff and the contractor to ensure smooth construction.	–	Safety training was facilitated using BIM models.	BIM was integrated with construction schedule and planning tools. BIM was used to simulate the project buildability and site program and operation to ensure safety on site.	Prompt access to project team members to BIM models and project data and information.
Case 3	Consultative meetings among project consultant to resolve issues with the BIM model. Project team regularly review the BIM model and overall design.	The case project was the first project the client utilized BIM in their project.	–	BIM was used to visualize the entire construction process. BIM was enhanced to check for safety issues and manage the project.	The BIM model assists the key stakeholders to manage project information and ensure things are in place and position.
Case 4	There were weekly meetings where updates about the project were shared. The need of the design team and contractor were prioritized.	–	–	Navisworks was used to compare the architectural BIM model and the as-built structural model for accuracy.	A central hub was created to facilitate the ease of access of key stakeholders to project information. Timely and accurate communication of all project issues

Step 3: Semantic linking of the process level (P1) and product level (P2) with the key indicators to establish the BIM-PIMF

At this stage, the identified factors under (1) BIM Process level and (2) BIM Product level was matched with the BIM-PIMF maturity areas (AC) established in step 2 by creating a set of causal links between the set of variables. The Protégé software developed and supported by the Stanford University, USA was used in identifying and defining the patterns (factors) match for the product and process levels in this study (Figure 5). More so, the software was also used to define semantic linkage and show the relationships between the subclasses of the BIM-PIMF maturity areas (AC1–AC9) with the process level (P1.1–P1.5) and product level (P2.1–P2.5) subclasses (see Figure 6) using the ontological framework. The OntoGraf visualization tool in protégé was used to organize the relationships of the OWL ontologies as shown in Figures 4 and 5.

OWL (web ontology language) was used in defining the framework because it "ensures that ontology knowledge is understandable to computers and human beings" (Zhong, Ding, Love, & Luo, 2015). Meanwhile, the study uses the RDF/XML format to represent the ontology structure. Moreover, the first step in defining the pattern of relationship between P1, P2 and AC was to identify the three classes: (1) AC-Class: 'BIM-PIMF Assessment Areas' rdfs:label "BIM-PIMF Assessment Areas"@en. (2) P1-Class: 'Process level' rdfs:label "Process level"@en; and (3) P2-Class: 'Product level' rdfs:label "Product level"@en. Moreover, the study classified the factors of P1, P2, and AC as subclasses of the classes (see Figure 4).

This procedure leads to the development of the Building Information Modeling-Project information management framework (BIM-PIMF) as indicated in Figure 5. Previous researchers have made use of ontology to develop different BIM frameworks such as Karan, Irizarry, and Haymaker (2016) that use an ontology to integrate GIS and BIM; also, Pauwels et al. (2011) adopted it for building performance checking. Other studies (Alatrish, 2013; Karan & Irizarry, 2015; Liu, Lu, & Al-Hussein, 2016; Mohd Zin & Egbu, 2009; Niknam & Karshenas, 2017; Oraskari & Törmä, 2015; Pauwels et al., 2011) exemplified the use of ontology frameworks for their research.

Step 4: BIM-PIMF Key Indicators (to demonstrate its application in projects)

BIM-PIMF was developed to serve as a metric to measure the capacity of the deployed BIM product and players (experts) to deliver a functional information management system. The BIM-PIMF assessment matrix is a stratified spectrum of deliverables that is set up to evaluate the level of implementation and adoption of the BIM-PIMF framework in construction projects. The purpose of the defined assessment matrix is to assist project teams, contractors, and other stakeholders to identify ways of improving their capacity to enhance and strengthen the project information network using a systematic approach. It would also help to foster collaborative working in information management and establish a good practice entrenched with knowledge transfer and exchange of ideas among project organizations using BIM as a platform.
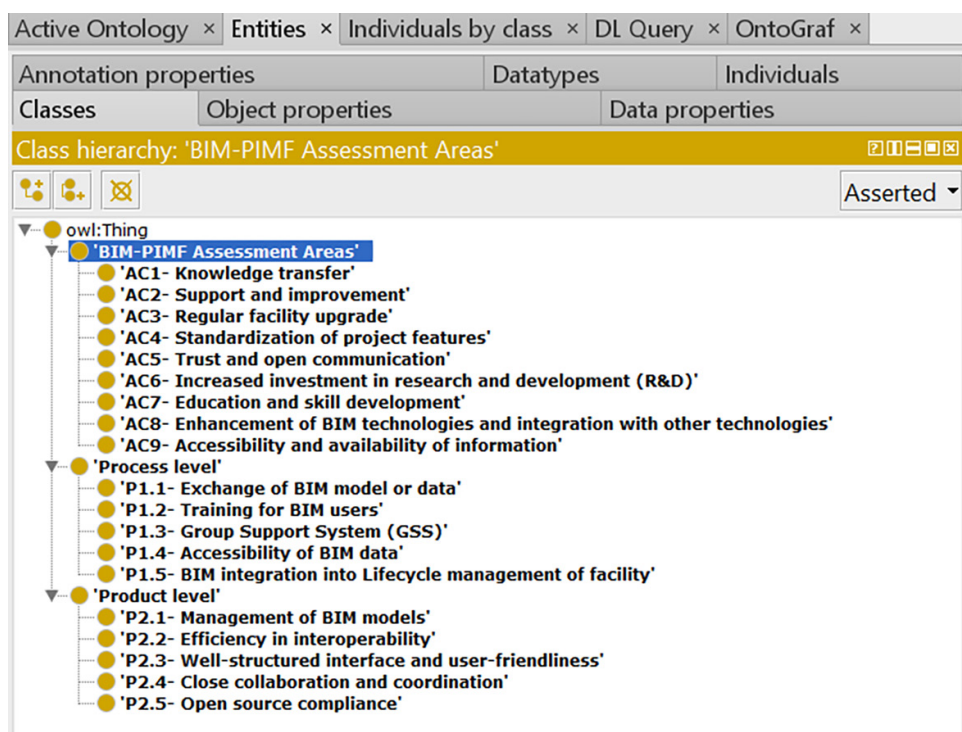

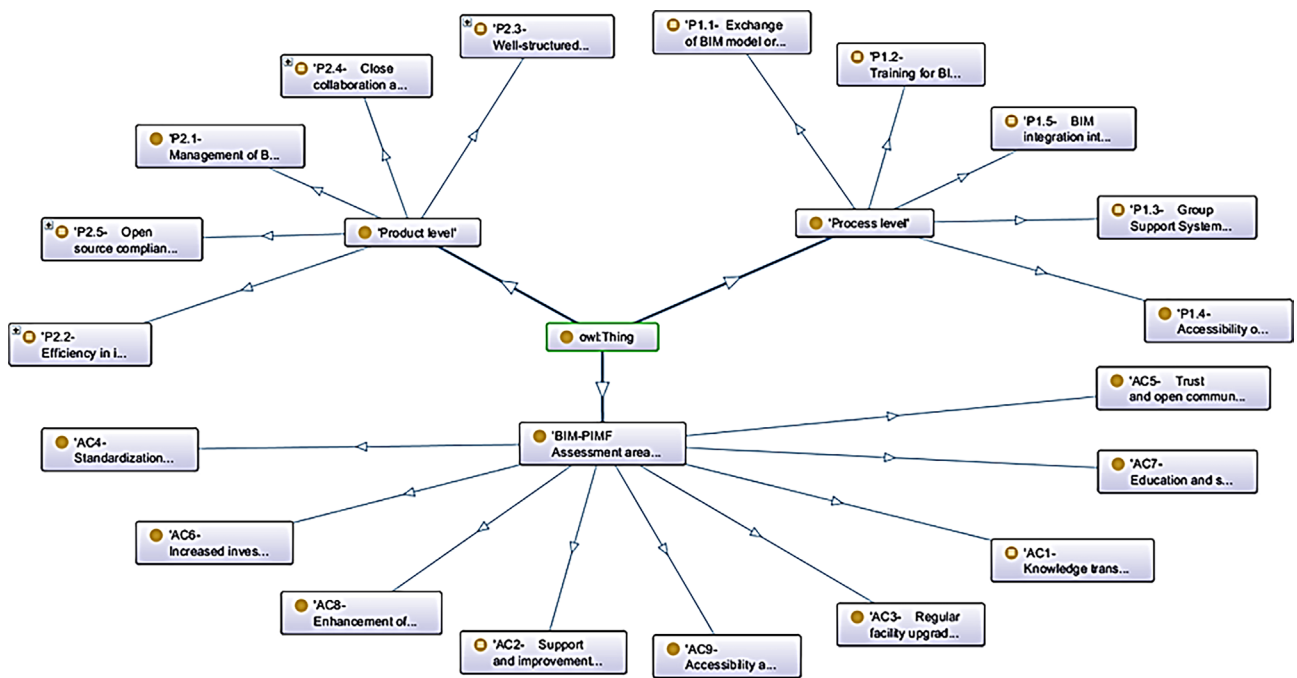Figure 4. Screenshot of the OWL classes and subclasses (Protégé-OWL 5.2)

Figure 5. BIM-PIMF model

Succar (2010) highlighted a list of different construction management maturity-index terminologies while this study modified and adapted the COBIT maturity level terminologies. The BIM-PIMF maturity matrix is of five (5) graded levels [*deliverables*]: (a) Initial (0 point); (b) Intuitive (20 points); (c) Defined (40 points); (d) Managed (60 points); (e) Optimized (80 points). More so, extant literature (see Succar, 2010; Lockamy & McCormack, 2004; McCormack, Ladeira, & Oliveira, 2008) pointed out that the progression from one level of maturity (say "initial") to a higher level (say "optimized") reveals a greater control mechanism to reduce the variations between "targets and actual results". Also, it reveals the ability and efficiency of the project team to achieve set goals and even pursue more advanced objectives. Table 7 and Table 8 outline the description of five (5) levels of BIM-PIMF key indicators; the purpose is to serve as a set of guiding principles in assessing the projects based on the earlier stated objectives.

The grading of the BIM-PIMF assessment matrix can be undertaken by (i) self-administered assessment [SA] (by one of the key project stakeholders), (ii) peer or formal assessment [PA] (more than two assessors), and (iii) external assessors or trained specialists [EA]. The assessors must have adequate experience in BIM and must have deployed BIM in previous construction projects.

Step 5: Scoring a sample project using BIM-PIMF Key Indicators

This section outlines a self-administered assessment of a sample construction project using the Public Rental Housing (PRH) project (*case #2 in Table 5 and Table 6*) to evaluate the process of grading typical projects using the following systematic procedure:

– Evaluation and establishment of the project progress in achieving the nine (9) BIM-PIMF key indicators.
– Assign points based on the maturity level attained: Initial – 0 points; Intuitive – 20 points; Defined – 40 points; Managed – 60 points; Optimized – 80 points.
– Aggregate the total points scored and divided by nine (9) to give the BIM-PIMF assessment score (x).
– BIM-PIMF Maturity index: to derive the maturity index the assessment score is subdivided by 100.

Table 8 provides the assessment index for the case study project (*Case #2- Public Rental Housing [PRH]*) discussed in step #2. The basis of the calculation of the assessment index of the case #2 housing project is based on the critical evaluation of the BIM-PIMF key indicators in Table 7 either via a self-administered assessment [SA] or peer assessment.

Table 9 gives the linguistic description for the scale or grade of a construction project calculated using the assessment procedure described in Table 7 and Table 8. The grade linguistic expression gives the various degrees or levels of classifications for the calculated maturity index (MI); this ranges from "very poor" (0.00–0.19) to "excellent" (>0.70). The authors acknowledged that some of the indices (*such as investment in technology*) might be subjective or difficult to measure during the assessment to develop a project maturity index. However, the five (5) scales (*initial, intuitive, defined, managed, and optimized*) of the matrix will help mitigate the challenges in the grading or measurement.

Table 7. BIM-PIMF Key Indicators

Code	BIM-PIMF Key Indicators	Initial	Intuitive	Defined	Managed	Optimized
AC1	Knowledge transfer [SA, PA]	The absence of a defined objective to identify and implement the exchange of knowledge among stakeholders in the project.	Project leadership is non-existent or non-consistent. Implementation is basically on individual initiative.	Exchange of knowledge and information is recognized as crucial to the project. Project leadership and implementation process are established.	The concept and roles are embedded and shared within participating organizations. Integrated with organization strategic practices and links with academic and professional groups are formed.	Project team members and organizations have incorporated the culture and are actively pursuing it. More dynamic and systematic ways are integrated to make the process more efficient.
AC2	Support and improvement [PA, EA]	No effort to initiate or improve project parameters or resolve project conflicts.	Efforts at improving construction information process are made independently of other interdisciplinary specialists. No collaborative support.	Establishment of a mechanism to improve the delivery of the right support and improvement in the project. Involve related discipline and is temporary.	The framework has progressed to collaborative and integrated support system involving many key stakeholders.	The concept, risks, and responsibilities are incorporated into the contract and revisited to enhance the quality and efficiency.
AC3	Regular facility upgrade [SA, PA, EA]	BIM software and associated tools are obsolete or unsuitable for the project. No regular update of BIM facility.	The push to ensure BIM equipment are up to date, and appropriate for the project is unidimensional, resulting in interoperability issues.	Regular upgrade of BIM equipment is identified as key, concerted effort of stakeholders is secured.	There is a uniform agreement among stakeholders on the choice of the project BIM software and tools. Investment in software is maintained.	Deployed BIM software and tools are regularly checked and upgraded. Support is secured from the software vendors.
AC4	Standardization of project features [PA, EA]	There is the absence of a structured or defined process or software for the different project phases.	Each project stakeholder decides on *how to* undertake their piece of the entire project. No uniformity or shared approach.	The need to standardized project processes and phases is acknowledged and communicated among the project team. A uniform approach is agreed with mechanism put in place to ensure compliance.	It is integrated and shared by the project stakeholders. Guidelines are made available to facilitate its seamless integration and understanding by key stakeholders	The standardized procedure and process are continually reviewed and examined to ensure it delivers the best possible results and aligns with project objectives.
AC5	Trust and open communication [PA]	There is no evidence of free and open interaction, collaboration and coordination among project stakeholders.	The stakeholders establish separate links to facilitate communication. Reactive-type of communication.	A formal link or platform for communication is set up between the primary stakeholders. The communication is proactive, and ideas & opinions are freely shared and expressed.	The communication and collaboration among the key stakeholders are well-managed and organized. A timely and dynamic schedule is incorporated to resolve salient issues.	Technological innovations are integrated to optimize the process. A culture of trust, respect is entrenched among project staff.

Note: SA – self-administered assessment; PA – peer or formal assessment; EA – external assessors or trained specialists.

Table 7. BIM-PIMF Key Indicators (cont'd)

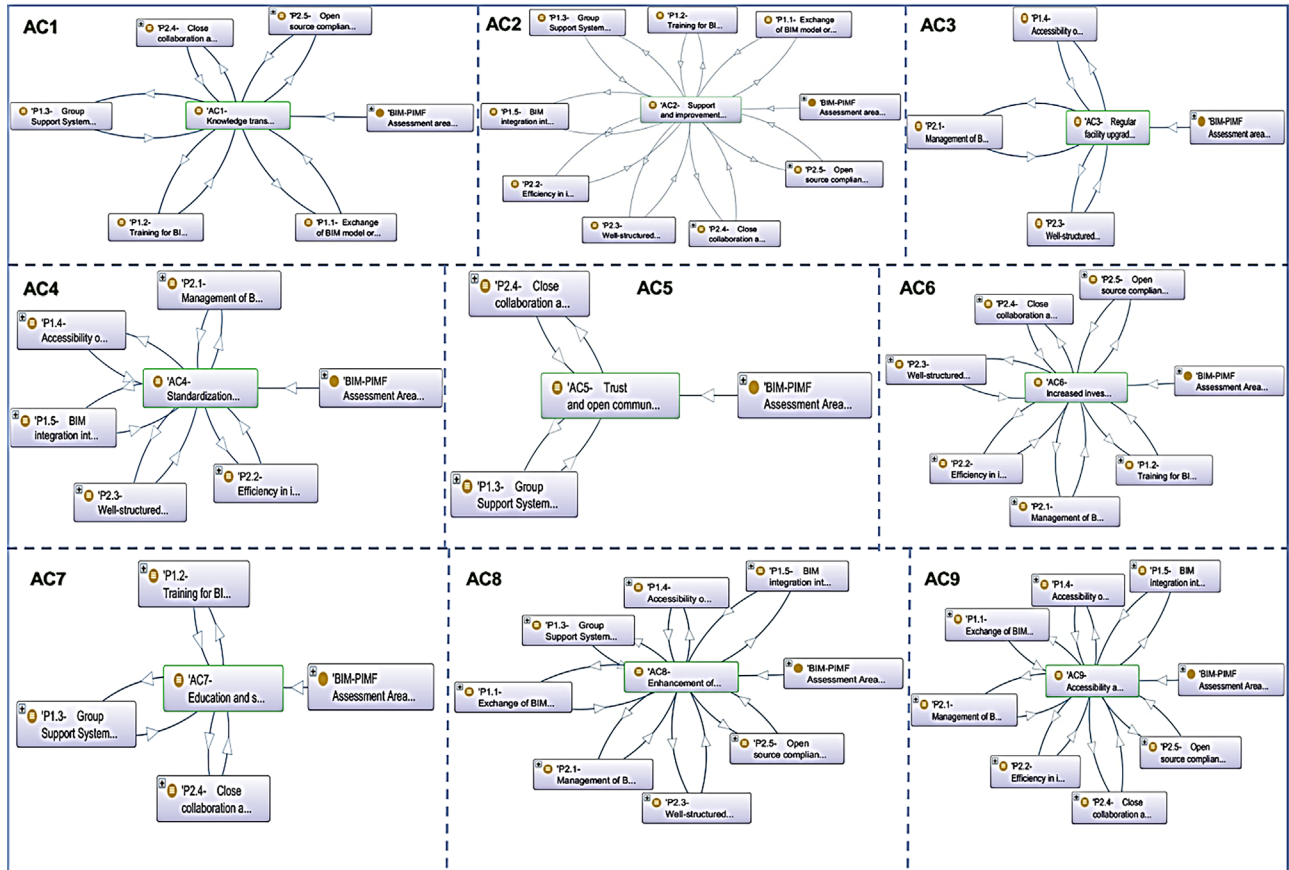| Code	BIM-PIMF Key Indicators	Initial	Intuitive	Defined	Managed	Optimized
AC6	Increased investment in research and development (R&D) [EA]	No evidence of investment in BIM infrastructure in the project. Much focus is still be directed to traditional practices.	R & D is recognized as essential; benchmarks and attainable objectives are confirmed. Little evidence of investment.	Actions plans, and policy framework are set in motion and gravitated towards achieving the defined objectives.	R & D is integrated into the organizational setup and managed to complement corporate and project policies and strategies.	R & D is optimized and deployed to improve the brand image of the project team or organization. Continual improvement and feedback mechanism is setup.
AC7	Education and skill development [PA, EA]	Little or no evidence of training of project staff on BIM. Teams do not have necessary BIM expertise.	The concept is not integral to project but recognized by several stakeholders as having the potential to aid the project positively.	Strategy and policies to facilitate a valuable training and skill development regime are implemented. The on-project learning process is encouraged and supported.	Discipline and process-specific training are integrated. Teaching and training based on a set of competencies criteria. Access to educational opportunities (academic linkages) is enhanced.	The continual and progressive development of staff skills and strengths in the use of BIM software and management of construction processes. A regular evaluation of the training and feedback from staff.
AC8	Enhancement of BIM technologies and integration with other technologies [PA, EA]	Zero enhancement or non-integration of BIM software to facilitate other construction processes other than being a modeling or design tool.	Requirements and protocols to enhance BIM integration with other construction management tools are identified within the project team.	The tools and equipment to facilitate the integration are made available. The requirements are adaptable to users' skill sets. The tools are deployed in the project.	BIM and the integrated tools and solutions are well-managed and align with project strategies and goals. Interoperability is enhanced, and process performance and quality are monitored.	Progressive multi-facet enrichment of BIM technologies. Security of the integrated data and processed results. The implementation of Cloud-BIM.
AC9	Accessibility and availability of information [SA, PA]	There is no platform to ease access to project information. Not recognized as an essential factor in the project.	Informal pathway to information use and retrieval. Each stakeholder work around to secure the required information.	A defined and formal pathway to information documentation and retrieval. Role and responsibilities of each stakeholder to enhance the pathway is well-understood and consistent. Prompt access to information.	A centralized hub to ease access to information for key stakeholders. The concept, its requirement in innovative product or processes are integrated into the project and organizations' strategic policy and culture. The integrity of the BIM model as a key asset to the project is secured.	Continual improvement and optimization of the information channel. Improved quality, quantity, and timing of project information. Regular feedback and monitoring to deliver substantial value to stakeholders and enhance project objectives.

Figure 6. The semantic structures for the BIM-PIMF key indicators (AC1–AC9) with P1 and P2

Table 8. BIM-PIMF Assessment scoring system (for sample case study project #2)

BIM-PIMF Key Indicators	Initial (0 points)	Intuitive (20 points]	Defined (40 points)	Managed (60 points)	Optimized (80 points)
AC1 – Knowledge transfer				√	
AC2 – Support and improvement			√		
AC3 – Regular facility upgrade	√				
AC4 – Standardization of project features		√			
AC5 – Trust and open communication			√		
AC6 – Increased investment in research and development (R&D)		√			
AC7 – Education and skill development		√			
AC8 – Enhancement of BIM technologies and integration with other technologies			√		
AC9 – Accessibility and availability of information			√		
Sub-level points	**0**	**60**	**160**	**60**	**0**
Aggregate points					**280**
Assessment score					**31.11**
Assessment index					**0.31**
Remark	Middling (Average) level of BIM-PIMF implementation in the sample project.				

Table 9. BIM-PIMF Assessment index values

Assessment index values	Level or degree
>0.70	Excellent
0.50–0.69	Good
0.30–0.49	Middling
0.20–0.29	Poor
0.00–0.19	Very poor

Conclusions

The primary focus of this study is the development of BIM-Project information management framework (BIM-PIMF) with the aim of enhancing BIM use for managing project information in construction projects. A review of the desktop literature revealed significant impacts of BIM in several areas of the AEC industry such as the design, construction, facility management, safety, and for sustainability. A review of the existing BIM frameworks revealed the use of BIM in aspects such as supply chain management, IT, knowledge retention, lean construction, and documentary evidence form case study BIM projects were used to augment the proposed BIM-PIMF.

The study also reviewed the current BIM practices in the AEC industry and emphasized the importance of BIM as an ICT driven system. It was established that the ability of BIM to facilitate the management of project information and process including its dynamic representation of building systems makes it suitable and relevant to the construction industry. Meanwhile, towards the development of the BIM-PIMF model for construction projects, the existing BIM frameworks were examined.

Also, the BIM-PIMF measures the capacity of the deployed BIM product and players (experts) to deliver a functional information management system in a construction project. The previous BIM frameworks focused on other construction-related aspects as highlighted in Sections 1 and 2. Also, the BIM-PIMF evaluates the adequacy and efficiency of information management in a BIM-enabled project and was established based on a set of nine (9) BIM key indicators, five process level factors, and five product level factors.

The nine BIM-PIMF key indicators developed included: knowledge transfer, support and improvement, regular facility upgrade, standardization of project features; and trust and open communication. Others are increased investment in research and development (R&D), education and skill development, enhancement of BIM technologies and integration with other technologies, and accessibility and availability of information. Furthermore, a semantic linkage of the process level (P1) and product level (P2) with the BIM-PIMF key indicators (AC) is expected to serve as a useful guide for project stakeholders or trained assessors and assist them when deploying the BIM-PIMF in construction projects. More so, using the BIM-PIMF key indicators together with the semantic map will provide a more accurate and holistic assessment of the nine (9) BIM-PIMF key indicators in the grading or evaluation of a construction project and determination of its BIM-PIMF assessment scores. Also, the four (4) case study projects assessment in the study have provided ample illustrations, and sound evidence of the various levels of implementation of the BIM-PIMF maturity areas and helps augment the framework as to its applicability in a project.

This study adopted a conceptual approach which catalogs current practices of BIM and uses a pattern-matching algorithm to develop the framework. Future studies can utilize data collection methods such as survey questionnaires and interviews to further probe and validate the conceptual framework. Future research can also extend the scope of the BIM-PIMF by providing additional process level and product level factors that could be considered in assessing the level of BIM-PIMF implementation in a project. Also, there exists a strong need for establishing a guideline of good practices for industry stakeholders to ensure that BIM becomes a more reliable and efficient information hub for construction projects from their inception onward.

A limitation of this study is that the current framework is conceptual for use by industry practitioners. However, the study has provided for the use of peer or trained assessors to evaluate the parameters of the framework. Whenever BIM-PIMF is to be deployed in a project, construction organizations are advised to consult academics or BIM experts who will be in a better position to interpret the BIM framework to evaluate the implementation of BIM in their projects as well as train their in-house personnel to use the model. Workshops could be organized by professional bodies and consortium of construction companies for their staff or members to gain more knowledge on the BIM-PIMF model and the existing ones in the literature.

Project teams and construction stakeholders can use the BIM-PIMF framework to: (1) improve the capacity of the deployed BIM and enhance the skills and technical competencies of project staff towards improving project information management; (2) assess the extent and the capacity of a construction project to achieve the desired maturity level and fulfill the BIM-PIMF key indicators; (3) improve and optimize the information channels and the progressive enrichment of BIM technologies, and (4) ensure technological innovations to be integrated to enhance the project information process. Policymakers and government departments can utilize the model in assessing the level of usage of BIM in a construction project and in gauging subsidies to be provided to construction organizations to improve their BIM uptake.

Disclosure statement

The authors declare there is no conflicting or competing interests.

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