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BIM Requirements across a Construction Project Lifecycle: A PRISMA-Compliant Systematic Review and Meta-Analysis

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Building information modelling (BIM) has been progressively adopted within the architecture, engineering, construction, and operation (AECO) industries across the globe. The main goals behind the BIM adoption are to save procurement costs, reduce greenhouse emissions, and improve the productivity of the AECO industry. However, these goals are still difficult to be achieved due to the ambiguity of BIM requirements across a construction project lifecycle. Therefore, in such a situation, there is a need to increase understanding among the AECO industry players on the requirements of BIM implementation in order for them to fully grasp the benefits of BIM. This article sets out to redefine the required components of BIM requirements for a successful implementation of BIM across a construction project lifecycle. A systematic review was guided by the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) method in evaluating relevant published studies. The study systematically derived 39 papers covering the various aspects of BIM requirements across a construction project lifecycle. The initial findings highlighted that the required components of BIM requirements predominantly reside within policy, process, technology, environment, and people interlocking themes. These five themes further produced a total of 41 subthemes. The findings then led to the development of a BIM requirements' process map across a construction project lifecycle. This study contributes to the body of knowledge by extending the required components of BIM requirements across a construction project lifecycle. This study also provides some valuable insights for AECO industry players across the globe on the full benefits of BIM.

Key words: *Building Information Modelling (BIM), BIM Activities, BIM Requirements; BIM Specifications, Systematic Review.*

Introduction

Formerly introduced as "descriptive system of the building" by Eastman in a 1974 publication (Eastman et al., 2011), building information modelling (BIM) has been progressively adopted globally within the architecture, engineering, construction, and operation (AECO) industry. The implementation of BIM is now mandated across various public policies with the aim of reducing procurement costs and improving the productivity of the construction industry (Mcauley et al., 2017). For instance, the US General Services Administration (GSA), through it's Public Buildings Service (PBS), mandated a 3D-4D BIM programme to be used as a spatial programme validation across all of it's projects in 2007 (Smith, 2014). In 2011, the UK Cabinet Office (2011) took further steps by introducing a five-year mobilisation programme for collaborative BIM to be fully mandated across public projects by April 2016. The policy driven approach taken by the UK government has awakened the global AECO industry, as evidenced by the development of the transformation programme of the Malaysian construction industry (CITP) 2016–2020 (CIDB, 2015). The programme states that all public building projects costing above RM100 million will be mandated to be delivered through BIM Level 2 by the fourth quarter of 2020. The UK BIM supporting standards are also seen as the world's leading suite of documents through the high rate of adaption of those standards by public agencies across Asia and Australasian regions, including Hong Kong Housing Authority (HKHA), Singapore Building and Construction Authority (BCA), Australian National Building Specifications (NATSPEC), and New Zealand BIM Acceleration Committee (BAC) across of all their public projects (Mcauley et al., 2017).

Towards a Systematic Review of BIM Requirements across a Construction Project Lifecycle

A considerable number of systematic reviews of literature have been published on BIM requirements across a construction project lifecycle (Parllaku and Underwood, 2017; Farzaneh et al., 2018; Gao and Pishdad-Bozorgi, 2019; Ibrahim and Kingdom, 2013; Kamel and Memari, 2019; Sacks et al., 2016). Recent systematic reviews carried out by Farzaneh, Monfet, and Forgues (2018) and Kamel and Memari (2019). appear to focus solely on the requirements of BIM technology and tools while disregarding implementation processes and legal aspect requirements in delivering a project. In another major review study, Parllaku and Underwood (2017) provided a critical review on the industry's awareness towards the requirements of BIM Level 2 implementation. However, the credibility of the study would have been enhanced had the scholars included the requirements of BIM that were adopted by policy organisations from regions other than the UK. In another study, Sacks, Gurevich, and Shrestha (2016) performed a qualitative content analysis to analyse the guidelines, standards, and protocol documents of BIM published by public agencies, large-scale construction clients, and universities across the region. Nevertheless, instead of merely reviewing the publicly available BIM standards across the globe, the review could have extended the analysis to include empirical quantitative and qualitative studies because a different type of procurement route and scale of the project might require a different set of BIM requirements. Therefore, this article attempts to redefine the components of BIM requirements based on the synthetisation of variables within the General Practitioners Information System (GPIS) (Saleh and Alshawi, 2005) and protocols for a BIM collaborative design framework (Kassem et al., 2014). The systematic review was guided by the following research question (RQ): What are the requirements for a successful implementation of BIM across a construction project lifecycle?

Methodology

A systematic review protocol is developed in order to identify, screen, and critically access significant studies, as well as to collect and analyse data that are included in a review that is based on formulated research questions and explicit techniques (Green and Higgins, 2005). As for the present study, the protocol was guided by the PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Moher et al., 2009). PRISMA has been adopted in various studies within the field of built environment including those related to BIM strategies (Charef and Emmitt, 2018; Sidani et al., 2018; Fan et al., 2018). The PRISMA method has been adopted because it provides researchers with three explicit methods: (1) identifying large databases of scientific academic literature through keyword and search strategies, (2) screening inclusion and exclusion criteria, and (3) conducting eligibility process in appraising the relevant literature to analyse the data from the studies.

Stage 1: Selection of Journals and Databases

The main source of data for the systematic review was Scopus. A more significant number of journals have been indexed by Scopus in comparison to PubMed, WOS, and Google Scholar (Leslie and Chris, 2014; Chadegani et al., 2017). Unlike other databases, Scopus enables the operation of four key search techniques: (1) boolean operators, (2) phrases, (3) truncation, and (4) wildcards. Also referred were sources from top-ranked journals in order to cover the key reference points of BIM publications as recently listed by Hosseini, Maghrebi, Akbarnezhad, Martek, and Arashpour (2018) Table 1.

Table 1: The search string used for the systematic review process

Databases and Journals	Search Strings
Scopus	TITLE-ABS-KEY Adoption OR Implementation OR Readiness OR Maturity OR perspective* OR expectation*) AND (requirement* OR specification* OR deliverable*) AND (BIM OR “building information model” OR “building information modelling and management” OR “collaborative BIM” OR “integrated BIM” OR “integrated Building Information Modelling” OR “level 2 BIM” OR “level 3 BIM” OR “BIM level 2” OR “BIM Level 3”) AND (Organisation OR Firm OR SMEs OR Industry OR AEC OR “Construction Industry” OR Macro OR micro OR project))
Secondary source (prominent journals): (1) Automation in Construction, (2) Engineering, Construction and Architectural Management, (3) International Journal of Managing Projects in Business, (4) Journal of Architectural Engineering, (5) Journal of Building Engineering. (6) Journal of Construction Engineering and Management, (7) Journal of Information Technology in Construction, (8) Jurnal Teknologi, (9) Malaysian Construction Research Journal, (10) Construction Innovation, (11) Procedia Engineering	In contrast to Scopus, the combination of keywords outlined in Table 1 was formulated interchangeably because of the keywords did not support all of the four key search techniques

Stage 2: Keyword Sets and Search Configurations

A range of keywords (Table 1 and Table 2) and their synonyms were derived from the main research question (what are the requirements for a successful implementation of BIM across the construction lifecycle?). Prior to conducting the literature search, a set of key words and search configurations (Table 2 through the key search techniques, boolean operators, phrases, truncation, and wildcards) were formulated. As for the secondary sources, the keywords were arranged interchangeably because the keywords did not support all of the four key search techniques. A total number of n=339 and n=84 articles were retrieved from Scopus and secondary sources, respectively. All the retrieved articles at this stage were recorded in an Excel sheet before being exported to "Mendeley" software for screening of duplicated materials.

Table 2: Search terms

Process	Body of Knowledge (BOK)	Field Area	Context
Adoption Implementation Readiness Maturity Perspective Expectation	Requirement Specification Deliverables	BIM "Building information model" "Building information modelling" "Building information modelling and management" "collaborative BIM" "integrated BIM" "level 2 BIM" "Level 3 BIM" "BIM Level 2" "BIM Level 3"	Organisation Firm SMEs Industry "construction industry" AEC Macro Micro Project

Stage 3: Inclusion and Exclusion Criteria

After the database search and the elimination of duplications, 399 articles were screened based on predetermined inclusion and exclusion criteria Table 3. Firstly, only article journals with empirical evidence were included, whereas review articles, conference paper, conference review, book chapter and book series were excluded. Secondly, the searching activities focused merely on articles published in the English language in order to prevent any complication and confusion in interpreting non-English publications. Third, in regard to time period, a duration of 14 years (between 2005 and 2019) was determined because BIM was mandated by the US General Services Administration (GSA) for spatial programme validation across all of its projects in 2007 (Smith, 2014). Finally, because BIM has been widely diffused across the globe (Mcauley et al., 2017), (Cheng and Lu, 2015), articles that focus on BIM implementations in North and South American, Europe, Scandinavian, Australasia, and Asia territories were also included.

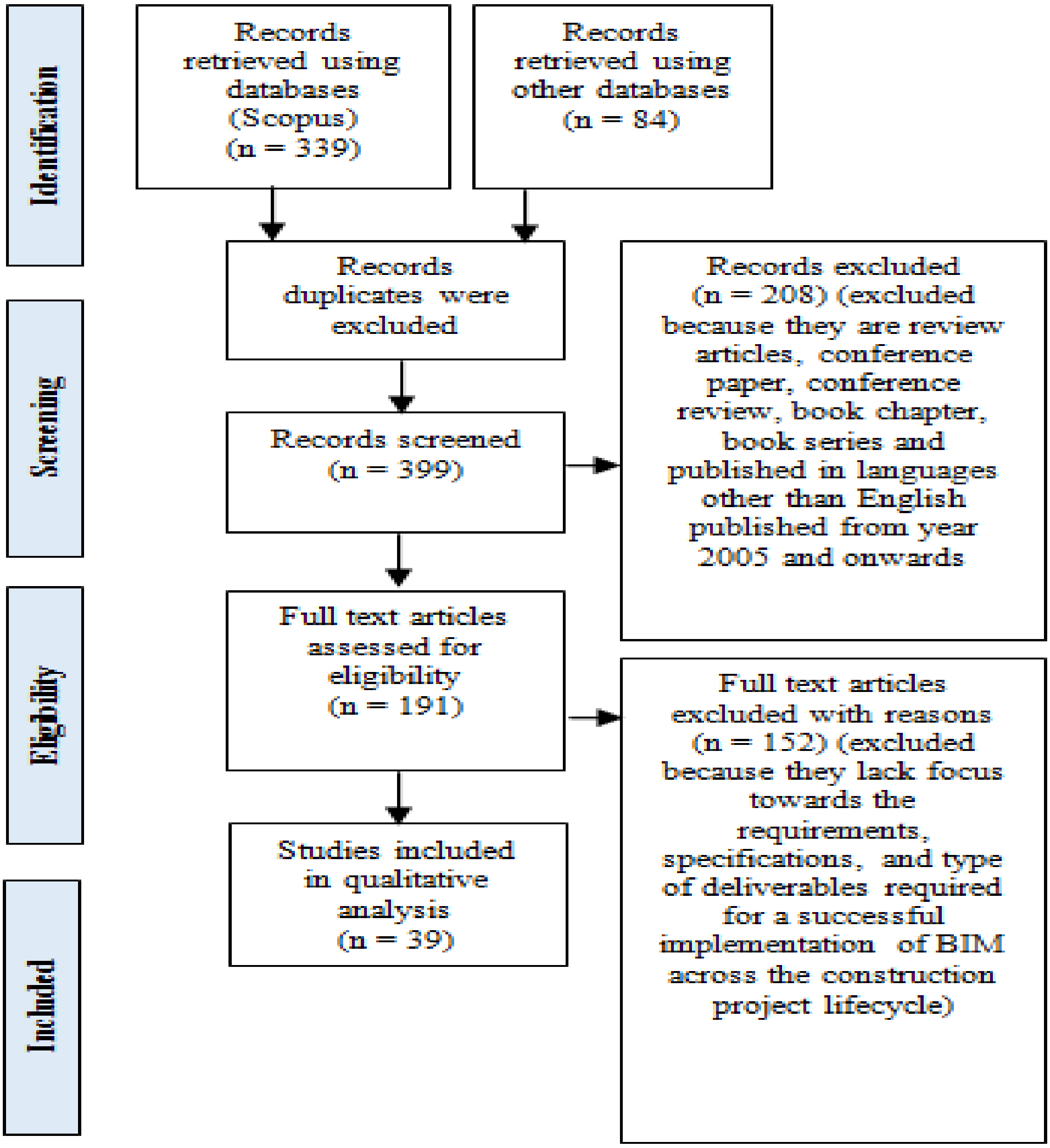
Table 3: The inclusion and exclusion criteria

Criterion	**Inclusion**	**Exclusion**
Document type	Journal (research articles)	Review articles, conference paper, conference review, book chapter and book series
Language	English	Non-English
Time Period	Between 2005 and 2019	< 2005
Countries and territories	North and South American, Europe, Scandinavia, Australasia and Asia region	

Stage 4: Eligibility Criteria

The eligibility screening of the remaining 191 articles was carried to include only relevant articles to be used for the qualitative analysis. The last stage of the review resulted in the exclusion of 152 articles due to the lack of focus towards the requirements, specifications, and type of deliverables required for a successful implementation of BIM across the construction project lifecycle Figure 1.

Figure 1. The SLR execution process (adapted from Moher et al., 2009).



Data Abstraction and Analysis

The remaining articles to be used for the analysis is finalised from the process shown in Figure 1. The qualitative analysis was conducted using the thematic analysis approach in order to identify themes and subthemes (codes) related to the requirements, specifications, and deliverables of BIM implementation. As recommended by Ryan and Bernard (2000), the authors identified a pre-existing set of codes and merged them with new emerging codes after completing the data collection.

Results and Discussion

The results obtained from the thematic analysis are presented in Table 4. The review derived five main themes and 41 subthemes associated with BIM requirements across the construction project lifecycle. The five interlocking main themes are policy (7 subthemes), process (16 subthemes), technology (6 subthemes), environment (6 subthemes), and people (6 subthemes). The results provided an exhaustive analysis of the required components of BIM requirements across the construction project lifecycle. Two of the studies adopted a mixed-method approach and another 12 studies applied a quantitative analytic approach. The remaining studies (25) employed a qualitative approach. The tendency of previous researchers to employ a qualitative approach might be due to their need to supply an in-depth understanding of BIM requirements. The following subsections will discuss in greater detail the main themes and subthemes that underpin the BIM requirements.

Table 4: Summary of findings

Authors	Research Design			BIM Requirements				
				P1: Policy	**P2: Process**	**T3:Technology**	**E4:Environment**	**P5: People**
Zanni et al. (2017)		QL		√	√	√		√
Almuntaser et al. (2018)		QL		√	√	√		√
Olawumi and Chan (2019)		QL			√			
Ahuja et al. (2018)	MM				√		√	
Olatunji (2013)		QL			√			
Gu and London (2010)		QL		√	√	√		√
Arayici et al. (2011)	MM				√	√	√	√
Kokkonen and Alin (2016)		QL			√			√
Sebastian (2011)		QL		√		√		√
Lin and Yang (2018)		QL		√	√			
Kassem et al. (2014)		QL		√	√	√		√
Amuda-yusuf (2018)			QN	√	√		√	√
Meex et al. (2018)		QL			√			
Alreshidi et al. (2017)		QL		√	√	√	√	√

Koseoglu et al. (2018)		QL			√			
Hanafi et al. (2016)			QN	√	√	√	√	√
Zhao and Wang (2018)			QN	√		√		√
Khosrowshahi and Arayici (2012)		QL		√	√	√	√	√
Chen et al. (2014)			QN	√	√	√	√	√
Kalach et al. (2018)		QL		√	√			
Farzaneh et al. (2018)		QL			√	√		
Gurevich et al. (2017)		QL		√	√	√		
Kang and Woo (2015)			QN	√	√	√		
Hooper and Ekholm (2012)		QL		√	√			
Alazmeh et al. (2018)		QL		√	√	√	√	
Hooper (2015)			QN	√	√			
Mahamadu et al. (2017)			QN	√		√	√	√
Pazlar and Turk (2008)			QN			√		
Wu et al. (2015)		QL			√			
Alreshidi et al. (2018)			QN	√		√		
Ashworth et al. (2018)		QL		√	√	√		√
Ghafar and Ibrahim (2018)		QL					√	
Hadzaman et al. (2016)		QL		√				
Haron et al. (2014)		QL		√	√		√	√
Matthews et al. (2018)		QL				√	√	√
Olawumi and Chan (2019)			QN	√	√	√	√	√
Shafiq et al. (2013)		QL				√		
Tse et al. (2005)			QN			√		
Ding et al. (2015)			QN	√	√	√		
Totals	**2**	**25**	**12**	**25**	**29**	**23**	**13**	**18**
MM= Mixed Methods	QL= Qualitative				QN= Quantitative			

BIM Requirements: Policy Pillar (P1)

Out of the 39 studies, 25 discuss the policy requirements for a successful implementation of BIM (Table 4). Seven subthemes emerged under this theme:

(i) BIM standards, guides, and protocol (13 studies) (Kassem et al., 2014 Almuntaser et al., 2018 Gu and London, 2010 Lin and Yang, 2018 Hanafi et al., 2016 Gu and London, 2010 Khosrowshahi and Arayici, 2012 Chen et al., 2014 Gurevich et al., 2017 Hooper and Ekholm, 2012 Kang and Woo, 2015 Alazmeh et al., 2018 Hooper, 2015 Mahamadu et al., 2017);

(ii) BIM execution plan (6 studies) (Kassem et al., 2014) Almuntaser et al., 2018 Hadzaman et al., 2016;

(iii) Collaboration requirements (4 studies) (Olawumi and Chan, 2019 Amuda-yusuf, 2018 Alreshidi et al., 2017 Alreshidi et al., 2018);

(iv) Contractual agreement (6 studies) (Sebastian, 2011 Amuda-yusuf, 2018 Kalach et al., 2018 Gurevich et al., 2017 Mahamadu et al., 2017 Hadzaman et al., 2016);

(v) Employer information requirements (EIRs) (3 studies) (Ashworth et al., 2018 Alreshidi et al., 2017 Almuntaser et al., 2018);

(vi) Intellectual property (6 studies) (Kassem et al., 2014) Gu and London, 2010 Sebastian, 2011 Alreshidi et al., 2017 Zhao and Wang, 2018 Ashworth et al., 2018 ; and

(vii) Obligation of stakeholders (10 studies) (Kassem et al., 2014 Zanni et al., 2017 Almuntaser et al., 2018 Sebastian, 2011 Zhao and Wang, 2018 Khosrowshahi and Arayici, 2012 Chen et al., 2014 Kalach et al., 2018 Alreshidi et al., 2018 Ashworth et al., 2018).

BIM Requirements: Process Pillar (P2)

It is apparent from Table 4 that the majority of the previous studies have focused on the requirements of the BIM process. An exhaustive list of subthemes emerged within the requirements of the BIM process, consisting of:

(i) Benchmarking practices (5 studies) (Olawumi and Chan, 2019 Almuntaser et al., 2018 Olawumi and Chan, 2019);

(ii) BIM implementation plan (4 studies) (Arayici et al., 2011 Haron et al., 2014)

(iii) BIM model deliverables (4 studies) Gurevich et al., 2017 Almuntaser et al., 2018;

(iv) BIM project lifecycle process map (5 studies) (Zanni et al., 2017) Gurevich et al., 2017;

(v) BIM uses process map (7 studies) (Kassem et al., 2014 to Wu and Issa, 2015) ;

(vi) BIM-information delivery specification (IDS) (12 studies) (Kassem et al., 2014 ;Ashworth et al., 2018);

(vii) Construction operations building information exchange (COBIE) (1 study) (Almuntaser et al., 2018);

(viii) Cost implementation plan (5 studies) (Almuntaser et al., 2018) ;

(ix) Digital data management (2 studies) (Kassem et al., 2014);

(x) Identification of project team’s capability (6 studies) (Kassem et al., 2014)

(xi) Mobilisation (1 study) (Kassem et al., 2014);

(xii) Pilot project (3 studies) (Almuntaser et al., 2018 Haron et al., 2014) ;

(xiii) Process flow redesign (3 studies) (Zanni et al., 2017 Haron et al., 2014);

(xiv) Quality assurance (5 studies) (Almuntaser et al., 2018) Hooper and Ekholm, 2012;
(xv) Scoping activities and purpose (5 studies) (Kassem et al., 2014); and
(xvi) Risk management (2 studies) (Hanafi et al., 2016 Almuntaser et al., 2018).

The top three most highlighted sets of requirements within this theme are BIM-IDS. BIM uses a process map, and identification of the project team's capability. This result can be attributed to several possible explanations. The establishment of BIM-IDS prior to commencement of work is critical because BIM-IDS will provide an explicit requirement in regard to level of detail (LoD), level of information (LoI), and the party responsible for delivering information across a construction project lifecycle (Hooper and Ekholm, 2012). It is important to note that a different use of BIM (such as visualisation, energy simulation, coordination, or fabrication) requires a different level of information and detail of BIM model to work upon (Almuntaser et al., 2018 Lin and Yang, 2018 Farzaneh et al., 2018) . Therefore, establishing a BIM process map for each of the uses of BIM plays a significant role in determining the right information that should be relied upon in producing BIM deliverables. Failing to do so would result in delivery of wrong information of an asset to a client during a closeout stage. However, the interrelated tasks outlined in a BIM-uses process map would not operate effectively unless a competent BIM team is available. This necessity justifies the requirement of identification of the project team's capability, as highlighted under this theme.

Unexpectedly, findings from the systematic review uncover the fact that the requirements related to COBIE, mobilisation, and risk management have rarely been discussed. Although the COBIE deliverables have been prescribed as the main deliverables in complying with level-2 BIM, discussion on the reference appears only in Almuntaser et al.'s study (Almuntaser et al., 2018). One possible explanation is that different public agencies across the globe would have different interpretations of the required deliverables of BIM level 2. For instance, regions other than the UK might require only an asset information model (AIM) as a substitution to the COBIE deliverables. Another surprising result was the fact that less discussion has been provided on the requirements of mobilisation and risk management for a successful implementation of BIM across a construction project lifecycle (Almuntaser et al., 2018; Hanafi et al., 2016). We believe that this scenario was due to the external pressure from the client side in demanding a project delivery team to execute without proper analysis of the possible risks correlated with BIM implementation, and without examining all the required infrastructure, documents, and proposed BIM methodologies in place.

BIM Requirements: Technology Pillar (T3)

A total of 23 studies highlight the importance of addressing technological requiremenst in successfully implementing BIM across a construction project lifecycle (Table 4). Six subthemes emerged under this theme:

(i) BIM object library (4 studies) [51-52, 65, 67];
(ii) Collaboration server (9 studies (Kassem et al., 2014 Zanni et al., 2017 Almuntaser et al., 2018 Gu and London, 2010 Arayici et al., 2011 Alreshidi et al., 2017 Alazmeh et al., 2018 Mahamadu et al., 2017 Alreshidi et al., 2018 Shafiq et al., 2013) ;
(iii) ICT infrastructure (6 studies) (Almuntaser et al., 2018 Arayici et al., 2011 Alreshidi et al., 2017 Chen et al., 2014 Mahamadu et al., 2017 Ashworth et al., 2018),
(iv) Interoperability (11 studies) (Kassem et al., 2014 Zanni et al., 2017 Olawumi and Chan, 2019 Sebastian, 2011 Hanafi et al., 2016 Zhao and Wang, 2018 Khosrowshahi and Arayici, 2012 Farzaneh et al., 2018 Pazlar and Turk, 2008 Tse et al., 2005 Ding et al., 2015) ;
(v) Technical support (6 studies) (Kassem et al., 2014 Almuntaser et al., 2018 Almuntaser et al., 2018 Mahamadu et al., 2017 Ashworth et al., 2018 Tse et al., 2005) and
(vi) Vendor evaluation (9 studies) (Green and Higgins, 2005 Ryan and Bernard, 2000 Zanni et al., 2017 Khosrowshahi and Arayici, 2012 Chen et al., 2014 Mahamadu et al., 2017).

The most striking result to emerge from the analysis is the interoperability of data exchange compatibility. Interestingly, despite the technological advancement in BIM application, the issue of interoperability of data exchange across various BIM software has remained unresolved until the present time. In the early days of BIM introduction within the AECO industry, Sebastian (2011) and Pazlar and Turk (2008) expressed their doubt on the sufficiency of Industrial Foundation Classes (IFC) to be considered as an open and neutral data format. A similar issue has been highlighted in recent studies (Zanni et al., 2017; Zhao and Wang, 2018 Farzaneh et al., 2018 Olawumi and Chan, 2019). It has been reported that the integration of sustainability data between building performance analysis (BPA) and BIM authoring tools has been obstructed by the interoperability limitation. As a consequence, much rework issues in remodelling and re-entering of data into the building elements need to be performed, thus affecting the productivity of BPA process. We speculate that the issue of interoperability of data exchange has worsened because of the different ways a 3D BIM modelling technique and guideline has been applied by different AECO industry players.

Nevertheless, the studies have provided several recommendations in managing the potential risks associated with the interoperability of data exchange. Kassem et al., (2014) proposed the need to develop a BIM technological diagram based on BIM tools' functions (including programming, design, analysis, management and review) and to link the functions to the project deliverables required at every particular work stage. This finding corresponds to Gu & London's work (Kokkonen and Alin, 2016), who stressed the importance of having an in-depth comprehension of BIM application and it's capabilities through the development of a "tool-activity matrix and BIM-tool capability chart." Additionally, Arayici et al. (Kokkonen and Alin, 2016) and (Hanafi et al., 2016) suggested that an evaluation process be conducted on BIM tools to be adopted within the architectural practices in order to maximise the potential of BIM tools in fulfilling the organisational objective of BIM adoption. Upon completion of evaluating BIM tools, developing a technology diagram and addressing the interoperability of data exchange, the appointment of a BIM manager is required to set up a collaboration server, which is part of the requirements for a BIM-based project(Alazmeh et al., 2018) Alreshidi et al., 2018(Matthews et al., 2018 Shafiq et al., 2013) . The idea of collaborative working practice as advocated by BIM scholars and practitioners could be materialised only through the implementation of collaboration BIM server because such a measure will allow project participants to work concurrently on a most updated BIM models that live in the cloud. Therefore, in general, the findings of previous scholars apparently suggest that BIM requirements are very technical by nature. All of the required requirements of BIM process discussed in the previous studies would not be functioning efficiently without proper planning and preparation of ICT infrastructure.

BIM Requirements: Environment Pillar (T4)

A total of six subthemes emerged under environmental requirement of BIM (E4): (i) BIM research and development (2 studies) (Ahuja et al., 2018; Mahamadu et al., 2017); (ii) incentives and reward (1 study) (Haron et al., 2014); (iii) IT vision and mission (2 studies) (Mahamadu et al., 2017 Matthews et al., 2018); (iv) knowledge capture and knowledge sharing (3 studies) (Arayici et al., 2011; Matthews et al., 2018 Ghafar and Ibrahim, 2018); (v) organisational culture (9 studies) (Ahuja et al., 2018 to Olawumi and Chan, 2019); and (vi) senior leadership (5 studies) [34, 41, 43, 48, 54]. The notable theme that emerged is the organisational culture in driving and sustaining the collaborative working culture of BIM in daily practices. A continuous improvement culture within organisations does have a significant impact in motivating project team members to overcome potential resistance and to fully embrace the benefits of using a BIM-based approach in their organisation. Olawumi and Chan (2019) considered supportive organisational culture as a key enabler in successful implementation of BIM and in sustainability practices in the AECO industry. The findings of the current study are consistent with those of Hanafi et al. (2016) who recommended that the critical consideration of both BIM technology and social cultural environment are imperative for a successful implementation of BIM among architectural practices. However, a supportive organisational culture could have not be sustained without an effective leadership from the management team. This could be evidenced through a successful implementation of BIM-based collaborative workflow in a large Chinese UK-based engineering and construction organisation, which was materialised through an effective leadership from the senior management team (Alazmeh et al., 2018). These findings are consistent with those of other studies and suggest that an effective BIM governance is highly dependent on the effectiveness of leadership of the upstream players (Olatunji, 2013; Amuda-yusuf, 2018; Chen et al., 2014).

Apart from senior leadership, a continuous improvement culture within organisations could also be fostered through the establishment of a knowledge capture and sharing platform. The experiential knowledge gained by project team members will increase as the project progresses from one stage to another. However, this sort of knowledge is difficult to be explicitly transferred to other project team members due to it's complexity and subjectivity perceived by different individuals. In view of the above, Matthews et al. (2018) noted that the establishment of "communities of practice" (CoP) within organisations is critically needed in capturing and openly sharing the new knowledge, methods, and techniques gained during the project delivery process with the project team members. These measures will also indirectly lead to promoting the culture of research and development of BIM within organisations (Ahuja et al., 2018; Mahamadu et al., 2017). The conclusion is that striking a balance between fulfilling the technical and social cultural requirements is indispensable to successfully implement BIM across a construction project lifecycle.

BIM Requirements: People Pillar (P5)

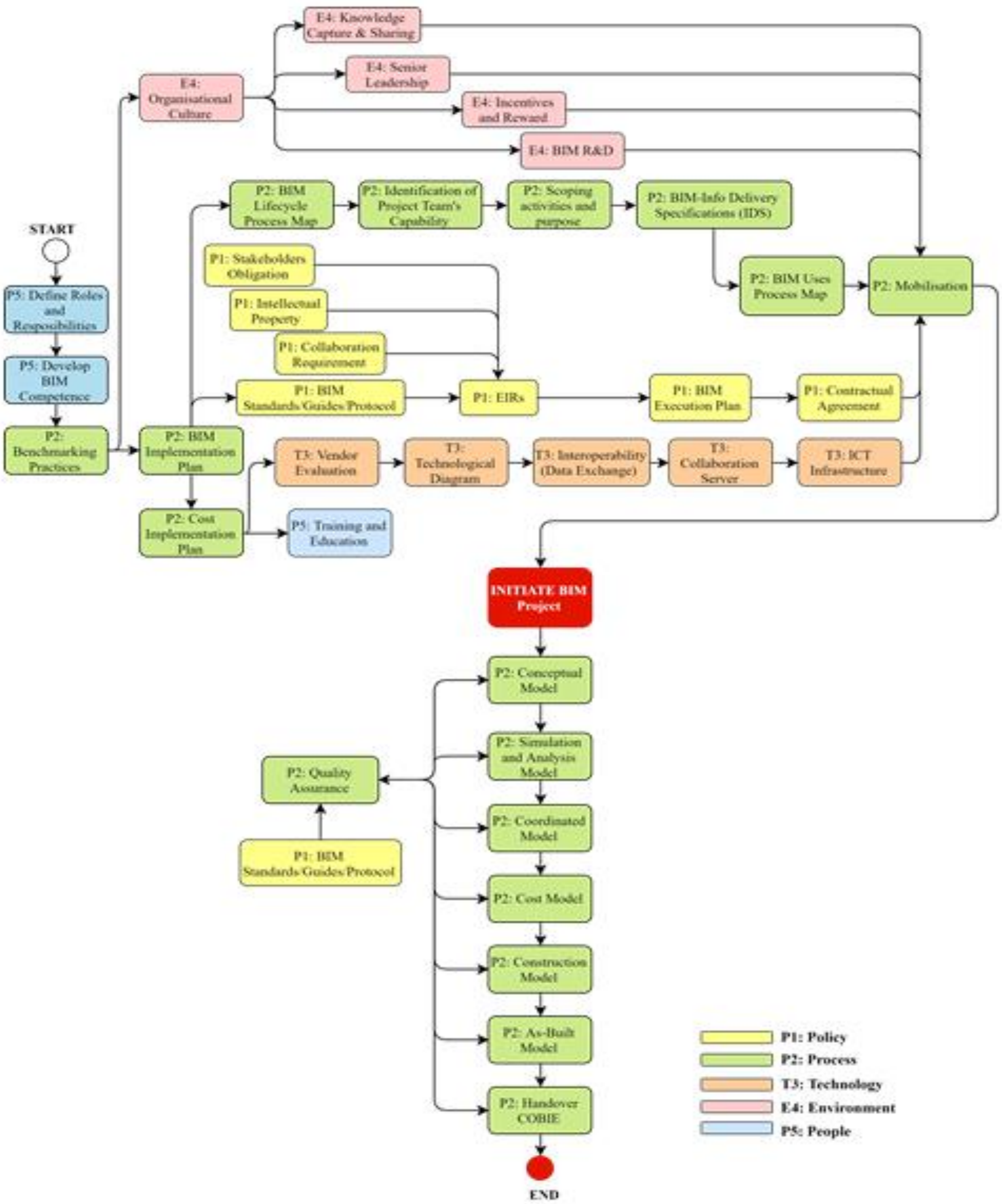
People-related requirements emerged as among the most critical elements that underpin other requirements for a BIM project to operate properly across a construction project lifecycle. Six subthemes emerged within this theme: (i) BIM competence (5 studies) (Zhao and Wang, 2018- Matthews et al., 2018; Olawumi and Chan, 2019); (ii) organisation experience (2 studies) (Kassem et al., 2014; Gu and London, 2010); (iii) qualification (1 study) (Mahamadu et al., 2017); (iv) roles and responsibilities (3 studies) (Kassem et al., 2014; Gu and London, 2010); (v) staff experience (2 studies) (Zhao and Wang, 2018; Mahamadu et al., 2017); (vi) training and education (13 studies) (Zanni et al., 2017- Haron et al., 2014). It is apparent that training and education are the most highlighted types of requirement discussed under this theme. As noted in previous studies, Zhao and Wang (2018) discovered that the potential risks correlated with BIM implementation (including technological issue, cultural resistance, data ownership issue, low data quality and design check issues) are fundamentally caused by the scarcity of BIM knowledge and expertise among the AECO industry players. These findings further support the proposition of Hanafi et al. (2016) who found that the root cause of the inability of AECO industry players to fully grasp the full benefits of BIM was the shortage of skilled manpower in handling BIM technology. Nevertheless, the authors strongly believe that the implementation of BIM is not merely about mastering BIM technology, the reason being that this shift requires AECO industry players to equip themselves with a new set of competencies that are beyond their technical capabilities. As extensively discussed in previous sections, it is apparent that BIM personnel need to be equipped with administration, managerial, and functional sets of competency in order to enable them to effectively plan and manage the legal aspect and information delivery process of BIM requirements across a construction project lifecycle.

Another striking result to emerge within this theme is the clarity of roles and responsibilities defined in a BIM-based project. The new dedicated roles of BIM such as a BIM technician, BIM coordinator, and BIM manager have been prescribed as a part of the requirements for large-scale BIM projects (Kassem et al., 2014; Gu and London, 2010; Sebastian, 2011). Nevertheless, the ambiguity of BIM roles and responsibilities surrounding the existing AECO professionals are yet to be resolved (Zanni et al., 2017; Khosrowshahi and Arayici, 2012). Based on our experience working in several BIM-based projects as both the design consultant and the main contractor, we observed that there are some overlapping duties among BIM-specific roles and existing AECO professionals. We believe that BIM roles and responsibilities fundamentally fall within the existing AECO professionals basic services despite being carried out with different methods and tools. Additionally, BIM-specific roles can only be seen as a temporary role in bridging the current deficiency of BIM knowledge and the skills possessed by existing professionals in the AECO industry. Taken together, these results suggest that the human side of BIM requirements (P5) is the core foundation for a successful implementation of BIM as it cuts across all other requirements including policy (P1), process (P2), technology (T3), and environment (E4). For demonstration purposes, the BIM requirement process map is developed to illustrate the interconnection of BIM core activities and requirements across the five themes, which are to be delivered during the whole lifecycle of the project (Figure 2). However, it is important to note that different types of procurement contracts and assigned roles and obligations would require different workflow to be shown in a BIM process requirement map.

Conclusion

The purpose of this systematic review is to redefine the required components of BIM requirements across a construction project lifecycle. We commenced the review with the RQ of "what are the requirements for a successful implementation of BIM across the construction lifecycle?". The findings highlight that the required components of BIM requirements predominantly reside within the policy, process, technology, environment, and people interlocking themes. These five themes further produced a total of 41 subthemes. This study adds to the existing literature by extending the base knowledge of BIM requirements based on the synthetisation of GPIS model and protocols for a BIM-collaborative design framework. Nevertheless, this study has brought about further queries in need of further investigation. First, more studies on people-related requirements of BIM are needed, the reason being that the other components that reside within the policy, process, technology, and environmental requirements of BIM would not be functioning effectively without the availability of BIM skilled manpower in the AECO industry. Secondly, future studies might investigate the required components of BIM competency needed by the AECO industry players to successfully deliver BIM requirements across a construction project lifecycle. Finally, this study could also be extended by investigating the required components of BIM requirements needed by different disciplines within the AECO industry.

Figure 2. BIM requirement process map



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