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BIM for sustainable project delivery: review paper and future development areas

Abstract

The evolution of Building Information Modelling (BIM) is transforming practice in the Architecture, Engineering and Construction (AEC) industry. BIM provided revolutionary ways of generating, visualizing, exchanging, predicting and monitoring information. Over the last decade, delivering sustainable projects has become a high priority along with the recognition of the role the BIM plays to improve efficiency. However, BIM-enabled sustainability practices are still relatively immature and inconsistent. Previous research has identified challenges in the delivery of green-rated buildings, that include: dealing with documentation, evidencing requirements, monitoring progress, and decision making. Limited studies focused on linking workflow obstacles of green projects to potential improvements using current BIM capabilities. Through interrogating existing research via a systematic literature review, this paper takes the original approach of constructing an 'analysis map' to 'bridge the gap' and highlight current limitations and successes between BIM and sustainability practices. The findings are formulated through two parallel investigation tracks: the first is design task/ BIM capability analysis, and the second is green project delivery problem/BIM enabled sustainability application. This research highlights future potential investigation areas, which are categorized into six clusters: representation; performance simulation; transaction and exchange; documentation; automation; and standardization and guidance.

Key words: Building information modelling, sustainable construction, green rating systems, BIM and green practices synergies, Green BIM, systematic review.

1. Introduction

Building Information Modelling (BIM) is defined in various ways, for example, which reflects the different understandings of BIM as product, method, or a tool/software. As it BIM is not limited to software, it is acknowledged that BIM is " the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions"(British Standards Institution (BSI), 2018). Regardless of the definition it can be agreed that it has provided a development of clusters of policies, processes and technologies (Succar, 2009); Eastman, 2011) which have promoted contemporary methods for collaboration within the AEC industry. BIM benefits have been discussed extensively in the last decade (Azhar, 2011; Ghaffarianhoseini et al., 2017; Succar, 2009; Volk, Stengel, & Schultmann, 2014). At the same time there is a debate around the unsatisfactory levels of improvements to productivity, as promoted, therefore its challenges, risks and maturity levels are in continuous investigation (Miettinen & Paavola, 2014); (Turk, 2016). The aim of this paper is not a review of BIM or its benefits, but to provide insight regarding required future areas of development in the synergy between BIM and sustainability.

The synergy between BIM and sustainability is considered to be an area of major interest with extensive critical attention in the AEC industry (Raouf & Al-Ghamdi, 2018a). Awareness of the importance of synergy has been raised because of global demand for delivering sustainable projects with increased process efficiency and client satisfaction. The main motivator towards sustainability is the construction industry's high consumption of resources and negative impacts on the environment, accounting for an estimated 30-35% of global energy consumption and waste generation, and 25% of global water consumption (International Energy Agency, 2017). The construction sector uses increasingly complex processes and systems, and is characterized to be fragmented, also require multidisciplinary participation, and include multi-systems, which has led to high amounts of waste in the project life cycle (Saad Sarhan & Christine Pasquire and Andrew King, 2017). In the last decade building information modelling (BIM) is promoted to enhance dealing with construction sector characteristics mentioned above over conventional ways. BIM's revolutionary proactive decision-making technologies have acted as a potential collaboration platform with which to deal with the construction challenges mentioned above. Therefore, this study aims to contribute to this growing area of research by exploring potential and deficiencies in the current synergies.

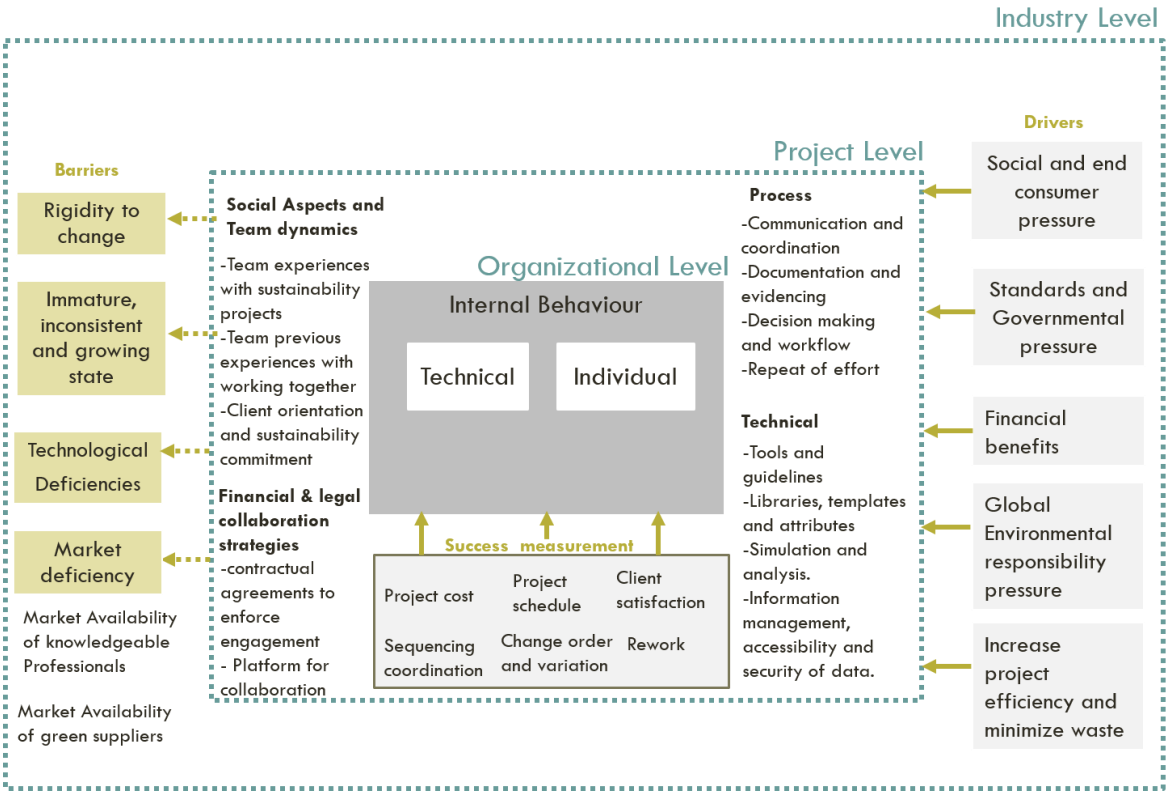

Figure 1: Drivers and barriers affecting the sustainability demands.

Studies deal with environmental assessment methods (EAMs), or green rating systems, as one way to evidence sustainability in buildings that serves the triple bottom line principle (Zuo & Zhao, 2014). Research interest in green rating systems has increased exponentially during the last eight years (Doan et al., 2017), and an increase in uptake of these systems in the industry has also been reported. Scholars have identified the major factors that act as drivers regarding the increase in demand for green rating systems: social and end consumer pressure; the need

to increase building performance and reduce life cycle cost; global pressure towards sustainability; governmental pressure regarding compliance; and finally financial benefits to the owner and property users; as illustrated in detail figure 1 (Ahn *et al.*, 2013; Olubunmi, Xia and Skitmore, 2016; Balasubramanian and Shukla, 2017; Darko *et al.*, 2017a; Darko, Zhang and Chan, 2017b; Shazmin *et al.*, 2017)**.** Researchers have also discussed the barriers to delivering sustainable construction at an industry level, such as: market deficiency in knowledgeable practitioners and green suppliers; risk of increase in cost; stakeholders' rigidity regarding change; deviation of the project schedule; immature and inconsistent state; and lack of sources of guidance; as illustrated in figure 1 (Ahn et al., 2013; Balasubramanian & Shukla, 2017; Nguyen, Skitmore, Gray, Zhang, & Olanipekun, 2017; Wimala, Akmalah, & Sururi, 2016).

These studies have shown the internal and external influences and motivators that effect change in the industry towards green projects (Ayman, Alwan, & Mclntyre, 2018). These factors can be categorized into three levels of investigation, relating to: industry level, project level and individual level. This study aims to expound the potentials and gaps in BIM for sustainability at the project level. It may be argued that aspects around BIM-enabled sustainability on project level can be clustered into four categories: process; technical; social aspects and team dynamics; and finally, financial and legal. In previous studies, BIM capabilities have proven to have high contribution in improving the technical and process problems in the industry.

2. Scope of the research

As can be seen from section one, and summarized in figure 1, the AEC sector is faced with many drivers for the integration of sustainability into processes, and also challenges regarding how to do this. Following the increase in demand for both collaborative building processes and sustainability, researchers have continued to address these concepts, and synergy between, them from different perspectives (Chong, Lee, & Wang, 2017); (Antwi-Afari, Li, Pärn, & Edwards, 2018); (Lu, Wu, Chang, & Li, 2017)(Raouf & Al-Ghamdi, 2018). Although there is a great body of literature and an increasing volume of research investigating the synergy between these leading concepts in the industry, there has been limited research aimed at clustering and synthesizing them to outline potentials and gaps. The aim of this review is to conduct a systematic thematic analysis and qualitative synthesis of literature that evidences investigation and development tracks in the field of BIM for sustainability in design phases. This study will contribute to a fill a gap in the current knowledge by linking the recognized problems of green project delivery to recently developed technologies and processes of BIM and sustainability studies. Due to this focus, it is important to note that the scope does not delve into the complexity of the design process in relation to sustainable or green buildings, nor BIM verses holistic design processes. To realise the aim, the following research questions were formulated:

> RQ1: What are the different capabilities of BIM technologies that are linked to improving the delivery of sustainable projects?

RQ2: What are the technical and process solutions presented in frameworks and models that were proposed by scholars in order to address obstacles to BIM and sustainability synergy?

RO3: What does the literature recommend in terms of future investigation to formulate the required areas of development for BIM enabled sustainability?

To date, limited contribution has been made in investigating both technical and process aspects of integration in terms of workflow, documentation, decision making, information management, ownership and responsibilities, and coordination. In addition, stakeholders should be aware of external factors that affect the efficiency of project handling, such as team dynamics and financial and legal aspects. Figure 2 summarizes the elements discussed in previous studies regarding process, technical, social and financial and legal factor. It may be argued that the development of BIM capabilities can contribute to alleviating technical and process internal obstacles. Therefore, the scope of this study will include a systematic review of both technical and process aspects of sustainability. It will amplify BIM functionality contribution as a main investigation area, with acknowledgment of social and financial aspects as enablers.

The research questions of this study aim to provide answers about the shortcomings and obstacles that the project team faces in order to deliver green certified projects, and investigate their link to BIM capabilities. Figures 1 and 2, which identify the obstacles that cause negative effects on project success indicators - increase in design cost, schedule overruns, failure to meet sustainable targets - that can directly affect client satisfaction. Previous studies have investigated the reasons behind the extra work and time required at the organizational level in order to deal with design complexities, heterogeneous decision making, documentation, information management, and providing evidence of performance (Raouf & Al-Ghamdi, 2018b). Other studies have criticised the green rating systems' approaches and argued that they do not reliably assure that certified buildings are sustainable (Gou & Xie, 2017); (Schweber & Haroglu, 2014). Although important to acknowledge, these areas of research; the complexity of the design process in relation to sustainable or green buildings and BIM verses holistic design processes and; a critique of Environmental Assessment Methods (EAM) are not within the scope of this paper.

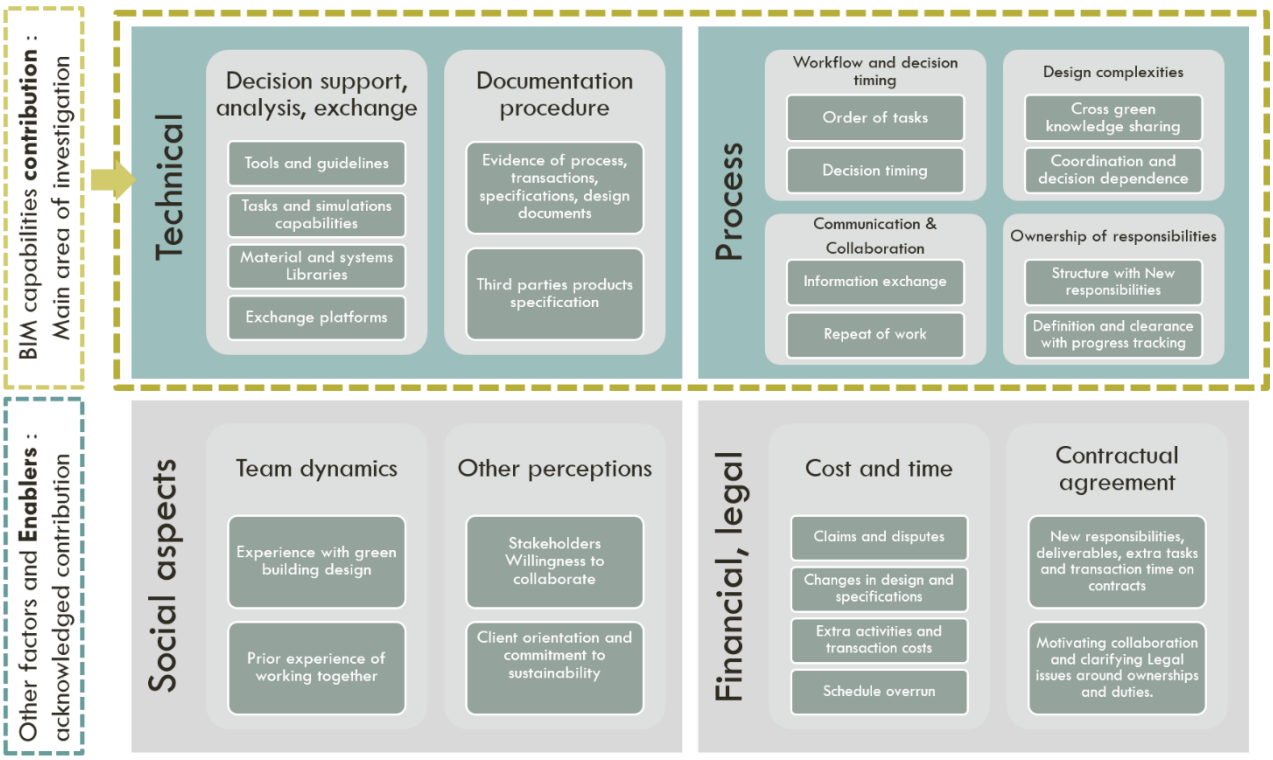

Figure 2: Main investigation aspects.

2.2 Sustainable construction

"Sustainable construction" is a term that was proposed in the late 1980s to define the construction industry's role and responsibilities in achieving the metrics of sustainability (Hill & Bowen, 1997). The main pillars that were used to define sustainability in the built environment are ecological, social and economic factors, known as the 'triple bottom line'. This paper's scope will focus on environmental/ecological sustainability and more specifically, energy and materials categories. According to the triple bottom line principle, green rating systems, also known as Environmental Assessment Methods (EAMs), such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Green Star, emerged to assess and evidence the overall quality of building processes and the final product. These rating systems are used as assessment tools, with defined categories and procedures to evaluate building processes and products. Multiple studies addressed the similarities and differences between the rating systems in terms of weighting of categories, available credits, classification of certification, procedure and flexibility (Awadh, 2017; Doan et al., 2017; Mattoni et al., 2018). The three pillars of sustainability are translated into the rating systems using different approaches, but they are all designed to assess common main criteria, which are: (1) energy, (2) site and transport, (3) materials, (4) water, (5) indoor quality and occupant well-being, (6) waste and pollution, and (7) management and integrative process (Mattoni et al., 2018). These categories are applied with different credits and definitions to analyse and evidence project design and planning. In order to meet the criteria, different interactions, tasks, design and

building performance analysis must take place between the project team, which requires collaboration.

3. Research methodology

The contribution of BIM in delivering sustainable buildings has been explored in the literature based on tools' capabilities, under the terminology of "green BIM" (J. K. W. Wong & Zhou, 2015). Previous reviews have summarized the concepts of green buildings and BIM technologies used with respect to building life cycle phases (Chong, Lee, & Wang, 2017; J. K. W. Wong & Zhou, 2015), BIM and green attributes with respect to project phases (Lu, Wu, Chang, & Li, 2017) and the potential of BIM to overcome sustainability obstacles (Raouf & Al-Ghamdi, 2018b). Although these studies had similar aims, new knowledge on the subject can still be discovered. The research methodology for this paper involves a systematic review through thematic synthesis of the existing literature themes. From this, an 'analysis map' is constructed to 'bridge the gap' and highlight current limitations and successes between BIM and sustainability practices.

The expansion of evidence-based practice and case studies in the AEC sector has led to an increasing variety of review types, therefore the typology of reviews can be overwhelming. Grant and Booth (2009), identified as many as fourteen types of review recognized by different methods used that satisfy different purposes. Systematic review was selected for this study as it seeks to, address knowledge and relationship gaps with an analysis; provide recommendations for practise and; highlight what remains unknown and uncertain around findings and recommendations. The justification of the selection is determined from the lens of research questions and characteristics of the topic discussed in section 2.

Three unique characteristics have been outlined by Schryen *et al.* (2015) in relation to systematic review these are "1. Synthesis and interpretation, 2. Focus on domain knowledge, 3. Comprehensiveness." The first characteristic involves highlighting the knowledge and relationship gaps in existing literature, through synthesis and interpretation. The second requires setting a well-defined research scope within a particular field in order to focus on the knowledge therein. The third, comprehensiveness, can be met by setting inclusion and execution criteria to maintain the quality of representation in order to aggregate important studies.

Systematic reviews have also been proven to satisfy these three characteristics (Tranfield, Denyer, & Smart, 2003), therefore it has been adopted in this study. The systematic review should enable filtering and categorization of the studies on a specific topic, provide insights and explanation on predicted inconsistencies, and evidence the findings and recommendations. It has been evidenced that the systematic review process helps to minimize bias and create a clear vision of the heterogeneity between similar studies in the same field, in order to produce trustworthy and rigorous new knowledge (Schryen, 2015).

The main stages of this paper include: research question formulation, allocation and selection of studies, analysis and synthesis, and evidencing the main findings and discussion through clustering areas of development. This section describes the method and stages of the research, as illustrated in figure 3. After planning the systematic review by defining the

motivations of the research, key concepts and terms, the research scope, and the research questions were formulated. The second stage is allocating and selecting studies; by using Scopus, Google Scholar and Science Direct.

In order to filter the data, ensure focus on the topic domain of knowledge, and assure comprehensiveness, refined key words and a set of inclusion and exclusion criteria were set, as shown in Table 1. Stages three and four were then applied on two parallel investigation tracks. The first track related to change that BIM caused in design processes and the resulting benefits to sustainability tasks. The second track involved categorizing existing synergies between BIM and sustainability through different technologies, processes and framework, and linking them to problems in green project delivery. The main findings of the literature are discussed in stages four and five, which evidence the elements of integration. The last stage discusses in depth future studies that are required to inform the knowledge gap in these areas of development, in order to amplify the synergy between BIM and sustainability practices.

Table 1: Search key words set, inclusion and exclusion criteria

Research entities	**Key words**	**Inclusion**	**Exclusion**
Integrated project delivery and Building Information Modelling	BIM AND + approaches, OR potentials, functions, stages, processes, tools, benefits, challenges and risks, adoption, future growth, technologies, processes, software, implementation, diffusion, current state, technical, functional, informational capabilities.	• **Journal and peer reviewed publications** • **Discussion in the new construction of building.** • **Applied/discussed the 2 key concepts and or together in case of BIM for sustainability** • **Cover preconstruction stages.**	• **Applied on industrial, infrastructure, urban scale, or other areas.** • **Mentioned both concepts but not for purpose of this research e.g. criticism of EAM.** • **Cover sustainability during construction, handover, and operation stages.**
Sustainable construction	Sustain* or green rating systems or environmental assessment methods or LEED, BREEAM + AND principle, analysis, problems in delivery, demand, process.		
BIM enabled sustainability	BIM AND sustain*/green, integration OR synergy, application, approach, framework, model, life cycle. BIM AND LEED OR BREEAM OR green rating system OR energy predict*, LCA Green BIM, building performance simulation		

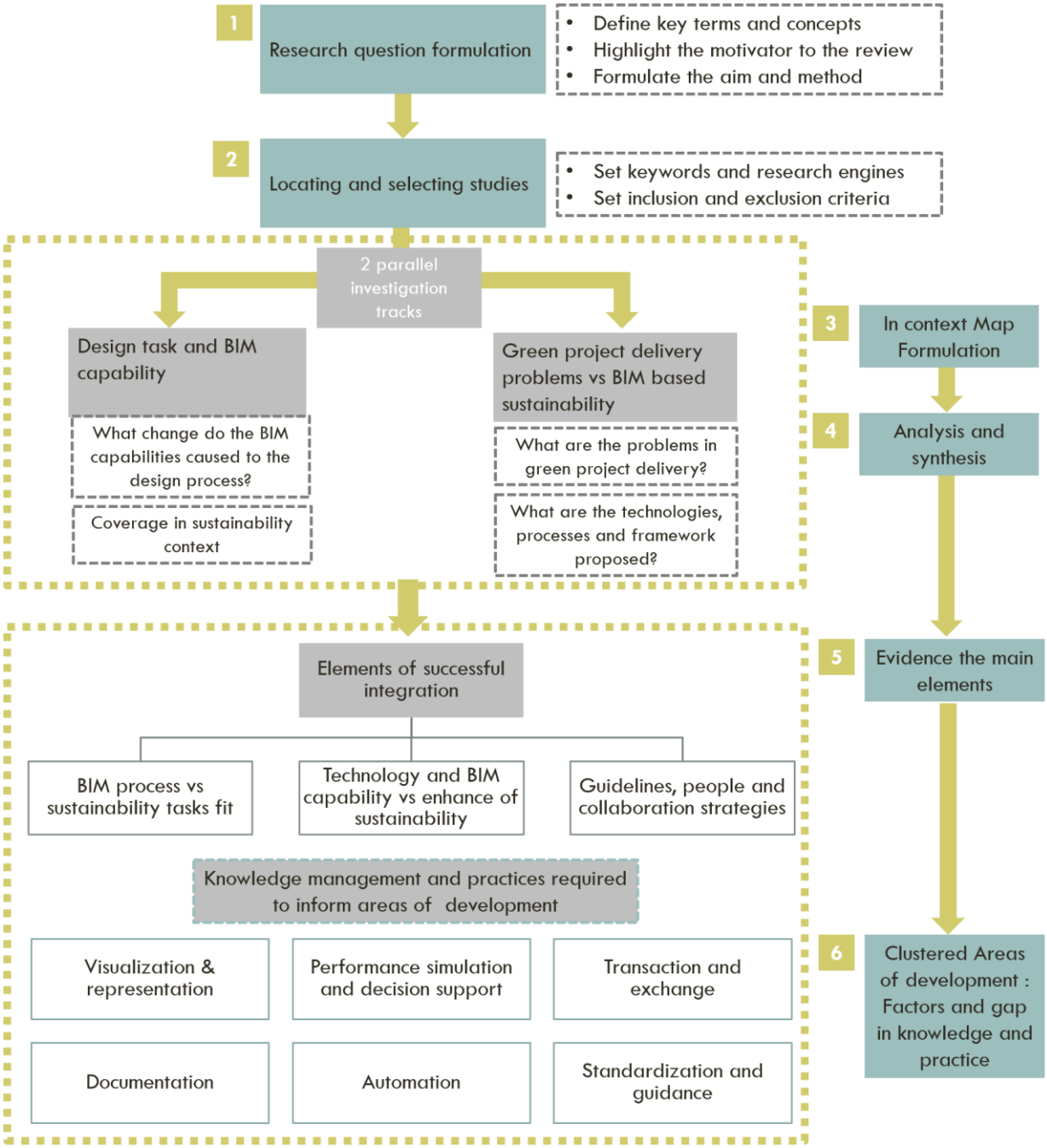

Figure 3: Visualized paper and detailed methodology

4. Contextual formulation and content analysis

As mentioned previously in this paper, traditional AEC practices have been described as fragmented and dispersed, and early studies highlighted the smart and interoperated methods that BIM offered (Fox and Hietanen, 2007; Eastman, 2011). These methods caused a major technical change through the use of digitalization to present the functional and physical characteristics of projects (Ghaffarianhoseini et al., 2017). The functionalities of the technologies and solutions, provided by the tools, enhanced the way the multi-disciplinary

characteristics of the building process could be dealt with to support evaluation and decision making. As a result of this, researchers observed a transformation in the ways with which organizations moved from a “silo” state due to the new characteristics of BIM collaboration (Barlish and Sullivan, 2012). These technical benefits have quickly grown to help facilitate more effective processes, better designs, controlled whole life cycle on building budget, time, environmental data and automated tasks, to increase work efficiency (Azhar, 2011). The following section will first define the problems in green project delivery that will be tackled, then analyse the changes and benefits that BIM has had on the design building process, and finally will conduct an in-depth analysis of BIM-enabled sustainability studies.

4.1 Problems in green project delivery

The potential benefits and shortcomings of the interaction between BIM and green construction strategies were reflected on in the previous discussion of the problems of green project delivery. Several authors have argued that delivering sustainable buildings using traditional methods lead to problems in terms of increased cost and time due to the increase in design complexities and variables, and the documentation and procedures required to enhance building performance (Raouf & Al-Ghamdi, 2018b). Breakdown of communication, lack of consistent data supply with a sufficient level of detail, and divorce of sustainability documentation from project documentation, were problems highlighted in a study by Hope and Alwan (2012). Complex legislation of green rating systems (Hwang & Tan, 2012) and the critical role of collaboration in order to deliver sustainable buildings and overcome industry fragmentation problems. Pero, Moretto, Bottani, & Bigliardi ,2017, have highlighted the importance of developing strategies to align both practices. The following section investigates interactions between sustainable practices and BIM with different perspectives to solve the problems mentioned.

In Addition, in order to fulfil the green buildings design objectives, high levels of interaction and interdisciplinary effort are required to achieve efficient collaboration between technical systems and design professions (Ahmad, Thaheem, & Anwar, 2016). This raised due to the fact that the design of projects in practice is a complex process and includes multi-interdepend decisions that can’t be simplifies into linear one as the tools deal with a certain problem. It can be described as a series of cycles where diagnosing, planning, taking action and evaluating the action take place by iteratively analysing a problem to reach a suitable solution (Petrova et al., 2018) (Bueno, Pereira, & Fabricio, 2018). Designer and engineer go through iterative, nonlinear, non-single model and multiple source of information and analysis to optimize decision making. Critical design decisions are related to requirements and constrains, that are interdependent and requires the designer interpretation of knowledge to utilize the tools simulation, representation and analysis of multiple outputs from different models. In this paper scope, BIM technologies and processes as a facilitator for attaining environmental sustainability targets for a project on as an important part of the holistic synthesis of the design. The distribution of the stakeholders’ effort along the project timeline are in continues change, within BIM process more effort is required from the project team to analyse and evaluate crucial decisions that were traditionally considered in later stages of

design. The following section discusses the change caused by use of BIM technologies to facilitate and reinforce the interdisciplinary effort required for design.

4.2 BIM change to design building process

The perspective of the BIM change to the design process is discussed through the lens of how the capabilities of BIM technologies are changing the architecture field into leaner practise (Y. Arayici et al., 2011). BIM functionalities provide the designer with new capabilities that can eliminate time consuming tasks of production and collaboration. They also allow margin for iterative analysis through design maturation and development cycles that reinforces the application of the designers' knowledge. The following section will discuss the literature through the lens of the perceived benefits of BIM as an asset of information. It will develop from the definition used by a pivotal early study in the field by Succar (2009), which divided BIM into three stages: modelling, collaboration and network-based integration, are identified. The benefits that BIM capabilities provide in the generation, sharing, management and reuse of information in projects within BIM stages defined by (Succar, 2009), are listed in table 2. Insights on the coverage of these functionalities to serve the delivery of sustainable projects for BIM stage 1 (modelling) and stage 2 (collaboration)are also considered. Table 2 shows an attempt to categorize the BIM technological benefits from previous studies focusing on information use in building design phases and their coverage in the literature related to sustainable delivery. It maps the BIM multi-functionality and heterogeneity benefits from literature, and its coverage in serving sustainability practices and green certification processes. BIM stage 1 (modelling) is represented from the perspective of representation and information generation. BIM stage 2 (collaboration) benefits are presented from the perspective of a multidiscipline heterogeneous platform, information and knowledge management, and finally analysis and performance simulation. Each category will be discussed separately in the following section.

Table 2: BIM benefits to improve work efficiency and coverage in sustainability context

BIM stage	Benefit	Coverage in sustainability context	Example reference
Stage1: Modelling **Representation and information generation**	Parametric features: ease remodelling and modification	●	(Fox & Hietanen, 2007) (Azhar, 2011)
	Early visualization and exploration of alternatives	●	(Fox & Hietanen, 2007) (Azhar, 2011)
	Object-based Information for specification and documentation	○	(Eastman, 2011) BIM handbook (Y. Arayici et al., 2011)
	Production: ease of execution, technical drawings and quantity take-off	○	(Eastman,2011) BIM handbook (Y. Arayici et al., 2011)
Stage 2: Collaboration **Multidiscipline platform**	Coordination and planning of work	○	(Singh, Gu, & Wang, 2011)
	Share and data exchange	●	(van Berlo & Krijnen, 2014)
	Data structure for: accuracy and reliability of data (fewer document errors and omissions)	○	(Biswas & Krishnamurti, 2012)
	Model checking and validation: assuring quality of information of different disciplines (consistency-correctness- completeness)	×	(Getuli, Ventura, Capone, & Ciribini, 2017)
	Compliance checking : regulations and code reviews	○	(Greenwood, Lockley, Malsane, & Matthews, 2010) (Biswas & Krishnamurti, 2012)
Stage 2: Collaboration **Information management: recall and re-use**	Progress tracking through model level of development definition	○	(Porwal & Hewage, 2013)
	Information life cycle and re-use	×	(GhaffarianHoseini et al., 2019) (Petrova, Pauwels, Svidt, & Jensen, 2018)
	Standardization and knowledge management.	○	(Zima, 2017)
Stage 2: Collaboration **Analysis and simulation**	Simulation and performance analysis: operational energy consumption, LCA, daylighting, carbon footprint	●	(Bahar, Pere, Landrieu, & Nicolle, 2013) (Azhar, Carlton, Olsen, & Ahmad, 2011) (K. Wong & Fan, 2013) (Mostapha Sadeghipour Roudsari, Michelle Pak, Smith, 2013)

● Discussed sufficiently in the context of sustainability practices
× Not discussed in the context of sustainability practices
○ Hardly discussed in the context of sustainability practices

4.2.1 Representation and information generation

Representation and information generation are considered a significant asset for stakeholders, as it saves time and effort using parametric and database storage features for designing and planning documents (Turk, 2016). Digital representation technologies are adopted to serve solutions that improve collaboration and productivity. Representation of building components in 3D form, rapid generation of design and design alternatives, automated generation of drawings and information required, integrity of model and traceability of information changes, rapid evaluation of design alternatives, and object-based

exchange are all technical functionalities which caused extensive transformation in the development of AEC practices (Arunkumar, 2018). In the context of sustainability delivery, parametric features, remodelling and realistic visualization functionalities are widely covered in the literature. Ease of technical execution drawings and quantity take-off for covering for sustainability tasks are hardly covered, while object-based information and specification for documentation of sustainability aspects are not addressed sufficiently in previous studies. This suggests that a better understanding of what needs to be presented and a breakdown of the sustainability information that needs to be generated and built up during design processes is still needed.

4.2.2 Collaboration: multidiscipline platform (IFC/xml and gbxml)

BIM enabled a transformation in approaches to collaboration between the project team by providing a multidiscipline platform which allowed stakeholders to model and associate the information required, and to share it with others (Akponeware & Adamu, 2017). The ability to combine different information models from different disciplines reinforced the capability to coordinate building services and systems with the structure and architectural elements, as shown in the benefits mentioned in table 2. This reinforced the reduction of uncertainty and provided privilege in planning, estimation and control over new construction projects. This is facilitated by innovation solutions and rapid evolvement of Information Technology (IT) and Information Communication Technology (ICT) to deal with the increasing complexity of projects in terms of data structure. The use of BIM as a collaborative platform has motivated the use of models to reach project goals at an optimum level. This has been enabled by the ability to exchange virtual information, evaluate performance, and rehearse the effect of decisions on aspects such as cost, time, sustainability, constructability and other factors.

In order to support multidiscipline collaboration and interoperability among BIM tool adopters, standard form data exchange formats have been developed, including IFC and MVD. BuildingSMART ("buildingSMART - The Home of BIM," n.d.) established the form of industry foundation classes (IFC) standard as a neural and open standard format to avoid the control of a certain vendor format. BuildingSMART also developed model view definition (MVD), which is a standard subset of IFC to define information required in models for a certain purpose. In addition, green building XML schema was developed to facilitate the transfer of BIM models to simulation analytical software tools, but was not considered a full data structure of all sustainability elements. These schemas are considered a fundamental ICT requirement in order to apply the benefits of the multidiscipline platform. The BIM development process was positively affected by this major change in enabling interoperability among project participants though the exchange of semantic and geometric building elements, but a mature definition of sustainability factors in those schemas has not yet established. Therefore, practices related to conflict and clash detection for data validation, accuracy and reliability of data to reduce reworking, document errors and omissions still do not include all sustainability parameters. Scholars have argued that it is necessary to develop parameters in MVD schema in order to deal with sharing and exchange of sustainability aspects and include all the functions mentioned (Maltese et al., 2017a). Also, it has been observed that sustainability parameters are not strongly tied to the BIM level of development

definitions, LOI and LOD, in BIM models. A few studies have triggered work in this direction, such as BIM standard to facilitate sustainability evaluation (Ramaji, Gultekin, & Crowley, 2017), and BIM execution planning in green building projects (Wu, Asce, Issa, & Asce, 2015a).

4.2.3 Information management: exchange, recall and re-use

BS 1192:2007+A2:2016 and PAS 1192-2:2013 (The British Standards Institution, 2013) are standard specifications for information management in the UK as BIM level 2 protocol; the information life cycle through project phases is described, and information and knowledge management assessment are proposed for re-use. The latest updated contribution is European standard BS EN ISO 19650-1:2018 (British Standards Institution (BSI), 2018), which will replace both BS 1192:2007+A2:2016 and PAS 1192-2:2013. These standards have aided the use of BIM in collaboration using data structures; information management as a standardizing exchange facilitated the recall and re-use of information to develop knowledge management strategies. The information included in the model may vary in order to provide the designer with sufficient elements for decision making, and reduces the risk of omitting any parameters. The information includes geometry and spatial connections associated with properties of building elements such as u-value, fire rating, specification, embodied carbon, finishes, etc. Any parameter can be associated with geometrical information whenever the user finds it advantageous for a particular purpose. This purpose could be documentation, coordination with other stakeholders through information exchange, or calculation and simulation. Building up knowledge contribution with the capability to combine input from different professionals in one model, as mentioned before, enables systematic review of the effect of changes in a project and progress tracking. RIBA (Royal Institute of Building Architects) have developed digital plan of work in 2013(Royal Institute of British Architects, 2013) that has BIM overlay using definitions in PAS 1192:2013 protocol(BSI, 2013) and linked it to guide of Green overlay (RIBA, 2011) document that outline tasks and information exchange for sustainable project delivery. These protocols provide architect broad guidelines for process of green BIM, but still Information life cycle, re-use, exchange frameworks, and knowledge management for sustainability delivery purposes are very general and not mature yet .

4.2.4 Analysis and performance simulation

BIM-based performance analysis and simulation is the most commonly recognized application of BIM to satisfy sustainability requirements (Heffernan et al., 2017); (Li, 2017); (Azhar & Brown, 2009). The inherited BIM features in the modelling phase enable easier changes to the model and interoperability between BIM modelling software and performance analysis software. The extra work of repeating the modelling on different simulation platforms is eliminated using gbxml schema, as mentioned before. The tools used are categorized into two phases; firstly, tools that have BIM-inherited features for modelling, and secondly BIM-based analysis tools in relation to green strategies. Previous research has addressed the simulation of potential performance, such as energy consumption, lighting analysis, environmental impact of material selection, CFD and ventilation (Wang *et al.*, 2017; Stapleton *et al.,* 2014b). Although a body of literature can be found concerning the use of BIM as a simulation platform, technical challenges in interoperability are still found (Noack, F. et al.,

2016). It is important to understand the relationship and transformation of data between the tools, and how data are exchanged between BIM authoring tools and dynamic Simulation Accredited Software, in order to determine technical deficiencies in exchange formats. Using the results of analysis to evidence performance required by codes, regulations and green rating systems demonstrates an attempt to automate the review process using BIM modelling (Biswas & Krishnamurti, 2012), but validated data structures and processes have not been developed yet. Alternatively, environmental plugins through visual programming language (VPL); Grasshopper ("Grasshopper3d," n.d.) and dynamo ("Dynamo BIM," n.d.), are rising due to the reported technical deficiency in the standard schema that caused problems in integration of simulation from early design stage, provoked by the limitations of the bidirectional modelling and simulation (Negendahl, 2015). Other plugins, such as ladybug tools (Sadeghipour Roudsari & Mackey, n.d.) and topologic are in continuous development to support architects need for fast, iterative and interactive feedback (Aish, Jabi, Lannon, Wardhana, & Chatzivasileiadi, 2018; Mostapha Sadeghipour Roudsari, Michelle Pak, Smith, 2013). The development in the VPL approach claim to achieve rapid and flexible analysis that is more sufficient for architects' use than the current gbxml and IFC schema packages (Negendahl, 2015).

4.3 Interactions between BIM and green construction strategies

In this section, research that addresses the interactions between BIM and green construction strategies will be presented and analysed. The approach used was to identify consistencies and inconsistencies within current literature through a systematic literature review of previous research dealing with technical or process obstacles of BIM-enabled project delivery. Each paper was analysed according to its contribution to the technical and/or process themes. The emerging themes are summarized in figure 4, and detailed analysis is presented in table 3. The analysis revealed four main clusters:

1. Process, workflow and managerial components of sustainability tasks within the BIM process.
2. Whole building performance: energy analysis, performance simulation and visual representation.
3. Data structures for sustainability (IDM, IFC, MVD, gbxml).
4. Automating green building (GB) process.

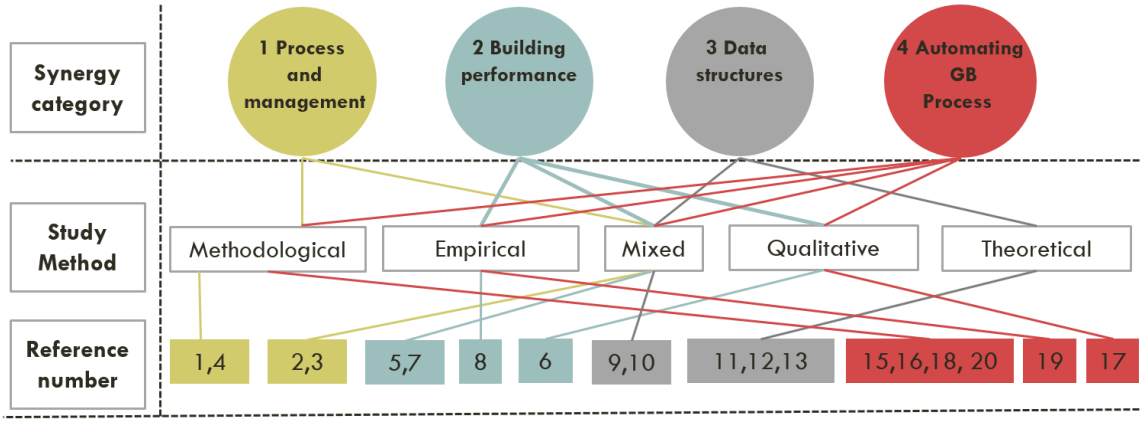

Figure 4: Thematic synthesis of the literature review.

Table 3 Analysis of BIM enabled sustainability literature dealing with delivery problems

Reference		Obstacle that the output deals with		Perspective of integration	Output and methods used	BIM integration	
		Technical	Process			Promoted benefits	Challenges, limitations and/or problems
	Process, workflow and managerial components of sustainability tasks within BIM process						
1	(M. A. Zanni, Soetanto, & Ruikar, 2017)		Define managerial components and workflow	Presented BIM-enabled sustainability framework from a management viewpoint, with critical components of roles, responsibilities, tasks, and decision points. Workflow of sustainability tasks are defined in terms of timing, sequencing and level of definition.	**Methodological** Through interviews with experts in the field.	**Standardizing sustainability workflow:** A system model for information exchange, allowing efficient project handling.	▪ System flexibility to fit with different typologies of projects with similar workflow patterns.
2	(Wu et al., 2015a)		Mapping of LEED credits and activities in BIM process	Proposed new process model that maps the LEED activities required in BIM execution plan. Green and non-green BIM processes are defined to translate the required level of development of BIM models with respect to project phase.	**Mixed** Identified a BIM execution plan for LEED projects and verified it using a case study.	**Standardizing EAM BIM execution:** Sustainability activities within the BIM process provide guidance on workflow.	• Capturing best practice and knowledge management to inform the business process of green BIM projects.
3	(Lim et al., 2015)		Define sustainability decisions in BIM process	Developed BIM-based process-driven decision making for optimizing building façade. Framework includes façade design variables, sustainability strategy, BIM object and function, guidance for decision and performance check by calculation or returning to guidance.	**Mixed** Developed a BIM objective-based process which is performance driven.	**Support decision making in early process**: Providing guidance on the BIM element object function and required evaluation tool.	• Open BIM standards hierarchy still do not support the exchange of object functions for interactive and dynamic decision making.
4	(M.-A. Zanni, Soetanto, & Ruikar, 2018)		Critical decision actions with information and level of detail	Presented a detailed BIM execution plan including BREEAM assessment and RIBA plan of work 2013 and building performance tools. A definition of information exchange required is presented in terms of the modelling level of detail and depth of analysis at each stage of the RIBA plan of work.	**Methodological** Developed a BIM-enabled sustainable design process model through in-depth interviews.	**Structured collaborative process** allows systematic iterations and reviews of the sustainable design to ensure critical decisions are coordinated.	• Tasks other than performance analysis are not emphasised.

	Whole building energy analysis, simulate performance and visual representation						
5	(Lim et al., 2015)	BIM tools capabilities for environmental analysis		Mapped design parameters with the available BIM-based sustainability analysis. An analysis of available software advantages and disadvantages is presented to inform selection of software that determines the effectiveness and reliability of simulation process and outputs.	**Mixed** Comparative analysis of the available BIM-based analysis software.	Using **BIM inherited features for performance analysis** to reduce cost and time of producing output analysis in comparison to traditional methods.	**Interoperability** • Well-defined transaction and exchange process and schema are not developed yet.
6	(Azhar et al., 2011)	BIM tools capabilities for LEED environmental analysis		Determined the relationship between sustainable design-related analysis and LEED credit points. It also presented the possible credits that can be supported with BIM capabilities. The study showed the credits that can be achieved directly or semi-directly, as well as those not achievable through BIM integration.	**Qualitative** Determined the relationship between BIM capabilities and simulation tools with LEED credits requirements.	Using **BIM inherited features for performance analysis** to reduce cost and time of producing output analysis in comparison to traditional methods.	• Reliance on manual checks for accuracy and quality of BIM data to assure reliability of performance simulation.
7	(K. Wong & Fan, 2013)	BIM tools capabilities for environmental		Investigated the use of BIM-based analysis for design optimization decisions. The tools capabilities were mapped along with potential green strategies and sustainable decision support types.	**Mixed** BIM exported to simulation tools. Evidenced with a case study.	**Visualization and performance simulation** using BIM-based simulation tools and strategies.	**Interoperability** • Lack of mature BIM data exchange standards to support sustainable design.
8	(Alwan, Greenwood, & Gledson, 2015a)	BIM tools capabilities for environmental analysis for LEED		Examined the interoperability of BIM models into simulation tools in order to streamline the environmental assessment of buildings. Showcase of a rapid BIM-based sustainability analysis was presented to serve LEED criteria decisions.	**Empirical** Mapped LEED credits with corresponding software analysis, and a case study is presented.	**Early rapid visualization** of simulation analysis through BIM-generated data.	• Effect of estimations done in early design stage on the accuracy of the predicted results.
	Data structures for sustainability (IDM, IFC, MVD, gbxml)						
9	(Baeza Salgueiro & Ferries, 2015)	Analysis and performance evidence	Define informational components and workflow	Presented the required environmental BIM data for 10 common credits between LEED and BREEAM, through a BIM process map to produce environmental analysis through identification of required activities, necessary data exchange and required software. Investigated preliminary design with the ability to do several iterations for process and result optimization.	**Mixed** Developed a process map with workflow and software identification, presented via a case study.	**Rapid early and iterative assessments:** Using visualization, BIM modelling and data generation in relation to environmental analysis tools to save time and effort and eliminate extra work.	**Compliance and verification** • Data loss within transfer. • Level of development verification of BIM modelling is not defined to assure accuracy and reliable analysis.

10	(Biswas & Krishnamurti, 2012)	Data structure for transaction and exchange		Presented an approach for developing data structure for sustainable building assessments using Cobie and IFC as data structure to bridge between LEED and BIM. Proposed to apply rule sets to assess project achievements to overcome the fragmentation and aggregation of the information delivery.	**Mixed** Developed an automatic analysis model to augment the available BIM data with LEED requirements. Used a case study for validation.	**Reduction of data loss and fragmentation of work:** Decreased the potential loss of information through systematic BIM-enabled documentation and data storage.	• Rule sets can only deal with quantitative requirements. • Hard to define all corresponding information that needs translation in Cobie and where and how to store it for all LEED credits.
11	(Maltese et al., 2017a)	Green attributes in IFC schema	What, how, and when green information is exchanged	Presented an approach to translate rating systems calculation criteria in BIM data structure using IFC data structure. Using the current state of IFC data structure, the different rating systems credits vs. IFC hierarchy of data analysis were presented.	**Theoretical** Analysed the IFC standard in order to define which green rating data can be directly stored in an IFC project.	**Data schema development for sustainability** assures completeness and quality of information shared between stakeholders and between tools.	• Guidelines and data structure for sustainability are still immature. Challenging to define all green rating criteria into attributes in the current IFC schema.
12	(Cemesova, Hopfe, & Mcleod, 2015)	Extending IFC schema with energy domain		Addressed the problems of processing IFC geometry to be transferred to calculation energy simulation tools. Proposed a technical solution involving programmed Java script to allow data transfer necessary for simplified heat demand calculation.	**Theoretical** Developed an IFC extension for energy simulation that deals with geometrical and semantic energy simulation requirements.	Enhanced reliability of simplified heat demand calculation to **allow energy design optimization**.	• Complex geometry, with more slopes and curves, is not validated. • Requires definition of MVD for consistent IFC generation to limit errors in energy analysis.
13	(Pinheiro et al., 2018)	MVD of BIM for energy simulation		Investigated the IFC, model view definition (MVD), and information delivery manual (IDM) from a mechanical system point of view to define the required information transfer of BIM models into building energy performance simulation (BEPS) models.	**Theoretical** Developed IDM and MVD by defining the required IFC schema for energy modelling.	Decrease in repetitive manual operations in order to do energy simulations. **Increase in the reliability and consistency of IFC subset** for energy simulation.	• Inconsistent and missing concepts in the current state of MVD definition and hierarchy to support mechanical building energy performance.

	Automating Green building process						
14	(Han, Motamedi, Yabuki, & Fukuda, 2017)	Analysis and performance evidence		Developed an automation tool to calculate the design achieved LEED credits from BIM model. Through translation/ mapping of LEED credits into IFC entities required in BIM model, a tool was developed with programming code in order to check the required target. The developed design support system applies rule checking to report the achieved credit and provide design suggestions.	**Mixed** Process map used to present system architecture and illustrate code, using a case study approach.	**Automation of the design assessment process** to facilitate the green rating system through a rule checking system.	• This system is dealing with quantitative credits, and is not readily applied to behaviour and complex logic.
15	(Ilhan & Yaman, 2016)	Documentation and automated credit calculation		Developed an automated calculation and documentation tool that reports the design accomplished of all the credits in the BREEAM material category. Presented an approach that can deal with BREEAM requirements in BIM models, by translating credits in BIM language of IFC through defining minimum required MVD, and proposed to link green material library (GML) to the green materials database with the use of BIM model.	**Methodological** Presented a BIM-integrated data model for BREEAM materials category and used a case study to validate the model.	**Automated materials credits calculation and documentation** for green building assessment.	• Limited to specific BIM software and certain BREEAM categories. • Manual effort required by user to convert BREEAM material database (GMDB) to the BIM material library (GML)
16	(Jalaei & Jrade, 2015)	Eliminated documentation through automating the certification process		Presented a model suggesting the automation of the LEED certification process by identifying the required number of points based on the selected LEED certification categories. In addition, the model estimates the total soft cost associated with the registration and certification of proposed buildings.	**Methodological** Designed and developed a model that automates the calculation of credits with BIM models and model implantation.	**Automating the LEED certification process** to eliminate the documentation process, which reduces the soft costs (time and effort) of the project arising from documentation.	• Based on calculation points derived from credits from user input. No clear connection of database to BIM information. • Lack of Database for sustainable material and building systems.
17	(J. K. W. Wong & Kuan, 2014)	Existing and new parameters and attributes for BEAM plus in BIM models		Mapped BEAM plus credits that can be assessed through BIM tools and translated them into BIM functions and parameters. It also sorted activities of the non-BIM credits and listed into (calculation, documentation, modelling and testing/measurements). It presented an approach for using the BIM scheduling functionality to capture and produce information for certification.	**Qualitative** Developed a framework BEAM plus certification using BIM attributes and parameters functionality. Case study used for validation.	**Ensured documentation of the BEAM plus rating system in a BIM environment** to capture and streamline the green system submission process.	• Information required to assist analysis and simulation for decision making are still to be defined.

18	(Jrade & Jalaei, 2013)	BIM model structure and components for LCA	Model development process for LCA, cost and LEED analysis	Presented a methodology for BIM modelling in order to support decision making of material selection in the conceptual stage by integrating BIM, LCA, and relational databases. The methodology enabled connecting and analysis of functional, technical, and financial (cost) specifications with the measurement of environmental impact.	**Methodological** Presented the phases for the development of the model with components and data analysis. Case study is used for validation.	**Time reduction, fast calculation and professional reliable outputs** to support selection of materials with regard to cost, environmental impact and green certification achievement.	• Requires development of generic green families and libraries of materials and building elements. • Semi-automated process: manual work is needed to link the BIM model to LCA tool and cost calculation.
19	Bank *et al.*, 2010	Model for automated multi-object decision making		Developed a model that allows the flow of data between system dynamic model and BIM model software by using application programming interface (API) for design optimization.	**Empirical** Presented a dynamic model with relationships between BIM, API, Java and system dynamic model	**Automated checking of sustainability metrics** with the use of information in a BIM model for a more interactive process.	• Limitation found to translate all sustainability metrics into automated programming script.
20	(El-Diraby, Krijnen, & Papagelis, 2017a)	Linking BIM to sustainability analysis	Defined a business process green BIM management for communication	Developed an online system to leverage advancements in (BIM), energy-efficiency simulation tools, and online social network analysis methods to enable a data-driven approach to building planning, construction and maintenance. It allows interaction between project participants through comments and view-sharing, and it connects BIM to energy analysis software to allow user energy optimization though selection of products.	**Methodological** Design of online social network business plan for green BIM interactions.	**Socio-technical analysis and online collaboration**: Managing green BIM participants' interactions. Allowing data driven design process and facilitating interactions between decision makers.	• It is challenging to develop an open platform with sufficient open source material library.

Technical: Developing technological solutions through use of tools functionality

Process: Providing a framework or methodology through analysis of transactions, tasks and interactions

5. Discussion

The objective of this review was to reveal what the existing literature recommends in order to formulate research themes for the development of BIM enabled sustainability. Following the analysis and synthesis of literature presented in section 5.3, this section will discuss, in-depth, the findings relating to required development that will enable and reinforce BIM and sustainability synergy in construction phases.

5.1 Elements of integration

From the analysis of the literature using the categories of aspects for the development of BIM within the AEC industry and the current body of research discussing the synergies between BIM and sustainability, it can be concluded that there are three main elements of successful integration. These are: BIM process and sustainability decisions fit; BIM technologies and sustainability tasks fit; BIM guidelines, people and collaboration strategies with sustainability activities. Further studies are required to analyse and investigate the alignment of BIM process and sustainability tasks and decisions fit.

The first element of successful integration relates to understanding the fit of sustainability related decisions and tasks into the BIM process and information workflow. Although some studies have attempted to develop BIM-enabled sustainability design process framework (Zanni *et al.,* 2017), this has not yet been sufficiently defined or verified in depth. Development of this managerial framework should be informed by an understanding of the interactions, roles, tasks, deliverables and decision points of sustainability criteria, in order that they are accommodated in the BIM process. It is also crucial that the transaction of information be defined; understanding of sustainability criteria and how, what and why the team need information should be translated to the level of development (LOD) required (Lim et al., 2015). Information exchange should be facilitated through the definition of BIM data structures for sustainability. The second element relates to the fit between the BIM technology functionality and sustainability task, including the mapping of tools and software to automate processes, reduce work load, and increase the reliability of predicated performance of the building. It also includes the deficiency in interoperability and data structure definition between BIM modelling tools and building performance analysis programs. In addition, due to the sociotechnical nature of the AEC industry, readiness to accept new tools is an important issue, and frameworks should include the study of both technical issues and team relationships in order to achieve better collaboration (El-Diraby, Krijnen, & Papagelis, 2017b). The third element references BIM-enabled sustainability guidelines in relation to key participants' perspectives and views about the process, to develop the guidelines and standards. The next section will include discussion of how understanding of these three elements should inform the functional areas of development in BIM for green projects.

5.2 Development areas

The findings of the systematic review lead to the conclusion that, although there is great potential for synergies between sustainable practices and integrated project delivery processes, investigation is still required in the industry to address deficiencies in the synergies. It is proposed that six areas of development are important for future implications on practice. These six areas have been derived from the systematic analysis of the literature, and are listed as follows: representation; performance simulation; transaction and exchange; documentation; automation and standardization; and common guide. Figure 6 gives short definitions of the six developing areas. It is also argued that analysis of best practice and knowledge management of the three elements of integration mentioned in the previous section have an essential role in informing the process of integration. The following section discusses each developing area in terms of current state, potentials, and information system and knowledge management required to develop these BIM areas towards delivering green buildings. These development areas need to be investigated in relation to the elements of the sustainability fit within BIM uses and processes in order to determine future directions.

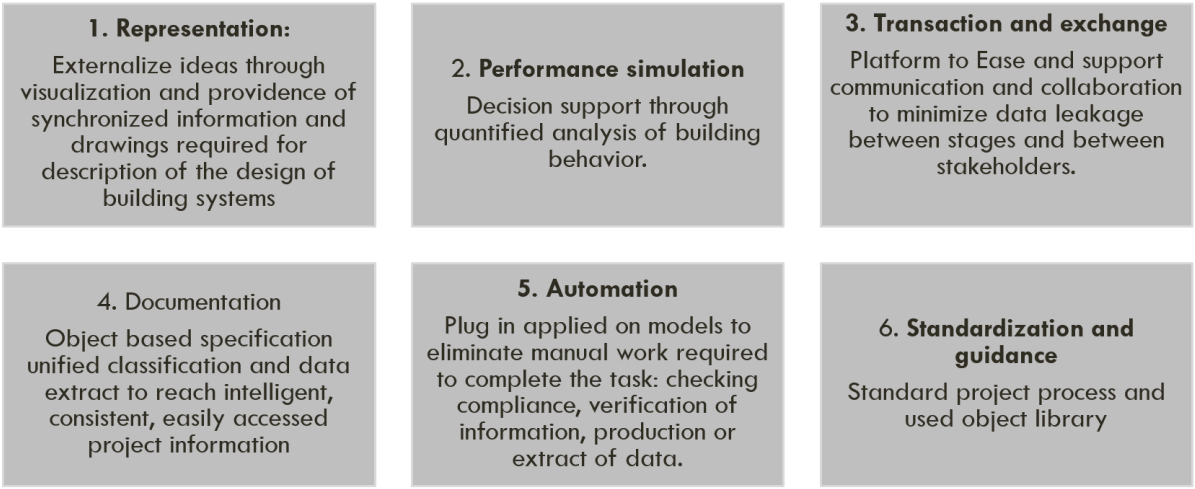

Figure 5: Brief definition to the areas of development

5.2.1 Representation

In the previous section, it was highlighted that visualization is one of the most powerful benefits of BIM technologies, and has acted as a major driver in the shift in stakeholder processes to deal with and exchange information on designated elements in buildings. As discussed earlier, better understanding of the designed project and the relationships between the various systems within the building is provided through 3D visualization using BIM tools (Tulubas Gokuc & Arditi, 2017). There are three purposes of representation and visualization between stakeholders listed as follows:

- Realistic representation using different tools to show ideas of designed elements, selected forms, materials, envelope, etc., to serve sustainability targets. Such

visualization options have improved the ability to rigorously analyse different alternatives with clients and other stakeholders (Tulubas Gokuc & Arditi, 2017). Sustainable design solutions are easily modelled and changed in the project real-time and this is already common practice in firms which are adopting BIM, which indicates that further development is not a major concern or a critical aspect in enhancing decision making processes regarding sustainability.

- Technical representation advantage: generation of updated and synchronized drawings which illustrate the required information is considered a great advantage compared to the traditional delivery method of CAD. In order to evidence sustainability decisions in building, a number of technical drawings need to be provided, and these can easily be generated from the model. There is a need for a data sheet development that fits the required tasks.

- Coordination advantage: The ability to visualize building elements within the context of other systems has facilitated the ability to eliminate clash between building systems. Different disciplines use the power of combined models in order to visually identify problems in the relationships between systems. One example of this is specifying mechanical systems, with high performance that will achieve the required sustainability targets, where the specification for the device requires certain room dimensions that are not compliant with in the architecture design. The development of a system which establishes different checking point scenarios would allow benefit to be gained from this advantage within the BIM execution plan.

5.2.2 Performance simulation and decision support

As mentioned before, a large body of studies were found that investigated sustainable design related analysis types in relation to their interoperability with BIM models (Azhar, 2009). Indicators for environmental performance analysis, such as energy and thermal simulation (Bahar et al., 2013), daylighting, value and cost, materials impact analysis and LCA can be simulated on separate specialized tools (Azhar et al., 2011). There is increasing recognition of the value of adopting performance-based design according to simulation results as quantitative evidence of building performance. However, the problems that limit increased adoption of these tools from the early stages are: complexity; increase in cost of process due to the requirement to invest more time and effort; and the reliability of the results (Azhar & Brown, 2009). Although a number of studies are developing ways to benefit from the models and data created through BIM models and eliminate extra effort caused by duplication of modelling using an IFC format, challenges and problems are still observed and recognized in interoperability (Yusuf Arayici, Fernando, Munoz, & Bassanino, 2018). The research focus in this area is derived from the use of the IFC gbxml BIM model to be imported into all other simulation programs, avoiding problems in geometry disorder and data loss, which all require technical interoperability solutions. Another perspective of development is substation in order to benefit from simulation within the process. This perspective is the inspection through knowledge information management and use of best practice to ascertain the timing and number of simulations required to inform design decisions, and the level of development of

the model with suitable estimations in order to reach reliable results. The new approach of simulation using VPL; grasshopper and dynamo, are developing because the method provides a potential to overcome challenges and problems in gbxml IFC exchange schemes which are: interoperability, usability and customization, precision and validity and model speed which provides more dynamic integration of simulation models (Negendahl, 2015).

5.2.3 Transaction and exchange

BIM technologies acted as a platform for collaboration by enabling easy exchange of related graphical and non-graphical information (Singh et al., 2011). As discussed in the design tasks, many applications in the BIM functionality fit section were derived from the ability to exchange, combine and check BIM models of different disciplines in order to maintain an optimum decision making process, with minimum requirement for changes in later stages (Biswas & Krishnamurti, 2012). Research approaches were developed focusing on deficiencies in the process of exchange of sustainability aspects within the BIM environment, such as data sharing (Biswas & Krishnamurti, 2012), BIM execution planning for green buildings (Wu, Asce, Issa, & Asce, 2015b), process map and exchange requirement (Baeza Salgueiro & Ferries, 2015), and data schema and workflow structure (Maltese et al., 2017b). However, limited studies were found on developing collective ways of building up data, monitoring the progress of information completeness, checking compliance and extracting information related to sustainability and assessment method requirements within BIM models. In order to reach sufficient exchange of sustainable aspects within a BIM model, it is necessary to set the attributes and parameters which are needed to describe the desired level of information, and then develop a system for monitoring its degree of completeness and compliance. IFC and MVD are agreed standardised method for information exchange for use within the building sector, as mentioned before. It can observed from the literature and practice that the development of defined MVD and BIM execution plan for delivering sustainable projects is still lacking (Volk et al., 2014). A clear definition of transaction and exchange of sustainability aspects within BIM environment might encourage key participants' engagement leading to successful collaboration. It is therefore suggested that a system for building up data/information, tracking and monitoring progress visually, checking compliance of the information model with regard to the assessment requirements, and extracting the relevant data would ensure enhanced benefit from BIM exchange capability.

Another potential research direction concerns the need to define how to develop better BIM structures for sustainability data, as this is considered a prerequisite to all integration applications. One challenge is to develop a data structure that supports sustainability in the ways the literature review has revealed. It is argued that the process of developing a schema that fully deals with geometric and semantic information (attributes and function) pertaining to all elements about the building is not achievable because it is an endless process (Pinheiro et al., 2018). Nevertheless, it is possible to initiate a framework of sufficient definition to translate sustainability requirements into information objects in a schema (MVD), and then develop it further using built up knowledge about the building systems. This should support the aim of reducing the amount of information about the building that is not digitally linked to the model.

5.2.4 Documentation

The literature regarding problems with EAM processes revealed that the tasks of documentation and evidencing for environmental assessment methods are considered a source of additional effort because they are separated from the work process (Alwan, Greenwood, & Gledson, 2015b). Extra time and effort is required to evidence the sustainability information within a project, therefore multiple studies found with attempt to automat this process in order to ensure that the data is generated within the project stages (Ilhan and Yaman, 2016) (Jalaei and Jrade, 2015). BIM models are considered information assets; researchers have given attention to the development of systematic procedures to enable these models to contribute to reducing the amount of effort, cost and time in order to produce the required documentation for EAMs. Tracking of documentation is usually done through a separate system which is not linked to the built up information in the BIM models; for example, Tracker Plus software ("Tracker Plus," n.d.) for LEED and BREEAM certification. Therefore, taking responsibility for categorizing the type of documentation that is needed, and from whom and when it is required, is necessary so that a digitalized documentation system that is linked to the current BIM process can be fully developed. The system for documentation should allow the project team to build up data, monitor progress, check compliance, and extract information within BIM process.

5.2.5 Automation

The evolution of automating activities and tasks in the construction industry has arisen from the need to work effectively by using the tool's capabilities to inform decisions and minimise the time and effort required to complete work. The second part of the literature review showed that applications of automation in previous studies have tended to focus on generating models that estimate EAM credit points achieved for design assessment and real time feedback (Han et al., 2017); (Ilhan & Yaman, 2016), partial automation of materials category documentation (Ilhan & Yaman, 2016), proposed automated certification processes (Jalaei & Jrade, 2015), and cloud BIM models for automated online certification (Wu & Issa, 2012). It may be argued that automation investigation areas have a direct connection to documentation and transaction and exchange tasks to improve communication, inform design, and reduce work load of certification process activities. However, it is still unknown whether these applications would increase efficiency of the work process or not; further development is necessary to enable them to reach a more mature state. It may be argued that such maturity could be achieved through knowledge management and best practice investigations to generate a database within the framework that can deal with building system decision process complexities. However, in order to be able to ensure the reliability of the results of these automated systems, it is important to be able to trust the quality, completeness and validity of the information in the model. Therefore, it is vital to generate rule sets for intelligent model checking of relationships between systems, constraints, and classification, in order to assure that input data is compliant with standards and regulations. It is suggested that insufficient attention has been given to this issue in previous applications.

5.2.6 Standardization and guidance

Standard and guide providence, as discussed in the benefits of collaborative project delivery, is considered one of the advantages of BIM implementation. This concept can be understood with reference to two directions. The first is that the production of standards and protocols defines processes, execution plans, and responsibilities to facilitate BIM adoption and the use of overlapping green assessment methods. In this way guidance is provided for technical and non-technical procedures regulating new processes and roles. Secondly, in generating comprehensive object libraries, templates and schemas that are not vendor-oriented, the process acts as a standard and guide for classification of model data and data organization in order to structure the project life cycle. Standard vocabulary is still a challenge when building, sharing and exporting consistent data, but it is potentially one of the main pillars on which to motivate integrated process.

5.3 Summary

In summary, this study revealed that the analysis of BIM technologies, processes and collaborative standards with sustainability decisions and tasks fit should inform the potentials and development required in the six main pillars of BIM benefits to sustainability. Future research may contribute to the attainment of a mature state of system management for sustainable digital delivery and a BIM-enabled dynamic design environment. This could facilitate mechanisms for change within the industry towards enhanced efficiency by a focus on the development of the information layer, technology utilization layer, management layer and generative sustainable design data, tasks and decisions. A model of the literature summary is presented in figure 6.

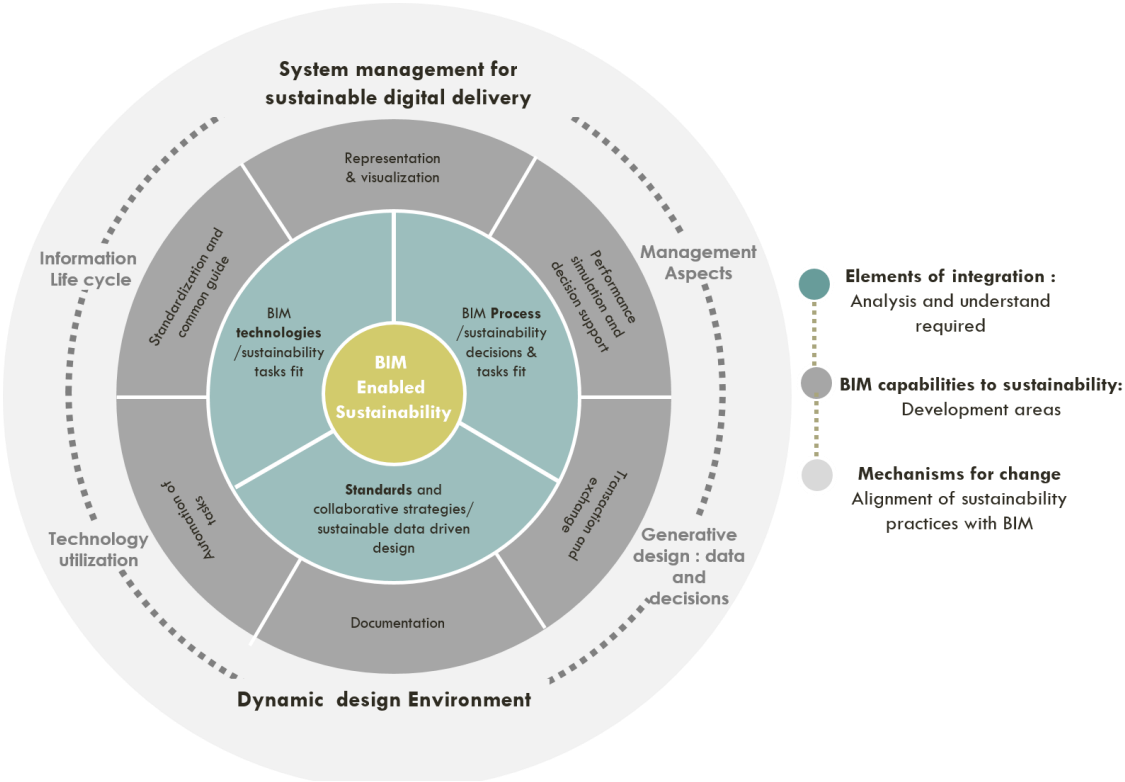

Figure 6: Conceptual model for literature recommendation to future research contribution.

6. Conclusion

The findings from this systematic literature review on the collaborative design process suggest that uncertainties in sustainable construction processes can be handled by employing BIM technical capabilities in order to manage resources. This motivates both research and practice towards developing and testing new strategies to address deficiencies relating to functional, informational, technical and organizational issues. The review provided insights into the diverse contexts of BIM-enabled sustainability applications, information generation and use within construction industry. Global recognition of the valuable perceived benefits of BIM was highlighted, in terms of technical and managerial capabilities to improve efficiency of information generation and knowledge management for different sustainability decision-making purposes. It was elaborated that in order to investigate the integration of any aspect within BIM, technologies should not be the only aspect to be examined, but investigations should also address the socio-technical system, including other factors that were presented in the literature. It was revealed that investigation of the elements of integration formulated within the literature should inform the development of BIM use in the following areas: representation; performance simulation; transaction and exchange; documentation; automation; and standardization and guidance. These elements of integration should be attained through in-depth understanding and definition of the fit between sustainability activities and tasks in relation to the BIM process, BIM technologies and guidelines, people and collaboration strategies. Limited studies were found which investigated both process and managerial factors in relation to technical and data structure issues. Understanding of the analysis of the element of integration should be reflected in the required development areas in order to amplify the implications of BIM-enabled sustainability in terms of increasing the efficiency of work. This paper addressed the limitation of the BIM technologies to deal with environmental sustainability aspects in more dynamic frameworks, which attempt to provide the stakeholders the ability to reduce effort, time and errors on traditional tasks. These developments aim to allow margin for designers' and engineers' knowledge interpretation. It can also be said that sustainability is not always easy to define and has many aspects such as building performance, which require greater definition. Finally, the findings of this paper should be valuable for both green practitioners and researchers with an interest in the current potential and deficiencies in BIM-enabled sustainability practices.

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