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CHARACTERISING BIM-BASED CONSTRUCTION PROJECTS: A STRATEGIC AND CONTINGENT BIM APPLICATION MODEL

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ABSTRACT
BIM application on construction projects is a potential risk that must be managed. Risk factors in construction projects will also increase with the extent of BIM application due to the challenges associated with BIM application. Managing the risk of BIM application on projects and the realisation of BIM value depends on the appropriate use of BIM. Several studies have identified the balance between BIM value, project characteristics, and BIM application as a way of mitigating the risk of BIM application on projects. However, frameworks or models providing the balance between the BIM value, project characteristics, and BIM application are scarce. Hence, using a meta-synthesis of relevant studies, this study proposes a strategic and contingent BIM application model for construction projects. The strategic part of the model entails the determination of BIM value and BIM effectiveness on a construction project by using appropriate BIM tools and processes for the project. The contingent part of the model involves the use of project complexity to determine the project expectations. The model turns into a strategic and contingent application of BIM on construction projects by matching the extent of BIM application to the level of project complexity. The model presents unique attributes for characterising BIM-based construction projects and provides a guide and research focus for case studies of BIM-based construction projects. Also, the model will make it easier to plan and manage BIM-based construction projects as well as enable a widespread application of BIM tools and processes.

Keywords: BIM; BIM-based projects; BIM application; characteristics of BIM-based projects; strategic and contingent BIM application.

1. INTRODUCTION
The continued development of Building Information Modelling (BIM) tools and processes as well as the slow rate of transition from the traditional work process to BIM will affect the level of BIM implementation in different construction industries, organisations, and projects (Mihindu and Arayici, 2008; Ghaffananhoseini et al., 2017; Khosrowshahi and Arayici, 2012). This reality has influenced the development of BIM implementation strategies and BIM maturity levels in countries such as United Kingdom, United State, Singapore, and Finland (Smith, 2014; Wong et al., 2011). However, the challenges of applying BIM on construction projects are the major BIM implementation concerns owing to the problem of finding the balance between BIM effectiveness (BIM performance on projects), BIM value (project

benefits from BIM application on construction projects), project success (project performance), and project characteristics (project expectations) (Azhar, 2011; Becerik-Gerber et al., 2011).

In finding the balance between these concepts, recent studies have established the relationship between BIM effectiveness and BIM value (Barlish and Sullivan, 2012; Becerik-Gerber and Rice, 2010) and relationship between project success and project characteristics (Chan et al., 2004; Lam et al., 2008). The effectiveness of BIM has been explained to have a direct effect on BIM value. For instance, Lee et al. (2013) said that BIM effectiveness has a direct impact on BIM value. Singh et al. (2011) and Gu and London (2010) concluded that BIM has a different level of effectiveness, which can be used for various project benefits depending on project expectations. In other words, the level of BIM application on projects is directly related to the level of BIM effectiveness and the expected BIM value or project expectations (Czmoch and Pekala, 2014; Arayici et al., 2012).

Similarly, project characteristics have been established to have a direct effect on project success (Chan et al., 2004; Duy-Nguyen et al., 2004); while both project characteristics and project success have been linked to project complexity (Chen et al., 2011; Al Khalil, 2002). Thus, finding the balance between BIM effectiveness, BIM value, project success, and project characteristics, implies that the extent of BIM application on a project meets the level of project complexity. In that way, the effectiveness of BIM on a construction project will translate to project success through the realisation of BIM value based on project characteristics. Also, finding the balance between the extent of BIM application on a project and the level of project complexity is necessary because risk factors in construction projects increase with the level of project complexity (Chien et al., 2014). This means that BIM application on construction projects is a potential risk that must be managed because risk factors on construction projects increase with the extent of BIM application and the challenges associated with BIM application such as capacity factors and experience (Liu et al., 2017). Hence, end-users and decision-makers on BIM application on construction projects require a benchmark for managing BIM value and BIM effectiveness on construction projects (Becerik-Gerber and Rice, 2010).

A considerable number of models and frameworks have been proposed for benchmarking BIM application on construction projects (AEC-UK BIM protocols, 205; Moore, 2017; Kassem et al., 2013; Kassem et al., 2014; Liang et al., 2016; Ding et al., 2014; Hartmann et al., 2012). For instance, Ding et al. (2014) proposed a BIM application framework with a focus on methods of utilising nD-building information models on construction projects. Hartmann et al. (2012) proposed a model for matching BIM tools with construction management methods. Kassem et al. (2014) proposed a protocol framework for collaborative design on BIM-based construction projects. Most of these models and frameworks have been developed based on industry characteristics and not on project characteristics making the models applicable in both developed and developing countries. This would have also resolved the problems of balancing the extent of BIM application on a project and the level of project complexity (Tulenheimo, 2015; Hartmann et al., 2012; Cao et al., 2015). Sackey et al. (2014) noted that the availability of these models and frameworks had not aided the understanding of the practical application of BIM tools and processes on construction projects. Cao et al. (2015) and Coates et al. (2010) concluded that the appropriate use of BIM tools and processes is yet to be understood and that this affects the realisation of BIM value. This is because only the proper use of BIM tools and processes will generate BIM value. Gong and Lee (2011) observed that the appropriate use of BIM and the realisation of BIM value depend on a strategic application of BIM on construction projects. Smits et al. (2017) concurred that the strategic application of BIM on construction projects is the only reliable predictor of project performance. Therefore, there is a need to understand how BIM could be effectively and practically applied to construction projects. BIM application is the best way to realise and evaluate BIM value.

This study aims to identify strategic and contingent systems for effective and practical BIM application on construction projects and establish their usefulness for characterising BIM-based projects. This paper posits that characterising BIM-based construction projects will enhance the effectiveness of BIM application as this allows the use of suitable BIM tools and processes as well as ensure control. Besides, it will support the determination of relevant project expectations for BIM-based construction projects.

2. THEORETICAL GROUNDING

2.1 Relationship between project complexity and BIM application

Project complexity is the main characteristics that determine the approach to project delivery because it deals with the extent of difficulty, instability, uncertainty, uniqueness, and dynamism of construction projects (Wood and Ashton, 2010; Vidal and Marle, 2008). According to Wood and Ashton (2010) and Lebcir and Choudine (2011), project complexity is beyond having a large number of interconnected projects. Project complexity also relates to the interaction, interdependencies, and interrelationships between parts of a project and organisation.

The primary criteria for determining construction project complexity include project size, project duration, project milestones and deadlines, construction systems, political and cultural sensitivity of the project, regulatory requirements for technology, and project team composition and size (Baccarini, 1996; Williams, 1999; Engwall, 2013; Muller and Turner, 2007; Pich et al., 2002; Maylor et a., 2006; Shenhar and Dvir, 1996; Ahn et al., 2016; Shokri et al., 2012). The different levels of these criteria provide information on how to characterise construction projects based on their level of complexities. For example, Yang et al. (2011) pointed out that highly complex projects are technologically and logistically demanding, requiring multidisciplinary collaboration. Brockmann and Girmscheid (2007) maintained that megaprojects epitomised high project complexity because of their high capital cost and long duration. Qazi et al. (2016) and Lu et al. (2015) concluded that large projects are more demanding and challenging than other projects. Equally, Hwang (2014) suggested that construction projects with a project duration of fourteen months or less and project costs between US$ 0.1 million to US$5million must be classified as small projects.

In the BIM application literature, the levels of complexity of construction projects have been established to have a significant relationship with the extent of BIM application on construction projects (Cao et al., 2015; Lattifi et al., 2013; Singh et al., 2011; Chau et al., 2003). A notable example of this relationship is Cao et al. (2015), which recognised project size as predictors of the extent of BIM application on construction projects. Lattifi et al. (2013) and Singh et al., (2011) clearly illustrate the relationship between the levels of complexity of construction projects and the extent of BIM application on construction projects by suggesting that BIM-enabled multi-disciplinary collaboration is more suitable for highly complex projects because of their high risks and expectations.

2.2 Relationship between project expectations, BIM effectiveness, and BIM application

Construction projects are an instrument for meeting a purpose, and this purpose determines the expectations from the projects (Ryd, 2014). This makes construction projects to be unique because the project expectations as constituted by the need, interests, and requirements of project stakeholders concerning the projects' objectives differ from projects to projects (Becerik-Gerber and Rice, 2010; Lau and Kong, 2008). In BIM-based construction projects, project expectations integrate BIM benefits and project performance indicators (Coates et al., 2010; Du et al., 2014; Azzouz et al., 2016). Table 1 presents a summary of BIM-based construction projects expectations.

The management of expectations from BIM-based construction projects has become an important consideration in BIM application, since the effectiveness of BIM on construction projects depends on the realization of project expectations (Linderoth, 2010; Barlish and Sullivan, 2012; Love et al., 2014; Cao et al., 2015; Won and Lee, 2016; Dakhil et al., 2016). This suggests that there is a substantial relationship between project expectations, BIM effectiveness, and BIM application. A considerable number of studies have established the relationship between project expectations, BIM effectiveness, and BIM application on construction projects (Ding et al., 2014; Zandieh et al., 2016; Tulenheimo, 2015; Coates et al., 2010). An example is a conclusion by Ding et al. (2014) and Zandieh et al. (2016) that the needs and requirements inform the extent of BIM application on construction projects of the construction projects. Liu et al. (2017) submitted that BIM application on construction projects must start with ensuring efficiency before moving to effectiveness such as collaboration. This is because efficiency issues in construction projects address the social and technical problems such as information development, sharing, optimization, buildability, and integration. Coates et al. (2010) also pointed out that the effectiveness of BIM application on construction projects depends on the specific usage of BIM tools, the scale and stage of the application, number of team members, and BIM capacity of participants.

Additionally, scholars have demonstrated that the extent of BIM application on construction projects moderates the realization of project expectations and the effectiveness of BIM. This is aligned to the argument of Porwal and Hewage (2013) and Davis et al. (2008) that BIM application on construction projects must have corresponding project expectations. This is because it enables the assessment of BIM effectiveness and enables the technical, procedural, and organisational challenges associated with BIM application on construction projects to be overcome. Similarly, Lau and Kong (2008) and Baiden and Price (2011) concurred that project expectation must determine the extent of BIM application on a construction project. This is because the extent of BIM application will determine the extent of BIM effectiveness, which is a determinant of the extent to which project expectations will be realized.

The moderation of BIM effectiveness and the realization of project expectations through the use of different levels of BIM application on construction projects becomes essential to guide against wastage of time, efforts, and money as a result of BIM application on construction projects. Although, substantial project expectations will be achieved if BIM is applied throughout all stages of construction projects; however, the implementation of BIM is still limited mainly to the early stages of construction project delivery (Eadie et al., 2013). This is an indication of the inadequacies of the existing BIM execution/application models which has limited BIM application to conceptual and design stages by not outlining strategic and contingent application of BIM tools and processes.

Table 1. Project Expectations as enabled by BIM Effectiveness

BIM effectiveness	Related project expectations/BIM value to project performance	References
Cooperation	Improved client satisfaction, improved contractor satisfaction, improved quality performance	Staub-French and Khanzode (2007), Jiang *et al.* (2013), Grilo and Goncalves (2010), Ghaffarianhoseini *et al.* (2017)
Coordination	Improved client satisfaction, improved contractor satisfaction, improved quality performance, Improved time performance, improved consultants' satisfaction,	Baiden and Price (2011), Miettinen and Paavola (2014), Ericksen (2015), Liu et al. (2017), Grilo and Goncalves (2010), Ghaffarianhoseini *et al.* (2017)
Partial integration	Improved client satisfaction, improved contractor satisfaction, improved quality performance, Improved time performance, improved consultants' satisfaction, Improved contractors' satisfaction, improved suppliers' satisfaction, improved cost performance	Lu *et al.* (2013), Liu *et al.* (2017), Ericksen (2015), Ghaffarianhoseini *et al.* (2017)

Full integration	Improved client satisfaction, improved contractor satisfaction, improved quality performance, Improved time performance, improved consultants' satisfaction, Improved contractors' satisfaction, improved suppliers' satisfaction, improved cost performance, Improved health and safety performance, improved industry satisfaction	Alreshidi *et al.* (2017), Liu *et al.* (2017), Miettinen and Paavola (2014), Ghaffarianhoseini *et al.* (2017), Cao *et al.* (2015), Rahman *et al.* (2014), Baiden and Price (2011), Erickson (2015).

2.3 Relationships between BIM tools, BIM process, and BIM applications

The full application of BIM tools and processes comes with a significant cost that may not be advantageous and justifiable on less complicated projects (Czmich and Pekala, 2014). The solution to this challenge is a strategic and contingent application of BIM tools and processes on construction projects through the grading of the application of BIM tools, the integration of building information models, and the collaboration among the project stakeholders (Ding et al., 2014; Vidalakis et al., 2011; Eriksson, 2015; Mathousi and Thwala, 2012; Han and Golparvar-Fard, 2015; Han et al., 2015; Fai and Rafeiro, 2014; Boton et al., 2015; Cao et al. (2015). Table 2 presents a summary of the types of BIM tools that are commonly utilised on construction projects. The grading of the application of BIM tools depends on the extent of usage of BIM software platforms, the extent of usage of BIM tools, and the project phase at which the BIM tools are applied (Yang et al., 2011; Baiden et al., 2006; Ciribini et al., 2016). For example, Ding et al., (2014) concluded that the extent of BIM application is associated with the phase of work at which BIM is to be utilized.

BIM supply chain, number of building information models to be developed, choice of collaborative procurement system, and intensity of collaboration have been identified as the determinants of the extent of collaboration in BIM application on construction projects (Vidalakis et al., 2011; Eriksson, 2015; Davis et al., 2008; Oraee et al., 2017; Baiden and Price, 2011). The implication of this, according to Vidalakis et al. (2011) is that the supply chain network in BIM-based construction projects must include only members who have substantial involvement, responsibilities and direct contributions to BIM processes in terms of authoring of building information models, information sharing and exchange, and knowledge transfer. In support, Baiden et al. (2006) observed that the higher the complexity of a construction project, the higher the number of team members required, and collaboration required because of the increase in the numbers of building information models to be developed. These requirements also have a significant impact on the choice of collaborative procurement systems (Ciribini et al., 2016).

Collaborative procurement systems are project delivery systems that focus on supply team integration through team formation and collaborative working (Wilkinson and Shestakora, 2007). BIM requires collaborative project delivery systems such as traditional collaborative procurement systems (design and build, construction management, design-build-operate, design-build-finance-operate, design-build-manage, and public-private-partnership), partnering and alliancing, and integrated project delivery because of the need to bring the design and construction team together (Davis et al., 2008). The traditional collaborative procurement systems allow the creation of BIM during the bidding phase, thereby allowing a more significant understanding of project complexity and cost. They ensure accurate cost estimation and better cost control; although, these procurement systems limit the full potentials of BIM unlike Integrated Project Delivery (Ciribini et al., 2016). According to Baiden et al. (2006), partnering and alliancing offers a climate where collaborative culture can be nurtured over a number of projects. This allows the project participants to have some measure of collaboration by enabling trust development, common goals, commitment, teamwork, shared risk, and win-win philosophy (Baiden et al., 2006). Also, Wilkinson and Shestakora (2007) maintained that partnering and alliancing remove adversarial behaviour between participants, establishes good working relationships, leads to quality improvements, provides control over cost overruns, allows more open communication and increased profitability.

Table 2. Types of BIM Tools

Types	Examples	References
Visualisation and review tools	Rendering, 3D-object based models, clash detection and model checking, 3D animation, visual walkthroughs	Zhang et al. (2013), Lafitti et al. (2013), Singh et al. (2011), Geodert and Meadati (2008), Wong and Zhou (2015), Wang et al. (2014), Roh et al. (2011), Hjelseth and Nisbet (2010), Zhang and Li (2010), Ku and Taibat (2011)
Planning and optimisation tools	Virtual reality mock-up models, construction simulation, optimisation, construction sequencing, laser scanning, ground penetration radar conversions	Dunston et al. (2011), Bazjanac (2008), Azhar et al. (2008), Kim et al. (2015), Costa et a. (2013), Chi et al. (2015), Zhang et a. (2011), Kim et al. (2016), Bosche et al. (2015), Hossain and Yeoh (2018)
Semi-automatic quantification and analysis tools	Fabrication modes [digital fabrication], automatic quantification, BIM maintenance plans, and technical support, sustainable element tracking, LEED tracking, conceptual energy analysis	Ambrose (2012), Cheng et al. (2015), Wong et al. (2014), Goucher and Thurairajah (2012), Patacas et al. (2015), Motawa and Almarshad (2013), Bonenberg and Wei (2015), Wu and Issa (2012), Azhar et al. (2011), Jalaei and Jrade (2014)
Full-automatic quantification and analysis tools	Life-cycle costing, budget simulation, automatic cost data extraction, forensic analysis, life-cycle analysis, as-built BIM model, intelligent asset management, automatic cost data update, detailed energy analysis, BIM-embedded operation and maintenance manuals, CoBie data population and extraction	Showlestani et al. (2015), Eleftheriadis et al. (2017), Zhang and Hu (2011), Kim et a. (2013), Jasek et al. (2014), Azhar and Brown (2009), Tang et al. (2010), Huber et al. (2011), Passini et al. (2016), Charlesraj (2014), Sabol (2008), Costa et al. (2013), Schlueter and Thesseling (2009), Kim and Park (2018), Kensek (2015), Jawadekar (2012)

The choice of collaborative procurement system is essential in determining the extent of collaboration in BIM application on construction projects because different procurement systems have different level collaboration (Mathousi and Thwala, 2012). Davis et al. (2008) noted that the level of collaboration in project partnering and alliancing is higher than that of traditional collaborative procurement systems; while integrated project delivery allows a higher level of collaboration compared to partnering and alliancing. This has led to the suggestion that traditional collaborative procurement systems and project partnering, and alliancing are suitable for simple and less complex construction projects and that integrated project delivery system be used for large and complex projects (Bresnen and Marshall, 2000; Eriksson, 2010; ElAsmar et al., 2013; Matthews and Howell, 2005).

The choice of collaborative procurement system as determined by the project complexity affects the form of BIM-enabled collaboration on construction projects (Oraee et al., 2017). However, the intensity of BIM-enabled collaboration is a function of the size of the project team (Miettinen and Paavola, 2014; Jupp and Nepal, 2014). The intensity of BIM-enabled collaboration is determined by the number of the interactive process and mutually beneficial relationships that take place among project participants. Baiden and Price (2011) explained that the intensity of collaboration among the design and build project team is limited because of professional barriers. Based on the size of the project team, a collaborative supply team and integrated project team can also be formed. Baiden et al. (2006), Xue et al. (2010), and Chen and Chen (2007) describe a collaborative supply team as a fully integrated team that has a flexible member composition, offers members equal opportunities to contribute to the delivery process, works towards mutually beneficial outcomes, shares information freely among its members, has a new identity, able to sustain long-term working relationships, and able to fully breakdown professional and organisational barriers. As explained by Azhar et al. (2008) and Forgues and Koskela (2009) integrated project team involves the partnering of different in-house project teams from various organisations. Some level of integration characterises it, but the individual project team will maintain their organisational identities and boundaries. The intensity of collaboration in the BIM process is summarised in Table 3.

Table 3. Intensity of Collaboration in the BIM Process

Intensity of collaboration	Description	References
In-house team	Project team staffed internally [or permanent supply chain]	Azhar et al. (2008), Lu and Korman (2010), Gledson (2016), Liu et al. (2017), Lu et al. (2015)
Integrated team	Project team staffed with internal and external members [or two or more supply chain networks] but with different contracts	Porwal and Hewage (2013), Zhao et al. (2015), McCuen (2008), Forgues and Iordanova (2010)
Integrated supply team	Project team staffed with internal and external members [or two or more supply chain networks] with a single contract	Rezgui et al. (2013), Papaonikolaki et al. (2015), Hossain et al. (2013), Franz et al. (2016)
Collaborative supply team	Project team staffed with internal and external members [or two or more supply chain networks] in conjunction with subcontractors and specialist suppliers, and with a single contract	Rezgui et al. (2013), Alreshidi et a. (2018), Kassem et al. (2014), Areshidi et al. (2017)

The extent of integration in BIM application on construction projects has been explained to be based on the BIM capacity of the BIM supply chain members, extent of integrating building information models (see Table 4), level of development (LOD) of building information models, and level of clarity of the parametric objects in the building information models (Fai and Rafeiro, 2014; Solihin and Eastman, 2015; Han and Golparvar-Fard, 2015; Cao et al., 2015; Leite et al., 2011). Cao et al. (2015) stated that a higher level of integration is an indication of a higher level of BIM application because high BIM capacity and high LOD are required to develop a fully integrated building information models.LOD is a fundamental issue in BIM application. It refers to the richness of the representation, specifies the content and reliability of information models in BIM, and determines the characteristics of model elements of different building systems and components (Fai and Rafeiro, 2014). LOD ranges from 100 to 500, but the choice of LOD depends on the specific needs of construction projects (Boton et al., 2015). LOD 100 represents components with a symbol or as generic elements without defining their specific properties (Han and Golparvar-Fard, 2015) while LOD 200 is an approximate representation that only shows shape, approximate quantities, location and orientation, and allows some non-graphic information to be attached (Solihin and Eastman, 2015).

These limitations make LOD 100 and 200 insufficient for a higher level of integration (Han et al., 2015). LOD 300 is sufficient for the design development phase of projects because of its usefulness in generating construction documents (Boton et al., 2015). It is a precise geometry that uses specific objects and shows precise size, shape, location and orientation, and information on interfaces with other systems (Solihin and Eastman, 2015). LOD 400 represents details of assemblies as they appear in shop drawings (Leite et al., 2011), and contains the information required for assembly, installation, and fabrication (Solihin and Eastman, 2015). LOD 500, on the other hand, is a field verified representation that provides sufficient details for planning, operation, and maintenance of construction projects.

However, some building components require more or fewer details, which imply that LOD must be standardized for BIM depending on project expectations. Although the higher the LOD, the more detailed the information (Solihin and Eastman, 2015), it is not necessary to model all building information to high LOD (Boton et al., 2015). Hence, the choice of LOD is determined by the level of integration required in a project because LOD has an impact on time and coordination. Also, it takes time to model components to details, but detailed information supports coordination (Leite et al., 2011).

Table 4. Extent of Data Integration in BIM

Types of data integration	Description	References
The integrated building information model	A master model created with common BIM software platforms	Quigley (2013), Succar (2009), Feng et al. (2010), Zhang and Issa (2012), Nepal et al. (2014)
Federated building information mode	A master model created through a one-way information exchange level to collaborate and integrate their designs or information models	Quigley (2013), Gibbs et al. (2015), Isikdag et al. (2007), Isikdag and Underwood (2010), Zhang et al. (2016), Solihin et al. (2016), Porwal and Hewage (2013)
Modified federated building information mode	A master model created by modifying a Standard Federated BIM using a single BIM platform to integrate the model further	Quigley (2013), Solihin et al. (2016), Beach et al. (2017), Lowe and Muncey (2009), Sackey et al. (2013), Moore (2017), Parn et al. (2018)
Standard federated building information mode	A master model created with various interoperable BIM software platforms and integrated on exchange platform such as IFC and COBie	Quigley (2013), Matthews et al. (2015), Parn et al. (2018), Bradley et al. (2016), Wijayakumar and Jayasena (2013), Solihin et al. (2017), Hijazi and Omar (2017), Alnaggar and Pitt (2019)

3. THEORETICAL LENS

Contingency theory and Benefits breakdown hierarchy theory was selected as the theoretical base for the extraction of insights from the theoretical background. Contingency Theory postulates that the project characteristics must match any variable that mediates the effect of project performance; and that projects must not be executed the same way because of differences in their characteristics (Husted, 2000; Morton and Hu, 2008; Sauser et al., 2009). Benefits breakdown hierarchy theory is a benefits or expectations management postulation on the realization of expectations and the capabilities to deliver them (Murphy and Lassaline, 1997; Bennington and Baccarini, 2004; Reiss, 2006). The hierarchical structure proposed by benefits breakdown hierarchy sets out the linkages between capabilities and expectations, as well as serves as a categorization system in which each category includes all the previous ones (Murphy and Lassaline, 1997). Categorization in the hierarchical structure comprises a basic level, subordinate level, and superordinate level. The expectations in the category levels range from extremely general to extremely specific, meaning that, the higher the category level, the more specific the expectations to be realised. The insights provided by contingency theory and benefits breakdown hierarchy theory facilitate the understanding of strategic and contingent BIM application on construction projects (Sauser et al., 2009; Howell et al., 2010; Gu and London, 2010; Barlish and Sullivan, 2012; Singh, 2013; Porwal and Hewage, 2013; Miettinen and Paavola, 2014; Isaksson et al., 2016; Zhu and Mostafavi, 2017). Section 5 describes the synthesis of the theoretical background into the proposed model.

4. RESEARCH METHOD

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method was adopted in this study following Shamseer et al. (2015). For each database (Scopus, Engineering Village, Ebsco, Google Scholar, and Web of Science), the key search terms were entered individually. The search terms were combined using different combinations as appropriate. Limitations such as years of publication (2002 - 2019) and English Language were applied. A total of 2,061 articles were identified at this stage. Articles that appear more than once were removed from the database for this study. At this stage, 2,014 number of articles remained. The title and abstracts of the remaining articles were screened for relevance to this study. Only the articles that appear to provide the information required for the study were included, totalling 903 articles. The eligibility of articles to be included in the final review was done by screening the articles for substantive relevance, context, and content. This stage gives a total of 34 articles (see Figure 1).

To develop the model for strategic and contingent BIM application on construction projects, a five-step meta-synthesis was conducted. The first step focuses on identifying the concepts that have direct effects on BIM application. As explained in Figure 2, BIM effectiveness, construction project complexity, and construction project expectation were identified to have a direct impact on BIM application on construction projects. The second step concentrates on understanding and identifying the elements of BIM application on construction projects. The extent of the implementation of BIM tools and extent of application of BIM processes were identified as the elements of BIM application on construction projects (see Figure 3). The third step concentrates on understanding and identifying the components of the elements of BIM application on construction projects. Usage of BIM software platforms, usage of BIM tools, and phase of BIM application were identified as the extent of application of BIM tools. The extent of the application of BIM processes splits into the scope of integration and extent of collaboration. For the extent of integration, the components include BIM capacity, database (data integration), level of development, and level of objects' clarity. The components identified for the extent of collaboration include BIM supply chain and several building information models, collaborative procurement, and intensity of collaboration (see Figure 3).

The fourth step focuses on synthesizing the literature on Contingency Theory, Benefits Breakdown Hierarchy Theory, and postulations relating to strategic and contingent BIM application on construction projects.

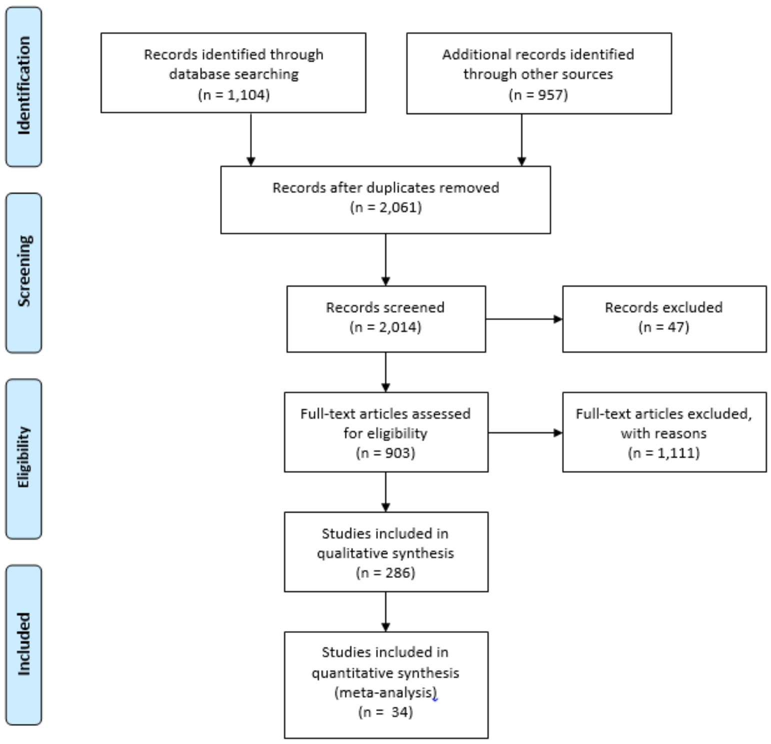

Figure 1. PRISMA flowchart for the study

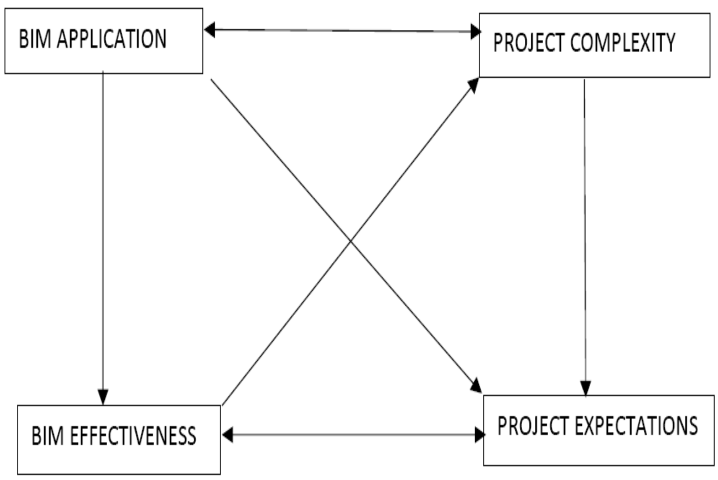

Figure 2. Relationships between BIM application, BIM effectiveness, project complexity, and project expectations

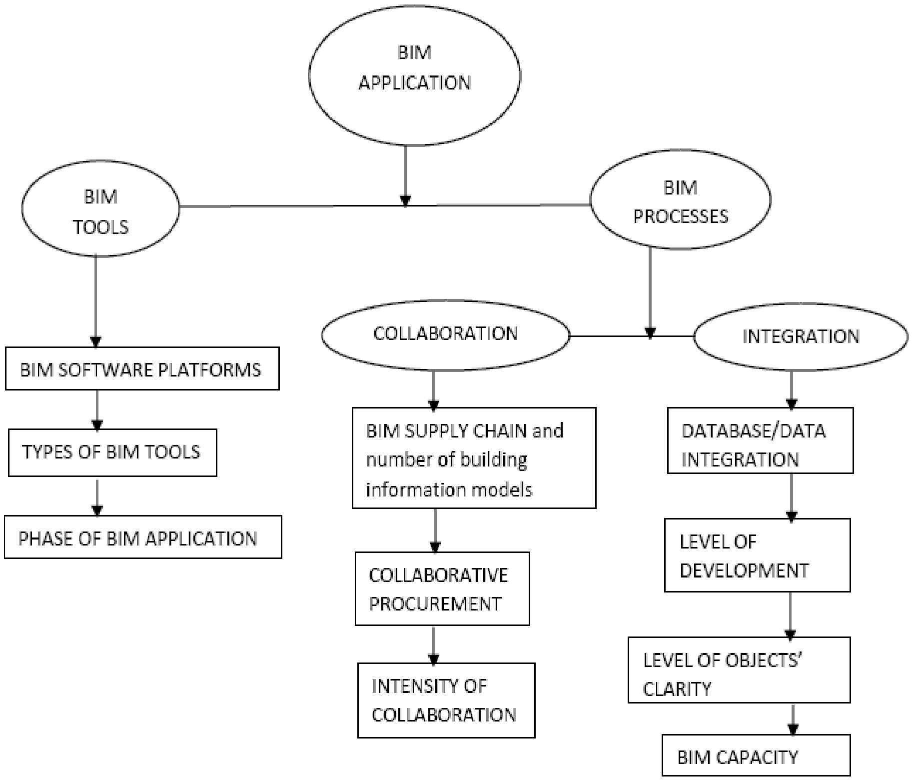

Figure 3: Elements of BIM application on construction projects

5. SYNTHESIS: DEVELOPING A MODEL FOR STRATEGIC AND CONTINGENT BIM APPLICATION ON CONSTRUCTION PROJECTS

This study derives the concepts for developing a model for strategic and contingent BIM application on construction projects from the theoretical background in Section 2. The above pieces of evidence have led to the conclusion that BIM has vast potentials that are of value to all types of construction projects regardless of their characteristics. This indicates that BIM is for all construction projects, but the application of BIM on construction projects must follow not just a plan but a strategic and contingency plan.

BIM application on construction projects becomes strategic and contingent when it takes the complexity and expectations of the construction projects into consideration. It does this by matching BIM tools and processes with the complexity and expectations of the construction projects. The case studies of BIM-based construction projects by Ciribini et al. (2016) and Czmuch and Pekala (2014) clearly illustrate the practicability of strategic and contingent BIM application on construction projects. Ciribini et al. (2016) reported a case study of a residential building on which BIM tools and processes were applied. As reported by the study, the traditional procurement system was used on the project, and full collaboration did not take place among the project participants. However, BIM application on the project optimized the design process and improved project coordination through semi-automatic quantifications and 4D scheduling. Also, Czmuch and Pekala (2014) reported a case study of an office complex involving ten professionals. The study reported coordination benefits such as elimination of errors and clashes in information, fewer request for information, fewer changes, accurate ordering of materials, and improved qualities of materials.

Based on these insights, this paper proposes a model of strategic and contingent BIM application on construction projects (see Figure 4). The model conceptualised that the extent of BIM application must be determined by the level of project complexity and project expectation. Project expectation, which also represents BIM value, must be determined by the extent of BIM application on construction projects. The extent of BIM application on construction projects must be determined by the extent of usage of BIM tools and processes. As conceptualised in the model (Figure 4), four elements are associated with the usage of BIM tools; while the BIM processes (integration and collaboration) have eight variables (four variables each). The model employs these elements to describe the different level of BIM effectiveness as well as to characterise different types of BIM-based construction projects.

6. FINDINGS AND DISCUSSIONS

Regardless of its huge potentials, inappropriate and unstructured use of BIM might not generate any benefits. Without a systematic BIM execution plan that concentrates on the desired outcomes and BIM uses on a project, the adoption of BIM would be counter-productive (Hadzaman et al., 2015; Smits et al., 2017). Performance cannot be measured without target standards; likewise, BIM performance in projects will be difficult to measure without setting targets before its usage. This paper introduces a strategic and contingent BIM application model for utilising BIM tools and processes on construction projects. BIM-based construction projects were also characterised using the extent of usage of BIM tools and processes on construction projects.

The model postulates that the extent of BIM application on construction projects increases with an increase in project expectation and project complexity. As illustrated in Figure 4 and 5, a strategic and contingent BIM application on construction projects will ensure that expectations from BIM-based construction projects are tailored to the level of complexity of the projects. It will also ensure that the extent of BIM application on a construction project is directly tailored to expectations and indirectly determines the BIM effectiveness on the construction projects. The model implies (as summarised in Figure 5) that project expectations and project complexity are interconnected – a change in project complexity will have an equal and direct effect on project expectations. The interconnection between project complexity and project expectation will affect the extent of application of BIM on construction projects. This means that a higher project complexity comes with higher project expectations and needs a higher level of BIM application. Studies by Liu et al. (2017), Fanning et al. (2014), and Smits et al. (2017) reported that the degree of project complexity is related to the project output as enabled by the extent of BIM application.

BIM APPLICATION			Characteristics of BIM-based Construction Projects			
			CLASS A	CLASS B	CLASS C	CLASS D
BIM Tools	BIM software platforms		Compatible/ common BIM software platforms			
BIM Tools	Type of BIM tools		Visualisation and review tools	Visualisation and review tools Planning and optimisation tools	Visualisation and review tools Planning and optimisation tools Semi-automatic quantification and analysis tools	Visualisation and review tools Planning and optimisation tools Semi-automatic quantification and analysis tools Full- automatic quantification and analysis tools
BIM Tools	Phase of BIM application		Conceptual design and planning	Conceptual design and planning Pre-construction	Conceptual design and planning Pre-construction Construction	Conceptual design and planning Pre-construction Construction Post-construction
BIM processes	Extent of collaboration	BIM supply chain and number of building information models	4 members and building information models	4 – 10 members and building information models	10 members and building information models	> 10 members and building information models
BIM processes	Extent of collaboration	Collaborative procurement	Traditional collaborative procurement	Traditional collaborative procurement	Project planning and alliancing	Integrated Project Delivery
BIM processes	Extent of collaboration	Intensity of collaboration	In-house team	Integrated team	Integrated supply team	Collaborative supply team
BIM processes	Extent of integration	Database (Data Integration)	The integrated building information model	Federated building information model	Standard federated building information model	Modified federated building information model
BIM processes	Extent of integration	Level of Development (LoD)	100 – 350 LoD		200 – 500 LoD	
BIM processes	Extent of integration	Level of objects' clarity	G0 – G2		G2 – G3	
BIM processes	Extent of integration	BIM capacity	Competence in BIM tools, information exchange skills, and information integration skills		Competence in BIM tools, information exchange skills, information integration skills, and multi-disciplinary collaboration skills	
Project complexity	Size		≤ $ 10M	$10M - $100M	> $ 100M	> $ 1B
Project complexity	Duration		≤ 1 Year	1 – 2 Years	2 – 3 Years	> 3 Years
Project complexity	Sensitivity (Political/Social/Economic/Cultural)		Very low	Low	Medium	Enormous
Project complexity	Construction system		Conventional	Advanced	Super advanced	Innovative
Project complexity	Milestones and deadline		Flexible	Aggressive	Ambitious	Over-ambitious
Project complexity	Technologies and regulatory requirements		Technologies with standard regulations		Technologies requiring new regulatory requirements	
Project expectation/BIM effectiveness			Cooperation	Cooperation Coordination	Cooperation Coordination Partial integration	Cooperation Coordination Partial integration Full integration

Figure 4. A Strategic and Contingent Model of BIM Application on Construction Projects

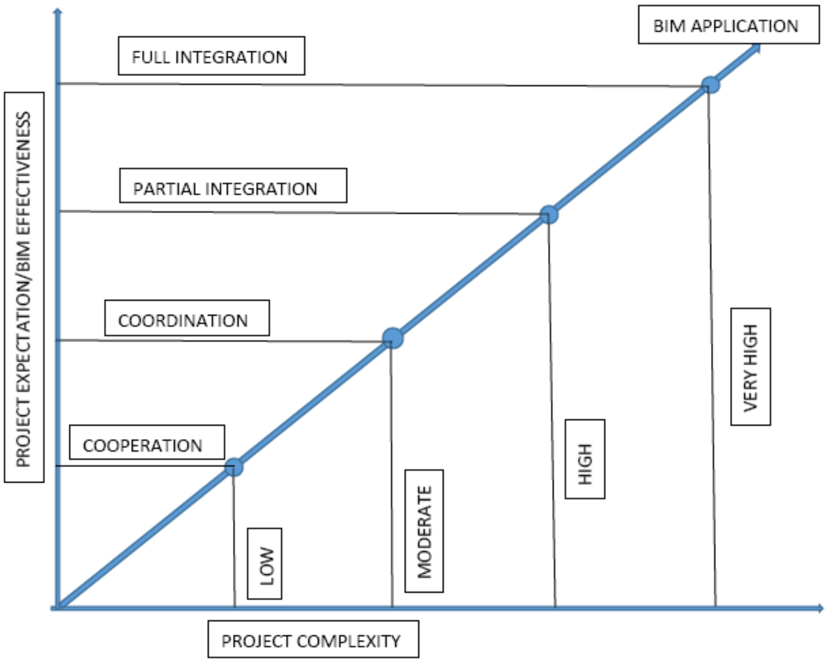

Figure 5. The BIM application curve showing the effects of project expectations and complexity on the extent of BIM application on construction projects

BIM application on construction projects provides a system of characterising BIM-based construction projects. BIM has revolutionised the construction industry, and its application in construction projects has impacted on the classifications of construction projects. According to Crawford et al. (2004), characterising projects is vital for identifying the appropriate methods and techniques for different types of projects. The characterisation of BIM-based construction projects, as proposed in the model, is useful in three ways. Firstly, it establishes a BIM application on construction projects as a method of determining project contingency based on complexity. This is in line with the argument by Qazi et al. (2016) and Chatterjee et al. (2018) that project complexity is the main characteristics of construction projects. Secondly, it provides a categorisation system for BIM-based construction projects, as well as serve as a system of distinguishing BIM-based construction projects from non-BIM-based construction projects. Harun et al. (2016) and Chen and Luo (2014) have argued for a system of drawing comparisons between BIM-based construction projects and non- BIM-based construction projects. Finally, it presents a practical strategy for selecting BIM tools and processes for construction projects with their associated set of deliverables. This represents the appropriate management systems for BIM-based construction projects because it gives them a unique and variety of attributes. This is aligned with studies by Singh et al. (2011), Lin (2014), Oh et al. (2015), and Zou et al. (2017) that identified BIM tools and processes such as the extent of collaboration, extent of integration, and extent of BIM usage platforms as a management system for BIM application on construction projects.

As explained in Figure 4, there are two major components in the model, namely the BIM application and BIM-based construction project characteristics. BIM application on construction projects are categorised into four aspects:

- *The extent of usage of BIM tools*: The type of BIM tools, type of BIM software platforms, and phase of application of BIM tools were used to explain the extent of usage of BIM tools on construction projects. These components were divided into various aspects and used to characterise BIM-based construction projects.
- *The extent of usage of BIM processes*: The model split the extent of usage of BIM process into the extent of integration and extent of collaboration. The extent of usage of BIM processes consists of BIM supply chain and several building information models, collaborative

procurement, and intensity of collaboration. BIM capacity, level of development, database creation, and level of objects' clarity were used to capture the extent of collaboration. Each of these components was grouped into four sections to enable the characterisation of BIM-based construction projects.

- *Elements of construction project complexities*: As conceptualised in the model, the complexities of construction projects are captured as project size, project duration, project sensitivity, construction system, project milestones and deadlines, and regulatory requirements for construction technologies. Each of these dimensions is sectioned into four components for easy categorisation under different classes of construction projects.
- *Elements of project expectations*: This indicates the expected BIM effectiveness on the construction projects. It also features the different types of expectations from BIM-based construction projects. These expectations were categorised into four aspects, namely, cooperation, coordination, partial integration, and full integration. Table 4 provides a summary of expectations from BIM-based construction projects.

The characterisation of BIM-based construction projects was done using the four aspects of BIM application on construction projects. The model proposes four significant categories of BIM-based construction projects:

- *Class A*: This is a type of BIM-based construction project with characteristics that include the use of compatible or common BIM software platform, the use of visualisation and review tools, the use of BIM tools at the conceptual design and planning stage of the project, four-member BIM supply chain with four key building information models (BIM), and the use of traditional collaborative procurement. The other characteristics of Class A BIM-based construction projects are the use of an in-house project team for BIM development and process, the creation of integrated bim, the use of LOD 100 – 300 and G0 – G2, emphasis on competence in BIM tools and information exchange and integration skills, a project size of less than or equal to $10million, and project duration of less than or equal to one year. The characteristics of Class A BIM-based construction projects also include cooperation among the project participants as project expectation, the use of conventional construction system, flexible milestones and deadlines, the use of technologies with standard regulations, and very low project sensitivity in terms of political, social, economic, and cultural impacts.
- *Class B*: This type of BIM-based construction projects consolidates on the characteristics of Class A BIM-based construction projects with unique characteristics such as the use of visualisation and review tools and planning and optimisation tools at conceptual design and pre-construction stages, the development of federated building information model, and the use of traditional collaborative procurement.
- *Class C*: Class C BIM-based construction projects features the development of standard federated building model, the adoption of project planning and alliancing, the application of visualisation and review tools and planning and optimisation tools as well as semi-automatic quantification and analysis tools at the conceptual to construction stage.
- *Class D*: This class of BIM-based construction projects epitomises the application of BIM on construction projects. The class characterises construction projects with the highest level of complexities. The general features of Class D BIM-based construction projects include some of the unique features of Class C BIM-based construction projects, the use of all the available BIM tools at all the project lifecycles, the adoption of Integrated Project Delivery, participation by collaborative supply team, and the development of modified federated building information model.

7. CONCLUSIONS AND IMPLICATIONS

This paper proposes a strategic and contingent BIM application model for construction projects. The strategic part of the model entails the determination of BIM value and BIM effectiveness on a construction project by using appropriate BIM tools and processes for the project. The contingent part of the model involves the use of project complexity to determine the project expectations. The model turns into a strategic and contingent application of BIM on construction projects by matching the extent of BIM application to the level of project complexity. The model presents unique attributes for characterising BIM-based construction projects. Characterising BIM-based construction projects makes it easier to identify non- BIM-based construction projects and makes it easier to plan and manage BIM-based construction projects. The model will enable a widespread application of BIM tools and processes in the developing countries where highly complex construction projects are rare.

The paper has established that BIM must be applied based on the project characteristics, requirements, and within the expected project benefits. It emerged from this study that a strategic and contingent BIM application will be achieved when the level of BIM application is matched with the level of project complexity and expectations. The paper concludes that a strategic and contingent BIM application on construction projects will ensure high BIM effectiveness in the delivery of construction projects; and that the performance of BIM on construction projects will be easy to assess with a strategic and contingent BIM application. The paper provides exciting theoretical implications by theorising on the technical feasibility of applying BIM tools and processes on all types of construction projects and theorising on the practical application of BIM to project complexities and requirements. The paper provides an understanding of how BIM could be effectively applied to construction projects. Also, the article offers insights on how BIM application characterises construction projects and benchmarks BIM value (project benefits), BIM application, and BIM effectiveness.

Although this paper will provide a guide and research focus for case studies of BIM-based construction projects; but future research should validate the practicability of the model through real case studies. This will further provide an understanding of the strategic and contingent application of BIM on construction projects and aid the widespread application of BIM on construction projects globally.

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