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Bakhshi, Javad; Golzad, Hamed; Martek, Igor; Hosseini, M. Reza; Papadonikolaki, Eleni

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Unveiling the complexity code: navigating BIM-enabled projects with a project management complexity index

Engineering, Construction and Architectural Management

Javad Bakhshi
UniSA STEM, University of South Australia, Adelaide, Australia
Hamed Golzad
School of Design and Built Environment, University of Canberra, Canberra, Australia
Igor Martek
School of Architecture and Built Environment, Deakin University, Melbourne, Australia
M. Reza Hosseini
Faculty of Architecture, Building and Planning, University of Melbourne, Parkville, Australia, and
Eleni Papadonikolaki
Department of Materials, Mechanics, Management and Design, Delt University of Technology (TU Delft), Delft, Netherlands

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Abstract

Purpose – This study aims to investigate the complexity factors associated with BIM-enabled projects. BIM has been widely promoted as a potential solution to numerous challenges that hinder productivity in construction projects, owing to its numerous advantages. Nevertheless, it is crucial to acknowledge the heightened complexity it introduces to project workflows, stakeholder coordination and information management.

Design/methodology/approach – This study employs the Delphi method to identify and extract complexity factors specific to BIM-enabled projects. A panel of industry and academic experts is engaged to discern and prioritise these factors based on their expertise and knowledge.

Findings – The study reveals a comprehensive list of 34 complexity factors that significantly impact BIM-enabled projects. Among the most influential factors are laws and regulations, variety of procurement methods, technical capabilities of teams, project manager competence, information transfer capacity, range of project deliverables and diversity of project locations. The findings highlight the importance of these factors and emphasise the need for proactive and adaptive management to navigate their impact and achieve positive project outcomes.

Originality/value – This study introduces the DEBACCS framework, a metric-based model designed to understand and evaluate complexity within BIM-enabled projects. DEBACCS stands for seven key dimensions: diversity, emergence, belonging, autonomy, connectivity, context and size. These dimensions represent essential aspects for gauging project complexity. By applying the concept of complexity from project management to BIM, the study offers valuable insights for practitioners and researchers. It provides a unique perspective on the challenges and considerations associated with implementing and managing BIM in construction projects. The findings have practical value for practitioners, enabling them to better understand and address the implications of complexity in BIM-enabled projects, ultimately leading to improved project outcomes.

Keywords Information management, Complexity, Digital construction, Virtual design and construction, Delphi, Construction management

Paper type Research paper

1. Introduction

Building Information Modelling (BIM) is a relatively new disruptive innovation for the construction industry (Chen *et al.*, 2023). The pervasiveness of BIM adoption is, however,

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unprecedented. The global BIM market is projected to grow to US$23 billion by 2027, with a compound annual growth rate (CAGR) of 18.0% during the forecast period 2019–2027 (Asif *et al.*, 2024). BIM introduces changes in working practices within and across organisations (Zomer *et al.*, 2021), changes that may be difficult and painful to sustain in a low-tech, low-skilled domain like the construction industry (Papadonikolaki, 2018). One such change is shifting from traditional collocated teams to BIM-based Construction Networks (BbCNs), on which BIM-enabled projects heavily rely. In fact, BbCNs are the central delivery unit of BIM-enabled projects (Oraee *et al.*, 2017). These are teams comprising members from specialist organisations contracted to execute BIM-related works (Mani *et al.*, 2022). However, maintaining effective teamwork among BbCN members, often geographically separated, coming from multiple disciplines and organisations in BbCNs, remains a problematic aspect of BIM-enabled projects (Merschbrock *et al.*, 2018; Mignone *et al.*, 2016). Investigating the factors that affect the effectiveness of teams working on BIM-enabled projects has, therefore, become very relevant (Hosseini *et al.*, 2018). One prominent factor, research shows, is project complexity (Abd Jamil and Fathi, 2020; Jiang *et al.*, 2021; Merschbrock and Munkvold, 2014).

Project complexity is a determinant of project team arrangements and the type of technology to be used (Martins and Schilpzand, 2011). The paramount importance of complexity is similarly proven in construction projects (Bakhshi, 2016; Luo *et al.*, 2017a, b). Complexity serves as a critical reference for decision-makers – project managers – in construction projects (Lu *et al.*, 2015; Luo *et al.*, 2017a, b), with Senescu *et al.* (2013, p. 184), emphasising that “managing project complexity is a critical factor affecting project success”.

The evidence for the prominence of project complexity on BIM-enabled projects is well documented. According to Merschbrock and Munkvold (2014, p. 20), “the perceived business value of BIM depends on project complexity”. Complexity influences the resources, skills and competencies required for implementing BIM (Akintola *et al.*, 2017; Succar *et al.*, 2013) and defines associated risks (Jin *et al.*, 2017). The adoption of BIM introduces various complexities, including technical, cultural, social, organisational, and political aspects (Eftekhari *et al.*, 2022; Liao *et al.*, 2022). BIM is a new process to the traditional work model, and a proper adoption of it would require high technical capabilities from the main participants of the industry (Dossick and Neff, 2010; Elghaish *et al.*, 2022).

Moreover, the emergence of new project delivery methods like Integrated Project Delivery (IPD) and its variants (IPD-ish and IPD-lite) adds to the complexity of BIM adoption (Mesa *et al.*, 2016). IPD is a collaborative project delivery method that integrates people, systems, business structures, and practices into a cohesive process, harnessing the talents and insights of all participants to reduce waste and optimise efficiency throughout all phases of design, fabrication, and construction (Fischer *et al.*, 2017). IPD-ish and IPD-lite are less formal adaptations of IPD principles, designed to be more flexible and easier to implement. These methods introduce new rules and relationships among stakeholders, increasing the complexities associated with BIM-enabled projects (He *et al.*, 2017).

Additionally, the readiness and practice of the organisations may also be totally different in executing different projects (Liao *et al.*, 2020). Last but not least, countries and even state governments adoption of BIM for publicly funded projects are completely different as some mandate the adoption of BIM (McAuley *et al.*, 2017) while others adopt a wait-and-see attitude (Juan *et al.*, 2017) or see BIM adoption as an extra effort (Liao *et al.*, 2017).

Given the above observations, the importance of measuring complexity, both objectively and subjectively, has been increasingly recognised. Consequently, researchers have pursued developing methods to measure the complexity of construction projects (Ji *et al.*, 2018). Nevertheless, research on metrics for measuring complexity in construction projects remains limited (Luo *et al.*, 2017a, b). For BIM-enabled projects, the now-available knowledge on measuring complexity is skeletal. Furthermore, current measurement methodologies are not necessarily applicable to BIM-enabled projects. That is, project complexity is a concept, largely relying on and affected by micro-influencing factors (Lu *et al.*, 2015). Thus, methods for measuring complexity must be tailored to the specific variables at play in a particular setting (Kiridena and Sense, 2016); factors that drive complexity vary across different types of construction projects (Lu *et al.*, 2015; Luo *et al.*, 2017a, b).

This study is an attempt to address this gap in the BIM literature. In pursuit of this objective, the study takes the lead in developing a comprehensive framework that enables the measurement of complexity in BIM-enabled projects. By establishing this framework, the study provides a valuable tool for researchers, practitioners, and project stakeholders to assess and evaluate the intricacies associated with BIM implementation and its impact on project outcomes. Findings provide a link between the theoretical aspects of BIM implementation and project complexity within the domain of project management. In practical terms, the tool benefits project managers and policymakers by enabling them to measure the complexity of their projects and giving them a point of reference for designing effective managerial policies for BIM-enabled projects informed by the concept of complexity.

2. Contextual and literature background

Project complexity can be understood as an intricate arrangement of varied interrelated parts, where these parts can change and evolve constantly, impacting project objectives (Bakhshi *et al.*, 2016). Vidal *et al.* (2011, p. 1101) referred to project complexity as "the property of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given reasonably complete information about the project system.". However, there is no consensus on the definition of complexity (Eftekhari *et al.*, 2022).

Floricel *et al.* (2016) highlight that project complexity influences the managerial capacity to predict structural and dynamic complexity. Structural complexity arises from component interactions producing unexpected effects that cannot be explained or deduced, while dynamic complexity represents processes that generate unpredictable change in systems (Daniel and Daniel, 2018). Complex systems science challenges traditional linear approaches, advocating for the recognition of dynamic interactions and emergent behaviours that define complex systems. Within this framework, two pivotal dimensions of complexity emerge: objective and subjective (Efatmaneshnik and Ryan, 2016).

Objective complexity serves as a foundational metric, offering a quantitative measure of a system's minimal description size (Morin, 1992). Unlike subjective complexity, objective complexity is independent of any observer's perspective. However, its evaluation is influenced by the domain, context, and specific objectives or goals associated with the system (Burachik *et al.*, 2023).

Conversely, subjective complexity introduces a nuanced perspective, emphasising the observer's role in complexity evaluation (Jackson, 2015). Subjective complexity quantifies a system's deviation from a selected reference of simplicity. This deviation is contextual and dependent on the observer's choice of a reference model. Subjective complexity is intrinsically linked to the notion that comprehending complexity necessitates a foundational understanding of simplicity (Burachik *et al.*, 2023). Each subjective viewpoint is distinct, defined by a subjective simplicity that establishes a pattern known as reference simplicity. The subjective complexity, a measure of the distance from this reference simplicity, acquires significance relative to a given context, subject, and viewpoint. It is important to note that unfamiliarity and lack of knowledge are not considered in this aspect (Bakhshi, 2016). This study leverages experts' opinions to address the subjective complexity of BIM-enabled projects.

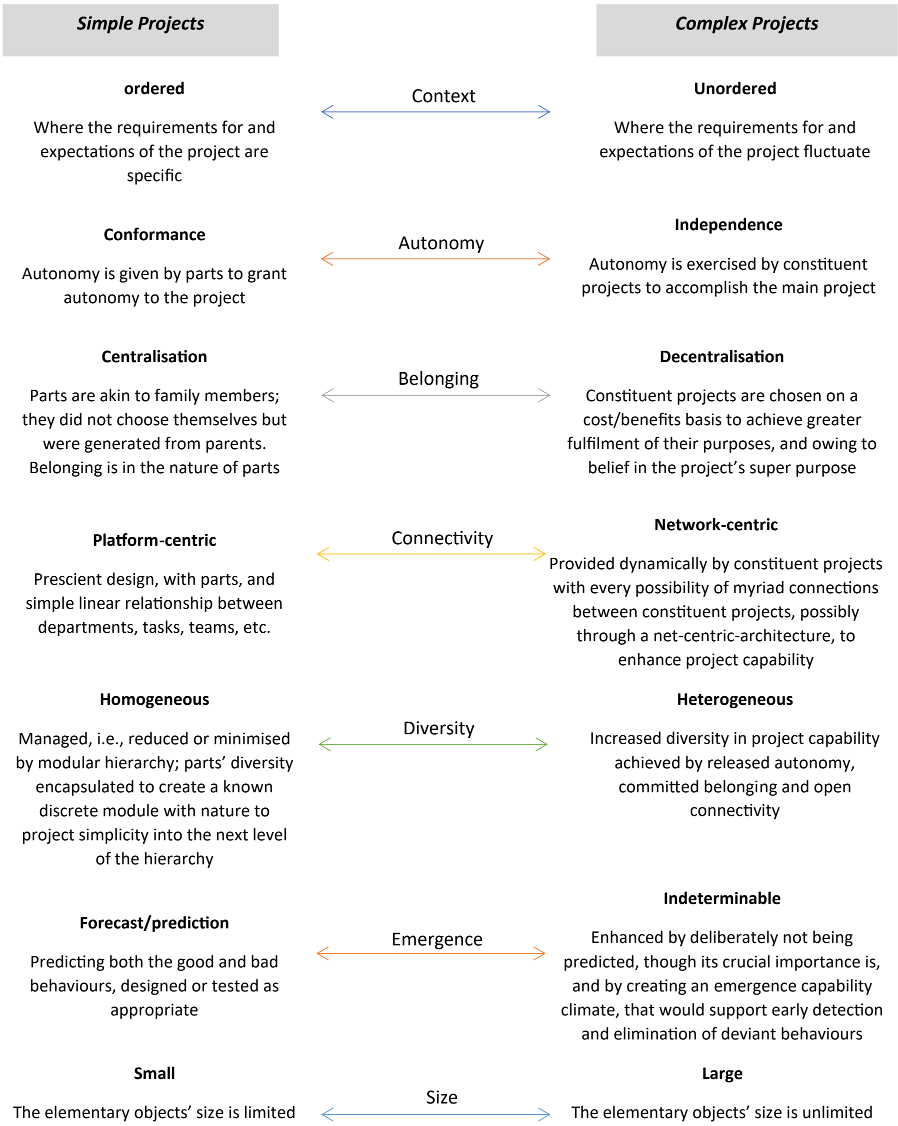
Past research has provided frameworks for modelling and evaluating complexity in the realm of project management context (Baccarini, 1996; Bakhshi *et al.*, 2016; Gorod *et al.*, 2021; Vidal and Marle, 2008). This topic has also garnered significant attention among scholars in the BIM literature. Efforts have been made to explore, for instance, the relationship between complexity and BIM performance (Crowther and Ajayi, 2021; Jiang *et al.*, 2021), the challenges of BIM implementation (Koseoglu and Nurtan-Gunes, 2018; Vass and Gustavsson, 2017), the interplay between project complexity and communication (Senescu *et al.*, 2013), BIM interoperability (Shirowzhan *et al.*, 2020), BIM adoption (Charlton *et al.*, 2020; Doumbouya *et al.*, 2016), and the evaluation of complexity (Liao *et al.*, 2022; Naveed and Khan, 2022). While these contributions are noteworthy, there remains a gap in the literature regarding a framework for assessing BIM-enabled project complexities. This paper aims to address this gap by proposing a metric-based framework to understand and assess the complexity of BIM-enabled projects.

Project complexity can be assessed using predefined scales (see Figure 1). Boardman and Sauser (2006) proposed a framework extended by Bakhshi (2016), who introduced seven complexity drivers: diversity, emergence, belonging, autonomy, context, connectivity, and size. This framework, referred to as DEBACCS, provides a solid foundation for measuring the level of complexity in projects and serves as the theoretical underpinning for this research, as described below.

(1) *Diversity:* Diversity has its common definition of requisite variety, that is, differentiation parsimony that creates system heterogeneity (Sauser *et al.*, 2009) and enables it to produce responses, adapt and co-evolve in a changing environment. Diversity creates necessary heterogeneity that often leads to the emergence of innovations in the course of a project; however, it requires additional effort and resources to manage; for example, it significantly increases coordination costs (Page, 2010). BIM-enabled projects may involve a diverse range of stakeholders and specialised software tools (Akintola *et al.*, 2020; Zomer *et al.*, 2021). The integration of these various tools and stakeholder knowledge can be associated with project complexity (Sacks *et al.*, 2010). However, it can also provide opportunities for innovation and problem-solving when managed effectively (Kensek and Noble, 2014; Succar, 2009).

(2) *Emergence:* The appearance of new properties and behaviours in the course of development or evolution is considered emergent (Ireland *et al.*, 2015). Project emergence is the result of the inability of the management systems to produce a good model of the production systems, as the production sub-systems themselves and their interactions change and evolve over time (Daniel and Daniel, 2018). As a result of this, unexpected project outputs and outcomes emerge, such as innovations, changes in scope, stakeholders and so on (Mani *et al.*, 2022; Papadonikolaki and Wamelink, 2017).

(3) *Belonging:* Belonging is the ability to accept and contribute goal-directed actions with respect to another entity. In the complex project context, constituent teams, departments, sub-contractors and partners choose to belong to the project not only on a cost-benefit basis but also in order to cause greater fulfilment of their own purposes, often because they believe in the project supra purpose and willing to contribute. In other words, "This choice is based on [the system's] own needs/beliefs and/or fulfilment" (Gorod *et al.*, 2008, p. 23). The sense of belonging among project stakeholders can be enhanced by fostering a collaborative and transparent work environment. BIM platforms can support this by providing a common digital workspace for sharing project information and enabling real-time collaboration (Chuang and Yang, 2023; Succar and Kassem, 2015). This can encourage stakeholders to actively participate and contribute to the project's success.



Source(s): Bakhshi (2023)

Figure 1. Project complexity drivers and their characteristics

(4) *Autonomy:* Autonomy is exercised by constituent departments, teams or partners in order to fulfil the purpose of the project; the ability to make independent choices. In the context of project management, autonomy is exercised by constituent departments, teams, or partners to accomplish the purpose of the project. This often raises the question of who is responsible for project requirements development, feedback and corrective actions when a project exhibits emergent behaviour (Monarch and Wessel, 2005). In BIM-enabled projects, the degree of autonomy among

different teams or partners may be affected by the level of standardisation and the adoption of common protocols and processes (Davies *et al.*, 2017; Schimanski *et al.*, 2021). A higher degree of standardisation and adoption of shared BIM standards and protocols can facilitate more effective decision-making and reduce the potential for conflicts and misunderstandings among project stakeholders (Patacas *et al.*, 2020; Sacks *et al.*, 2016).

(5) *Context:* The context of a project is related to the nature, scope, and environment of the organisation, where the needs and expectations of the project are met (Cicmil, 1997; Snowden and Boone, 2007). Project complexity is often associated with high uncertainty and changes in the socioeconomic and political environments (Chapman, 2016), as well as politics associated with funding, managing and governing complex project relations (Pitsis *et al.*, 2018). In the context of BIM-enabled projects, the degree of complexity may be influenced by the level of BIM adoption and the maturity of BIM technologies in the organisation (Chen *et al.*, 2023; Succar, 2009). Different levels of BIM maturity may impact the way organisations handle the complexity arising from the project environment and stakeholder expectations (Elghaish *et al.*, 2023; He *et al.*, 2017).

(6) *Connectivity:* Connectivity is defined as the capacity to form connections that benefit the entire system (Baldwin *et al.*, 2015). In the context of complex projects, connectivity is reflected in the formal and informal communication infrastructure established among project constituents. For instance, in large-scale complex projects, the ability of departments, groups, sub-contractors, and project partners to form links among each other can be described as connectivity. In such cases, centralised or decentralised governance models based on well-established rules and communication protocols are critical (Ireland and Statsenko, 2020; Rahimian *et al.*, 2022).

BIM technologies can enhance connectivity among project stakeholders by improving information sharing, communication, and collaboration (Azhar, 2011; Oraee *et al.*, 2017). BIM platforms provide a centralised digital environment for storing and exchanging project information, reducing the likelihood of miscommunication and promoting collaboration among different teams (Ali *et al.*, 2020; Preidel *et al.*, 2018). In other words, in BIM projects, connectivity can refer to the extent to which project stakeholders can effectively collaborate and communicate using BIM technologies and the level of integration between BIM tools and other project management systems (Peterson *et al.*, 2011; Rahimian *et al.*, 2022; Travaglini *et al.*, 2014).

(7) *Size:* The size and scope of a project is one of the significant factors contributing to its complexity (Bakhshi *et al.*, 2015). Large projects are often defined as megaprojects that involve multiple stakeholders, exerting a notable impact on communities, and are characterised by significant structural, political, technological and economic complexity and extended execution timeframe that make them hard to manage using conventional practices (Flyvbjerg, 2014). The size and scope of BIM-enabled projects may impact the complexity of managing and coordinating the different BIM-related tasks and processes (Akintola *et al.*, 2017, 2020). Larger projects may require more advanced BIM technologies and higher levels of collaboration among the numerous stakeholders involved (Akintola *et al.*, 2020). The extent of BIM adoption across the various disciplines and stakeholders can also contribute to the complexity of managing BIM-enabled projects (Arayici *et al.*, 2011; Mani *et al.*, 2022).

As discussed, a thorough review of the existing literature reveals a notable gap in understanding the concept of complexity, specifically in BIM-enabled projects. While previous research has explored complexity in construction projects, there is a clear dearth of knowledge and a lack of an established index to effectively measure and navigate complexity in the context of BIM-enabled projects. This gap underscores the motivation for the present study, which aims to bridge this critical deficiency by developing a comprehensive metric-based framework. The following methodology section outlines the systematic approach adopted to achieve this objective, detailing the processes of expert panel selection, data collection, analysis, and complexity factor extraction.

3. Research design and method

3.1 Research design

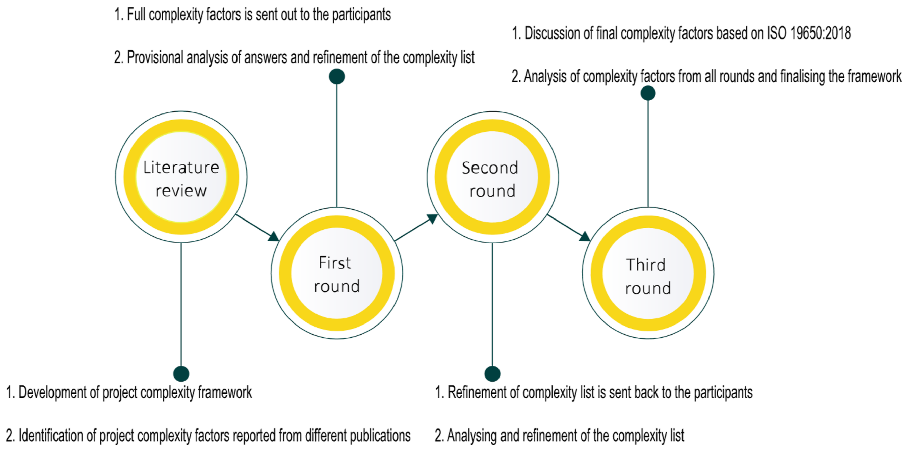
The Delphi method was adopted to achieve a consensus among experts on the complexity factors associated with BIM-enabled projects. That was because, according to Dalkey *et al.* (1969), this method provides the grounds for eliciting and refining group judgements. The method is specifically designed to gather and preserve 'experts' opinions (Yang, 2003). In this method, an expert panel must be defined to obtain the best information available on the topic (Filyushkina *et al.*, 2018). The key steps in this study are illustrated in Figure 2.

3.2 Expert panel selection

According to Duan *et al.* (2010), the involvement of qualified experts with a deep understanding of the issues under research is critical. The panel of 12 experts selected for this study were all BIM professionals and academics from Australia with at least two 'years of first-hand experience in implementing BIM and navigating the changes that follow adopting BIM in projects. According to Vogel *et al.* (2019), in Delphi practices, the number of respondents in this research is generally sufficient to enable consensus to be achieved. The details concerning the selected panel members are tabulated in Table 1.

3.3 Rounds and iterations

The Delphi method procedures were conducted following the guidelines established by Geist (2010). A total of three rounds were run with the panel, where the participants were introduced to the project complexity framework to provide a basis for identifying BIM-



Source(s): Authors' own work

Figure 2.
Research process

Table 1.
Profile of the selected experts

	1st round		2nd round		3rd round	
	Number (n = 12)	% of participants	Number (n = 7)	% of participants	Number (n = 4)	% of participants
Job title						
BIM coordinator	1	8	1	14	1	25
Project manager	4	33	2	28	1	25
BIM designer	3	25	1	14	–	
Academic	4	33	3	42	2	50
Years of experience						
≥10	7	58	4	58	2	50
4–9	4	33	2	28	2	50
≤3	1	8	1	14		
Gender						
Female	3	25	1	14	1	25
Male	9	75	6	86	3	75

Source(s): Authors own work

enabled project complexity factors. The following steps explain the Delphi method procedures.

Step 1. The complexity factors extracted from the study by Bakhshi (2016, 2023) forming the primary and distinctive framework of project complexity factors. Next, almost 130 project complexity factors were identified and classified within the seven meta-complexity metrics (see Appendix 1). This classification was achieved by reviewing over 420 relevant articles from project management literature.

Step 2. Round one took place in a synchronous online meeting format due to COVID-19 restrictions and began with:

(1) A short introductory workshop for the grouped experts where the basic concept of project complexity factors and factors associated with complex projects are explained.

(2) A one-hour focus discussion with participants was aimed at identifying those complexity factors that have no relationship to BIM-enabled projects.

(3) A refined list of complexity factors was then distributed to participants for further assessment and rating.

Following this, a complexity factors list was prepared for round 2 based on the expert opinions and responses and a provisional analysis of answers and refinement. At this stage, the count of factors relevant to BIM was reduced to 68.

Step 3. Round two was held synchronously online as well and began with the second meeting of the group, where experts shared their experiences and knowledge regarding complexity factor ratings and provided recommendations. In the view of the panel, the complexity factors list had to be further shortened to better contribute to the practical needs of academics and industry professionals. The list was returned to the expert panel to develop consensus among panel members, and in the final analysis, the experts agreed on 43 complexity factors.

Step 4. The final refinement and adjustment occurred in round three (again synchronous online), where the complexity factors were aligned to comply with specifications for information management regarding BIM-enabled projects according to ISO 19650 series, 2018. As a result of this process, the identified 43 project complexity factors were merged and collapsed into a final 34 factors. This list provided the basis for further expert consideration as to which were directly relevant to impacting the complexity of BIM-enabled projects. This finalised list of 34 factors was then returned to panel members who had partaken in round 2. They were tasked with evaluating the list to assess which factors did indeed impact BIM-enabled project complexity. Four participants were involved in this final stage, and the outcomes of their deliberations are tabulated in Figure 3. Additionally, the details of the final round statistics are provided in Appendix 2.

3.4 Ensuring the reliability and validity of the Delphi method

Although the reliability and validity of qualitative research can pose significant challenges, we took the necessary steps to ensure our research findings are robust and credible (Noble and Smith, 2015). As proposed by Aghimien *et al.* (2020) and Landeta (2006), we implemented the following measures: (1) all experts were selected based on their high degree of motivation to ensure their maximum effective contribution. (2) ensured all panel experts were thoroughly familiar with the Delphi process and the basic concept of complexity science. (3) a detailed and well-explained instruction was provided to the panel members about the process and how consensus would be achieved. (4) an induction session was conducted to highlight fundamental concepts and emphasise the importance of member participation. (5) while a pilot application was conducted to improve the precision and comprehension of the questionnaire, all experts were encouraged to provide comments and feedback on every question if needed. By taking these steps into account, we ensured that the research findings are representative of the collective opinions in the field.

4. From data to findings

Seven participants were involved in this final stage, and the outcomes of their deliberations are tabulated in Figure 3. The primary objective of this iterative process was to facilitate consensus-building among the experts and ascertain the level of agreement. To achieve this, participants were asked to provide their opinions on the extent to which selected complexity factors may impact the performance of BIM-enabled projects using a 5-point Likert scale. The scale included options such as “strongly agree,” “agree,” “neutral,” “disagree,” and “strongly disagree.” Subsequently, the level of consensus was calculated based on their responses. Thirty-four factors stand out, and a summary of these is discussed here under the seven complexity meta-factors. See Figure 3 and Table 2.

4.1 Project context

Project context refers to the circumstances under which projects are delivered, ranging from issues such as local characteristics, regulation jurisdictions, contract specifications and the like. See Table 2.

Eight contextual items were identified as impacting the complexity of BIM-enabled projects, two of which all experts agreed are critical, scoring 100%. These are: (1) local laws and regulations, which have the capacity to interfere with or ease the circumstances under which projects are delivered, and (2) the institutional structure of the company delivering the project (whether centralised and hierarchical or decentralised and agile) can present barriers and bureaucratic hurdles raising project complexity. The other six factors were: (1) the importance of the project (and therefore exposure of the project) to external interest groups

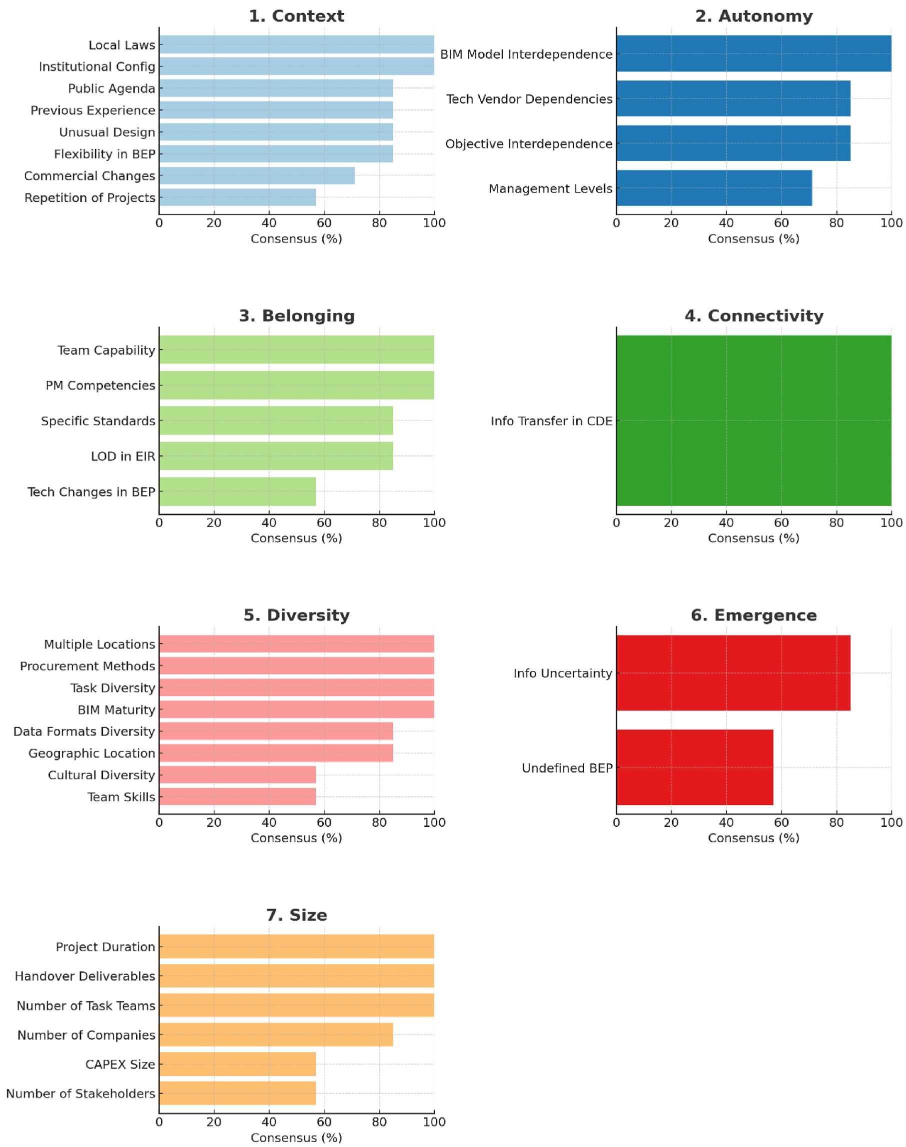


Figure 3. Complexity factors of BIM-enabled projects with expert consensus levels, aligned with ISO 19650 series (2018)

Note(s): Bim Execution Plan (BEP), Employer Information Requirements (EIR), Level of development (LOD), Common Data Environment (CDE), Capital expenditures (CapEx)
Source(s): Authors' own work

(85%); (2) the extent of previous experience of critical employees in the type of work undertaken (85%); (3) the complexity and uniqueness of the 'project's design (85%); (4) and related to design, the flexibility inherent in the design to accommodate change as the project progresses (85%); (5) the degree to which the components (and other factor inputs) were vulnerable to change, short supply or discontinuity (71%); and finally, (6) and somewhat

Table 2. BIM-enabled project complexity factors definition

Dimension	Complexity factor	Description
Context	- Commercial changes in the BEP during the project (new partners, team, process, etc.) - Degree of flexibility in BEP (in scope, process, organisation . . .) - Unusual type of design - Institutional configuration - Repetition of similar type of projects - Previous experience with parties involved - Significance on public agenda - Local laws and regulations	- Depending on the contract type, at different stages of a project, the supplier/main contractor would engage new parties such as new sub-contractors, consultants, etc. These changes require adjustment of the BEP to define new roles and processes - Construction projects can be subject to change in scope, organisation, and process due to financial interests, technical challenges, etc. This requires consideration of flexibility in the initial BEP. - Institutional configuration for BIM implementation in projects varies from a country to another depending on regulations, standards, and guidelines - Unusual designs often require complex structures and construction process, and this requires advanced skills and software platforms - In nature, construction projects unlike manufacturing works are less likely to be repetitive - Having previous experience with the parties involved smoothens the communication of project information in BIM space and reduces the time for alignment - BIM enables better awareness of public in projects by presenting virtual status of projects - Local and national laws can be challenging as some countries like the UK has mandatory and detailed regulations for implementation of BIM in the projects while others have provided guidelines for such a practice
Autonomy	- Levels of management are involved in project decision-making - Interdependence of objectives/interests among stakeholders - Dependencies on technology vendors - Interdependence between BIM models	- Execution of BEP can be managed by a BIM manager or require having managers for separate teams - Depending on the contract type, the involved stakeholders may have varying interests such as cost, time, and quality - Depending on the scope of BEP, BIM-enabled projects massively depend on technology vendors and their products for execution of projects from the scratch to operation phases - BIM models are interdependent and a change to one model (e.g. architectural design model) will be applied to the others (structural design model) and requires a fine coordination between the teams to apply required adjustments
Belonging	- Technological changes in the BEP during the project - Level of development (LOD) in EIR - Specific requirements/standards - Project Manager competencies - Technical capability of the teams	- Most BIM software undergo simple to major changes in their new versions every year. This might have a significant impact on projects with extensive timeline. Also, change of software requirement by the stakeholders can cause a major issue due to data interoperability problem among software products - The LOD requested by employers impact the cost, process, and implementation of BEP. For instance, LOD 500 requires more detailed design and construction compared to LOD 300 - Employers may ask in the EIR for specific requirements for the operation phase of the projects or ask to satisfy BIM standards of another country when there is no local regulation or guideline - Project manager competency in operating BIM models can have a great impact in better coordinating and execution of BEP. - Since the teams are developing and executing BIM models, their technical Capacity is essential

(*continued*)

Table 2.

Dimension	Complexity factor	Description
Connectivity	- Capacity of transferring information in the Common Data Environment (CDE)	- The CDE can host small to large volume of data and it becomes a major challenge when transferring larger volumes from one server to another or uploading to/downloading from a cloud server in absence of high-speed internet connection
Diversity	- Organisational skills of the team members (e.g. communication and time management) - Geographic location of the stakeholders (and their mutual disaffection) - BIM maturity level in BEP - Diversity of tasks in BEP - Variety of culture and language in teams - Variety of procurement methods - Variety of data formats in Employer Information Requirements (EIR) - Multiple project locations	- BIM facilitates communication of the team members as they can communicate technical issues through models stored in CDE. However, this require proper skills and trainings among team members - BIM-enabled projects facilitate engagement different stakeholders of the projects regardless of their geographic locations. However, this require timely updating of the project progress in the BIM models - Complexity of the activities increases in higher levels of BIM maturity. For instance, BIM maturity level 1 includes 3D CAD for concept work and 2D drawings of for documentation and construction while maturity Level 2 requires collaborative working by having in place an information exchange system and process - Depending on project size, number of involved teams and their size, BIM maturity level, etc. diversity of the tasks would vary - Diversity of written language used for communication among teams can impact efficiency of the teams as all communications are stored in a digital model - BIM-enabled projects can have similar variety of the traditional construction procurement methods such as traditional lump sum contracts, design and construct contractsetc. - The BIM file types are mainly associated with software developer. EIR requiring data formats of varying vendors can lead to extensive work in exporting data and detection of errors in transferring data - BIM is currently being used in large construction projects and it is likely to involve multiple locations
Emergence	- Unknown /poorly defined BEP - Information uncertainty	- Poor BEP developed lead to delays in delivery of projects, redundancies, rework, or gaps in the flow of information - Uncertainty in design information would lead to a large number of requests for information (RFI) by the constructors and accordingly delay in projects
Size	- Number of stakeholders in the BIM Execution Plan (BEP) - Number of companies/projects sharing their resources - Number of task teams in the BEP to be coordinated - Number of handover deliverables in the BEP - Largeness of CAPEX (Capital expenditures) - Duration of the project	- BEP can include a range of design team members to contractor team and facility manager - Companies involved in BIM enabled project are usually medium to large size companies that simultaneously use their resources in multiple projects - Task teams are any teams assigned to complete different types of tasks such as architectural design, structural design, etc. and depending on the client and project specific requirement, new task teams might be required - Handover deliverables in BEP can be EIR, CDE, BIM model of project (in the LOD requirement of the client), etc. - BIM enabled projects are medium to large size in terms of capital expenditure - One of the advantages of using BIM in the projects is to reduce the project duration which at the same time demands an accurate level of scheduling and planning

Note(s): Bim Execution Plan (BEP), and Employer Information Requirements (EIR)
Source(s): Authors own work

related to previous experience, the degree to which the current project mimics or repeats earlier similar projects. See Figure 3.

4.2 Diversity

Diversity refers to the degree of difference experienced across the various contributing factors involved in project delivery. These include items such as range of workforce skills, variety of languages spoken, data formats, number of locations, etc. See Table 2.

There are also eight diversity-related complexity items that have the potential to impact BIM-enabled projects. A full four of these were unanimously assessed as critical, scoring 100%. First, an increase in the number of locations involved in the delivery of a project heightens complexity. Similarly, the number of procurement sources also correlates with complexity increase. Third, the range of tasks to be undertaken in BIM-enabled projects raises complexity. Finally, the level of sophistication and integration in which the BIM software is embodied in the project also exacerbates complexity. This last point is ironic and speaks directly to the ultimate dilemma of BIM. While, on the one hand, BIM is used to streamline and better enable project delivery, it is itself a factor that adds to project complexity. BIM contributes to the problem it is solving, and it is again why an understanding of the specific factors impacting BIM-enabled complexity is necessary as a prerequisite to offsetting BIM handicaps.

A further four factors were also identified by experts, though not unanimously. First, data formats can exacerbate complexity, especially where a wide range is used (85%). Second, it is related to geographical dispersion, but here in regard to stakeholders, where stakeholders were not co-located, complexity is understood to increase (85%). Third, a wide range of cultures and languages inherent to the project workers and managers adds to uncertainty, misunderstanding, erosion of trust, and complexity (57%). Finally, related to culture are interpersonal and organisational skills, the lack of which again inflates human resource difficulties and complexity (57%). See Figure 3.

4.3 Size

Size refers simply to the measurable dimensions of the project. Items such as the number of people involved, both as clients and contractors, duration of the project, number of contractors and extent of deliverables. See Table 2.

Six factors related to project size are instrumental in adding to BIM-enabled project complexity. Three of these are agreed by all experts to be critical, scoring 100%. As a 'project's duration increases, so directly too does the 'project's complexity. Second, as the number of project teams increases, so too does the complexity inherent in the interfacing between BIM project teams. Similarly, complexity rises in proportion to the number of discrete deliverables to be completed in relation to the overarching project package. A further three factors were also identified by experts as contributing to complexity, but agreement as to their impact was not unanimous. First, complexity can be expected to increase as the number of companies party to the project (subcontractors and suppliers, etc.) increases (85%). Similarly, complexity grows as the number of stakeholders and interest groups rises (57%). Finally, as the CAPEX increases, so too does complexity (57%). See Figure 3.

4.4 Belonging

Belonging broadly refers to the alignment of the input factors to the project and their suitability for executing the tasks at hand. Here, we refer to matters such as the competence of the project leaders, the experience and know-how of the workers involved, as well as the suitability and compatibility of technical interventions and machinery brought to bear. See Table 2.

Five items contribute to the complexity of projects, falling under the rubric of belonging. Two of these were unanimously assessed by experts as critical, scoring 100%. Where the technical ability of teams falls short, complexity is compounded. Similarly, to the extent that the project manager lacks the requisite expertise to oversee and coordinate and by extension execute leadership effectively, so too will uncertainty, problems and complexity increase.

A further three factors are: (1) range of specific requirements to the project (85%); (2) level of project development (85%); and (3) technical changes that occur along the way as the project is delivered (57%). As each of these factors increases, so too does BIM-enabled project complexity. See Figure 3.

4.5 Autonomy

Autonomy refers to the degree to which all the resources – human, technical, and material – can deliver their contributions without dependency, interference, or impact from those other resources that are also engaged in project delivery. See Table 2.

Four factors related to the autonomy of project inputs add to project complexity. One only, however, was unanimously assessed by experts as critical, scoring 100%. That element was the degree to which the various BIM models used on a project were interdependent. Projects where different BIM platforms are used inflame complexity to the extent they are required to communicate with each other. As a corollary, different BIM platforms can be utilised relatively effectively when operated independently; however, such practice dilutes the potential effectiveness of the BIM-enabled project doctrine.

Technology has been variously identified as both mitigating or adding to project complexity, depending on how it contributes. Where a project is dependent on the technology provided by third-party vendors, such dependency can adversely affect project complexity (85%). Similarly, where a project has many and varied objectives (as can be the case between client and contractor in PPPs), this too amplifies project complexity (85%). Finally, an increase in managerial levels (with consequent increased layers in decision-making and approvals) also adds to complexity (71%). See Figure 3.

4.6 Emergence

Emergence refers to those elements affecting a project that remain undefined but which will ultimately shape the project outcome. Designs may be incomplete, the scope undecided, or technologies involved are still being developed. See Table 2.

Two factors related to emergence were assessed as contributing to BIM-enabled project complexity, but neither was identified unanimously by all experts as critical. Information uncertainty can delay or misdirect projects, adding to complexity (85%), while generally poorly defined or changing project goals will similarly compound confusion, adding again to complexity (57%). See Figure 3.

4.7 Connectivity

Connectivity is, in many ways, what BIM promises to provide, and this refers to the extent to which all parties to a project have access to relevant, accurate and timely information. See Table 2.

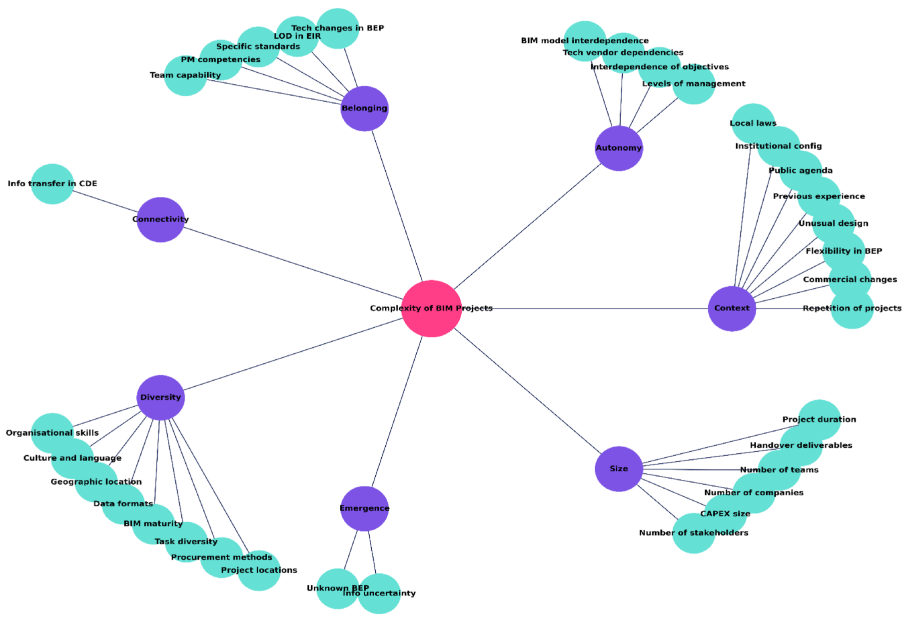
Only one item was identified as contributing to the complexity of BIM-enabled projects in relation to connectivity. That factor was the Capacity of project information nodes (BIM platforms) to effectively and accurately exchange relevant project intelligence. All experts, however, unanimously agreed that this one factor critically impacted project complexity, scoring 100%. See Figure 3.

5. Discussion

5.1 The framework

This study examined the factors contributing to the complexity of BIM-enabled construction projects. The complexity assessment studies in BIM-enabled projects are just emerging (Liao *et al.*, 2022), and the current study is the first in its kind to unearth 34 index factors in seven categories that are contributing to the complexity measurement of BIM-enabled construction projects (Figure 4). All 34 factors resented in Figure 4 were agreed by more than 50% of the experts following the approach taken by Duan *et al.* (2010).

The result of this study has some implications. Firstly, it is noticed that the BIM-enabled projects require several context-wise complexity assessment factors as items specific to BIM settings. BIM regulation and implementation plans vary from one country or state to another (Charef *et al.*, 2019). In addition, it is perceived from the results of this study that industry-based institutions that are standardising the BIM adoption plans have selective approaches rather than a universal approach. Having that said, the ISO 19650 standard is an international standard for managing information over the whole life cycle of a built asset using BIM. It contains all the same principles and high-level requirements as the UK BIM Framework and is closely aligned with the UK 1192 standards. Regarding publicising project progress to the relevant stakeholders, BIM has significant potential in presentation compared to traditional approaches. While this is a major advantage, the publicising level differs from one project to another, which can increase or reduce the complexity of BIM-enabled projects. In addition, the flexibility of BEP is another major contributor to the complexity of the projects. Depending on the availability of material, technology, expertise, etc., the scope and design of the projects might face variation during the project execution phase and having flexibility in the BEP considering such conditions would reduce the complexities. Lastly, the organisational experience in delivering BIM-enabled projects



Source(s): Authors' own work

Figure 4. Complexity factors framework for BIM-enabled construction projects

allows for the smoother execution of the projects as the system components can optimise the process over time.

Diversity aspects are also highly decisive in defining the complexity of the BIM-enabled projects. In BIM-enabled construction projects, teams comprising diverse members from specialist organisations require maintaining collaboration among members from diverse disciplines, organisations, cultural backgrounds, and even geographical locations has proved to be complex (Oraee *et al.*, 2019). Also, the procurement method for the delivery of projects that determines the allocation of risks and responsibilities can be diverse. Some procurement methods, such as the alliancing approach or integrated project delivery (IPD), have been shown to reduce the complexities in BIM-enabled projects (Holzer, 2015). The IPD and alliancing approaches foster collaboration among all stakeholders from the project's inception, which helps in aligning goals, sharing risks, and responsibilities. This collaborative environment can streamline decision-making processes, reduce conflicts, and enhance the integration of BIM technologies, thereby mitigating complexities. Lastly, BIM's technical diversities include having different data formats in the same project and tasks defined in BEP can be diverse. Previous studies argue that interoperability challenges with software packages lead to additional tasks (Jeppesen *et al.*, 2018) and since several vendors in the BIM market satisfy the needs of diverse tasks, transferring data across software packages becomes complex.

Although time and cost are traditionally known as the major factors defining the size of construction projects, the current study discovered that in BIM-enabled projects, other sizable complexity factors such as number of tasks, stakeholders, and deliverables in the BEP as well as number of companies/projects sharing their resources are considerable. As of the deliverables, the LOD can vary from 100 to 500 depending on the project lifecycle (e.g. LOD 100 at the conceptual design stage, LOD 200 at the preliminary design stage, LOD 300 at the detailed design stage, LOD 400 at the construction stage, and LOD 500 at the as-built stage). Also, the recipient of each design stage can vary depending on the size of the stakeholders involved, and that can define the number of tasks required to accomplish each stage. The competence of project leaders, the technical capability of the team, LOD and specific requirements in the EIR, along with variations to the BEP in the project lifecycle, are identified as belongingness complexity measures in the current study. The skills and capabilities of the project leader or in the case of BIM projects, the BIM manager, has a critical role in successful delivery of the project. BIM manager is at the centre of the BEP and is responsible for training the personnel and management of skills (Ahmadi Eftekhari *et al.*, 2022; Uhm *et al.*, 2017). Also, it is important to have an EIR that is structured well to ensure that the right information is available to optimise running costs and utility usage over their entire lifecycle (Ashworth *et al.*, 2019). Thus, the process of developing EIR requires a decent understanding of facility managers and/or clients regarding BIM process.

Autonomy complexity factors in BIM-enabled projects are mostly found around the dependency of the components on each other, while the previous studies indicate that collaboration is a key aspect of BIM adoption process (Oraee *et al.*, 2019). The dependencies in this process involve between BIM models (i.e. structural design depends on architectural design, etc.) and technology vendors to avoid interoperability complexities. As a highly project-based industry, construction requires collaboration between multiple organisations (Cao *et al.*, 2018). To avoid confusion between new roles (e.g. BIM manager) and traditional roles (e.g. project manager), further attention needs to be paid to defining BIM roles and responsibilities. In this regard, Akintola *et al.* (2017) suggest that project managers can be trained in BIM technology to become BIM managers.

As of the emergence aspects of complexity model, there are only two factors identified in the current study. Efficient and fast information circulation is one of the strongest points of BIM; hence this process can be hindered by the number of RFIs submitted for incomplete models. Although model checker tools are often employed to detect the errors in the models (Solihin and Eastman, 2015), the process is prolonged by the number of identified errors, which require to be addressed by a particular member of BIM team.

Lastly, the current identified capacity of transferring information in the CDE is the only factor under the connectivity complexity aspect. With the recent developments in BIM software, especially using laser scanners, the volume of files can be significantly huge (i.e. a point cloud data file can be up to 60 Gigabytes in size). Fortunately, cloud storage enables the transfer of files through an internet connection (Onungwa *et al.*, 2021), which saves the usage of physical transfer of data (i.e. hard drives). Thus, the internet connection speed might add some complexities to this process as not many countries have access to high-speed internet, and even with having that, it would take a long time to transfer a large file from a user to CDE.

5.2 Theoretical contributions

The findings of this study make significant contributions to the BIM body of knowledge. This study introduces the DEBACCS Framework, a comprehensive model designed to understand and evaluate the complexity within a system, particularly in the context of BIM-enabled projects. The DEBACCS acronym stands for seven key criteria: Diversity, Emergence, Belonging, Autonomy, Connectivity, Context, and Size. These criteria represent the various dimensions essential for gauging a project's complexity.

The name 'DEBACCS' is metaphorically akin to the intricate weaving of a complex fabric or the interrelated components of a sack. This analogy is apt, as complexity in this framework is conceptualised as a collection of elements that, while distinct, form recognisable and interconnected patterns. Just as a sack holds and unifies diverse items, the DEBACCS framework encapsulates the multifaceted aspects of complexity in a cohesive manner (Bakhshi, 2023).

By incorporating the DEBACCS Framework into project complexity, this study contributes valuable insights and a structured approach to understanding and assessing the complexity of projects. It offers a comprehensive set of criteria that encompass various aspects of complexity, allowing researchers and practitioners to evaluate and compare the complexity levels of different BIM projects. Furthermore, these theoretical implications will assist researchers, project managers, and other stakeholders in developing a deeper understanding of the complexities associated with BIM-enabled projects.

5.3 Practical implications

The results of this study have several practical implications for BIM-enabled projects. Firstly, the study identified 34 factors in seven categories that contribute to the complexity of BIM-enabled projects. These findings provide a basis for identifying and measuring BIM-specific complexity degrees that can be used by industry-based institutions to standardise BIM adoption plans. Secondly, the study identified context-wise complexity assessment factors that are specific to BIM settings. This information is critical in developing BIM regulation and implementation plans that are specific to a particular country or state. Thirdly, the study emphasised that diversity aspects are highly decisive in defining the complexity of BIM-enabled projects. Therefore, teams comprising diverse members from specialist organisations require collaboration among members from diverse disciplines, organisations, cultural backgrounds, and even geographical locations to reduce the complexities of BIM-enabled projects. Lastly, the study identified factors such as the number of tasks, stakeholders, and deliverables in the BEP as well as the number of companies/projects sharing their resources, which are considerable in BIM-enabled projects. This information is critical in determining the allocation of risks and responsibilities in the procurement method for the delivery of BIM-enabled projects.

In addition, the study revealed that the skills and capabilities of the BIM manager play a critical role in the successful delivery of BIM-enabled projects. Therefore, it is essential to train personnel and management in BIM processes to enhance their skills and capabilities. Furthermore, the study emphasised the importance of having an EIR that is structured well to ensure that the right information is available to optimise running costs and utility usage over the entire lifecycle of a built asset. Thus, facility managers and/or clients should have a decent understanding of the BIM process to develop an effective EIR.

Overall, the findings of this study provide a comprehensive understanding of the factors contributing to the complexity of BIM-enabled projects. The theoretical and practical implications of these findings will assist project managers, BIM managers, scholars, and other stakeholders involved in BIM-enabled projects in developing effective strategies to reduce the complexities associated with BIM-enabled projects.

6. Conclusion

In response to the pressures of having to deal with the rising complexity of construction projects, BIM has been invoked as a saviour of sorts, being a platform with the potential to absorb the multiplicity of activities, from design to execution and beyond of construction projects, integrate these and facilitate the timely and accurate dissemination of data, information and knowledge to all relevant parties. That is the rhetoric at least around which BIM is promoted, and in large part, this assessment of BIM's value is now taken for granted, with governments such as the UK mandating the use of BIM in project construction works.

The irony, however, is that while BIM indeed offers the very real potential of better managing the complexity of construction projects, its application itself adds an extra layer of complexity. There is much evidence supporting the proposition that BIM has the potential to compound project difficulties and confusion when not properly utilised. And proper utilisation is no mean feat. It requires a high level of expertise of all its various users on a project and with strong leadership and coordination of parties, as well as an organisational structure that fully aligns with a BIM-based work culture. Few organisations have in fact reported complete satisfaction in their capacity to integrate BIM into their operational workflows. BIM thus presents challenges even as it delivers improved project outcomes.

This background has triggered the current investigation that has been conducted and reported here. While complexity may seem an intangible concept, it has been defined and it has been investigated, with a plethora of some 130 factors described across 420 peer-reviewed publications. While offering an important insight into the problem, this list of factors is itself complex and is too large to be practical. Moreover, given that the utilisation of BIM is understood to drive down the overall complexity of projects (albeit, perhaps also adding somewhat to them), this begs the question of what, then, are the most critical factors that characterise and add to the complexity of BIM-enabled projects?

In answering that question, an expert industry panel was solicited to partake in a comprehensive multi-stage Delphi-driven process. Participants were presented with an initial list of potential factors and over a set of discussions and iterations, condensed this down to a manageable 34 factors that specifically impacted the complexity of BIM-enabled projects. That list was presented in a framework of meta-factors, as developed in earlier research, comprising the elements of (1) project context, (2) belonging, (3) diversity, (4) size, (5) connectivity, (6) emergence, and (7) autonomy.

The important insight gained in this study lies in identifying both the spread of complexity factors across these seven partitions, and establishing the degree to which complexity factors were assessed as impacting BIM-enabled project complexity. 27 of the 34 factors (80%) occur in the first four meta-factors only (project context, belonging, diversity and size). Moreover, of the 13 complexity factors that were unanimously agreed by expert informants as being critical, 7 of these (54%) fell within the two categories of project size and diversity. That is, complexity in projects heavily derives from variables such as the scale of elements involved (duration, range of tasks, number of deliverables), combined with the degree to which resources brought to bear fail to align with each other (locations involved, methods used, range of experience and inconsistent work practices).

No doubt more can and should be done to shed further light on this area of investigation. This study should be considered preliminary, noting that the sample of participant informants is relatively small. Also, the participants of this study were mainly from Australia, and these findings can be explored, interpreted, and transferred to other countries through other studies. Moreover, BIM-enabled projects are of various kinds, and distinction in that regard was not considered. Nevertheless, the findings are eye-opening and offer a ground-breaking hypothesis as to where complexity bites deepest in regard to BIM-enabled projects. This should be taken up in subsequent research to test the validity of what has been found and reported here.

References

Abd Jamil, A.H. and Fathi, M.S. (2020), "Enhancing BIM-based information interoperability: dispute resolution from legal and contractual perspectives", *Journal of Construction Engineering and Management*, Vol. 146 No. 7, 05020007, doi: 10.1061/(asce)co.1943-7862.0001868.

Aghimien, D.O., Aigbavboa, C.O. and Oke, A.E. (2020), "Critical success factors for digital partnering of construction organisations–a Delphi study", *Engineering Construction and Architectural Management*, Vol. 27 No. 10, pp. 3171-3188, doi: 10.1108/ecam-11-2019-0602.

Ahmadi Eftekhari, N., Mani, S., Bakhshi, J. and Mani, S. (2022), "Project manager competencies for dealing with socio-technical complexity: a grounded theory construction", *Systems*, Vol. 10 No. 5, p. 161, doi: 10.3390/systems10050161.

Akintola, A., Venkatachalam, S. and Root, D. (2017), "New BIM roles' legitimacy and changing power dynamics on BIM-enabled projects", *Journal of Construction Engineering and Management*, Vol. 143 No. 9, 04017066, doi: 10.1061/(asce)co.1943-7862.0001366.

Akintola, A., Venkatachalam, S. and Root, D. (2020), "Understanding BIM's impact on professional work practices using activity theory", *Construction Management and Economics*, Vol. 38 No. 5, pp. 447-467, doi: 10.1080/01446193.2018.1559338.

Ali, B., Zahoor, H., Nasir, A.R., Maqsoom, A., Khan, R.W.A. and Mazher, K.M. (2020), "BIM-based claims management system: a centralized information repository for extension of time claims", *Automation in Construction*, Vol. 110, 102937, doi: 10.1016/j.autcon.2019.102937.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K. (2011), "Technology adoption in the BIM implementation for lean architectural practice", *Automation in Construction*, Vol. 20 No. 2, pp. 189-195, doi: 10.1016/j.autcon.2010.09.016.

Ashworth, S., Tucker, M. and Druhmann, C.K. (2019), "Critical success factors for facility management employer's information requirements (EIR) for BIM", *Facilities*, Vol. 37 Nos 1/2, pp. 103-118, doi: 10.1108/f-02-2018-0027.

Asif, M., Naeem, G. and Khalid, M. (2024), "Digitalization for sustainable buildings: technologies, applications, potential, and challenges", *Journal of Cleaner Production*, Vol. 450, 141814, doi: 10.1016/j.jclepro.2024.141814.

Azhar, S. (2011), "Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry", *Leadership and Management in Engineering*, Vol. 11 No. 3, pp. 241-252, doi: 10.1061/(asce)lm.1943-5630.0000127.

Baccarini, D. (1996), "The concept of project complexity—a review", *International Journal of Project Management*, Vol. 14 No. 4, pp. 201-204, doi: 10.1016/0263-7863(95)00093-3.

Bakhshi, J. (2016), "Exploring Project Complexities and Their Problems: A Critical Review of the Literature. (Master of Philosophy)", The University of Adelaide.

Bakhshi, J. (2023), "The influence of governance and complexity on project outcomes in international development", The University of Sydney Sydney eScholarship database available at: https://hdl.handle.net/2123/32297

Bakhshi, J., Ireland, V. and Corral De Zubielqui, G. (2015), "Exploring project complexities: a critical review of the literature", *Paper presented at the AIPM National Conference*, Australia, Hobart.

Bakhshi, J., Ireland, V. and Gorod, A. (2016), "Clarifying the project complexity construct: past, present and future", *International Journal of Project Management*, Vol. 34 No. 7, pp. 1199-1213, doi: 10.1016/j.ijproman.2016.06.002.

Baldwin, W.C., Sauser, B.J. and Boardman, J. (2015), "Revisiting "the meaning of of" as a theory for collaborative system of systems", *IEEE Systems Journal*, Vol. 11 No. 4, pp. 2215-2226, doi: 10.1109/jsyst.2015.2430755.

Boardman, J. and Sauser, B. (2006), "System of systems-the meaning of of", *Paper presented at the 2006 IEEE/SMC International Conference on System of Systems Engineering*.

Burachik, R.S., Efatmaneshnik, M., Kalloniatis, A.C. and Kaya, C.Y. (2023), "Optimal organizations across many faces of complexity: synchronized networks with load-balance and minimum complexity", *IEEE Systems Journal*, Vol. 17 No. 4, pp. 5393-5404.

Cao, D., Li, H., Wang, G., Luo, X. and Tan, D. (2018), "Relationship network structure and organizational competitiveness: evidence from BIM implementation practices in the construction industry", *Journal of Management in Engineering*, Vol. 34 No. 3, 04018005, doi: 10.1061/(asce)me.1943-5479.0000600.

Chapman, R.J. (2016), "A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects", *International Journal of Project Management*, Vol. 34 No. 6, pp. 937-956, doi: 10.1016/j.ijproman.2016.05.001.

Charef, R., Emmitt, S., Alaka, H. and Fouchal, F. (2019), "Building information modelling adoption in the European Union: an overview", *Journal of Building Engineering*, Vol. 25, 100777, doi: 10.1016/j.jobe.2019.100777.

Charlton, J., Kelly, K., Greenwood, D. and Moreton, L. (2020), "The complexities of managing historic buildings with BIM", *Engineering Construction and Architectural Management*, Vol. 28 No. 2, pp. 570-583, doi: 10.1108/ecam-11-2019-0621.

Chen, Z.-S., Zhou, M.-D., Chin, K.-S., Darko, A., Wang, X.-J. and Pedrycz, W. (2023), "Optimized decision support for BIM maturity assessment", *Automation in Construction*, Vol. 149, 104808, doi: 10.1016/j.autcon.2023.104808.

Chuang, T.-Y. and Yang, M.-J. (2023), "Change component identification of BIM models for facility management based on time-variant BIMs or point clouds", *Automation in Construction*, Vol. 147, 104731, doi: 10.1016/j.autcon.2022.104731.

Cicmil, S.J. (1997), "Critical factors of effective project management", *The TQM Magazine*, Vol. 9 No. 6, pp. 390-396, doi: 10.1108/09544789710186902.

Crowther, J. and Ajayi, S.O. (2021), "Impacts of 4D BIM on construction project performance", *International Journal of Construction Management*, Vol. 21 No. 7, pp. 724-737, doi: 10.1080/15623599.2019.1580832.

Dalkey, N.C., Brown, B.B. and Cochran, S. (1969), *The Delphi Method: An Experimental Study of Group Opinion*, Rand Corporation, Santa Monica, CA, Vol. 3, p. 107.

Daniel, P.A. and Daniel, C. (2018), "Complexity, uncertainty and mental models: from a paradigm of regulation to a paradigm of emergence in project management", *International Journal of Project Management*, Vol. 36 No. 1, pp. 184-197, doi: 10.1016/j.ijproman.2017.07.004.

Davies, K., Wilkinson, S. and McMeel, D. (2017), "A review of specialist role definitions in BIM guides and standards".

Dossick, C.S. and Neff, G. (2010), "Organizational divisions in BIM-enabled commercial construction", *Journal of Construction Engineering and Management*, Vol. 136 No. 4, pp. 459-467, doi: 10.1061/(asce)co.1943-7862.0000109.

Doumbouya, L., Gao, G. and Guan, C. (2016), "Adoption of the Building Information Modeling (BIM) for construction project effectiveness: the review of BIM benefits", *American Journal of Civil Engineering and Architecture*, Vol. 4 No. 3, pp. 74-79.

Duan, Y., Nie, W. and Coakes, E. (2010), "Identifying key factors affecting transnational knowledge transfer", *Information and Management*, Vol. 47 Nos 7-8, pp. 356-363, doi: 10.1016/j.im.2010.08.003.

Efatmaneshnik, M. and Ryan, M.J. (2016), "A general framework for measuring system complexity", *Complexity*, Vol. 21 No. S1, pp. 533-546, doi: 10.1002/cplx.21767.

Eftekhari, N.A., Mani, S., Bakhshi, J., Statsenko, L. and Naeni, L.M. (2022), "Socio-technical and political complexities: findings from two case studies of large IT project-based organizations", *Systems*, Vol. 10 No. 6, p. 244, doi: 10.3390/systems10060244.

Elghaish, F., Chauhan, J.K., Matarneh, S., Pour Rahimian, F. and Hosseini, M.R. (2022), "Artificial intelligence-based voice assistant for BIM data management", *Automation in Construction*, Vol. 140, 104320, doi: 10.1016/j.autcon.2022.104320.

Elghaish, F., Hosseini, M.R., Kocaturk, T., Arashpour, M. and Bararzadeh Ledari, M. (2023), "Digitalised circular construction supply chain: an integrated BIM-Blockchain solution", *Automation in Construction*, Vol. 148, 104746, doi: 10.1016/j.autcon.2023.104746.

Filyushkina, A., Strange, N., Löf, M., Ezebilo, E.E. and Boman, M. (2018), "Applying the Delphi method to assess impacts of forest management on biodiversity and habitat preservation", *Forest Ecology and Management*, Vol. 409, pp. 179-189, doi: 10.1016/j.foreco.2017.10.022.

Fischer, M., Ashcraft, H.W., Reed, D. and Khanzode, A. (2017), *Integrating Project Delivery*, John Wiley & Sons, Hoboken.

Floricel, S., Michela, J.L. and Piperca, S. (2016), "Complexity, uncertainty-reduction strategies, and project performance", *International Journal of Project Management*, Vol. 34 No. 7, pp. 1360-1383, doi: 10.1016/j.ijproman.2015.11.007.

Flyvbjerg, B. (2014), "What you should know about megaprojects and why: an overview", *Project Management Journal*, Vol. 45 No. 2, pp. 6-19, doi: 10.1002/pmj.21409.

Geist, M.R. (2010), "Using the Delphi method to engage stakeholders: a comparison of two studies", *Evaluation and Program Planning*, Vol. 33 No. 2, pp. 147-154, doi: 10.1016/j.evalprogplan.2009.06.006.

Gorod, A., Gandhi, S.J., Sauser, B. and Boardman, J. (2008), "Flexibility of system of systems", *Global Journal of Flexible Systems Management*, Vol. 9 No. 4, pp. 21-31, doi: 10.1007/bf03396548.

Gorod, A., Hallo, L., Statsenko, L., Nguyen, T. and Chileshe, N. (2021), "Integrating hierarchical and network centric management approaches in construction megaprojects using a holonic methodology", *Engineering Construction and Architectural Management*, Vol. 28 No. 3, pp. 627-661, doi: 10.1108/ecam-01-2020-0072.

He, Q., Wang, G., Luo, L., Shi, Q., Xie, J. and Meng, X. (2017), "Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis", *International Journal of Project Management*, Vol. 35 No. 4, pp. 670-685, doi: 10.1016/j.ijproman.2016.08.001.

Holzer, D. (2015), "BIM for procurement-procuring for BIM", *Paper presented at the Living and learning: Research for a better built environment: 49th International Conference of the Architectural Science Association*.

Hosseini, M.R., Martek, I., Chileshe, N., Zavadskas, E.K. and Arashpour, M. (2018), "Assessing the influence of virtuality on the effectiveness of engineering project networks: 'Big Five Theory' perspective", *Journal of Construction Engineering and Management*, Vol. 144 No. 7, 04018059, doi: 10.1061/(asce)co.1943-7862.0001494.

Ireland, V. and Statsenko, L. (2020), "Managing complex projects and systems: a literature synthesis", *Australian Journal of Multi-Disciplinary Engineering*, Vol. 16 No. 1, pp. 93-110, doi: 10.1080/14488388.2020.1805861.

Ireland, V., White, B.E., Gandhi, S.J., Sauser, B. and Gorod, A. (2015), "Relevant aspects of complex systems from complexity theory", *Case Studies in System of Systems, Enterprise Systems, and Complex Systems Engineering*, Taylor & Francis Group, Boca Raton.

Jackson, S. (2015), "The essence of complexity: is it subjective or objective", *Research Gate*, available at: https://www.academia.edu/12369772/The_Essence_of_Complexity_Is_it_Subjective_or_Objectivelast%20time (Accessed 19 September 2024).

Jeppesen, J.H., Ebeid, E., Jacobsen, R.H. and Toftegaard, T.S. (2018), "Open geospatial infrastructure for data management and analytics in interdisciplinary research", *Computers and Electronics in Agriculture*, Vol. 145, pp. 130-141, doi: 10.1016/j.compag.2017.12.026.

Ji, W., AbouRizk, S.M., Zaïane, O.R. and Li, Y. (2018), "Complexity analysis approach for prefabricated construction products using uncertain data clustering", *Journal of Construction Engineering and Management*, Vol. 144 No. 8, 04018063, doi: 10.1061/(asce)co.1943-7862.0001520.

Jiang, H.-J., Cui, Z.-P., Yin, H. and Yang, Z.-B. (2021), "BIM performance, project complexity, and user satisfaction: a QCA study of 39 cases", *Advances in Civil Engineering*, Vol. 2021, pp. 1-10, doi: 10.1155/2021/6654851.

Jin, R., Hancock, C.M., Tang, L. and Wanatowski, D. (2017), "BIM investment, returns, and risks in China's AEC industries", *Journal of Construction Engineering and Management*, Vol. 143 No. 12, doi: 10.1061/(asce)co.1943-7862.0001408.

Juan, Y.-K., Lai, W.-Y. and Shih, S.-G. (2017), "Building information modeling acceptance and readiness assessment in Taiwanese architectural firms", *Journal of Civil Engineering and Management*, Vol. 23 No. 3, pp. 356-367, doi: 10.3846/13923730.2015.1128480.

Kensek, K. and Noble, D. (2014), *Building Information Modeling: BIM in Current and Future Practice*, John Wiley & Sons, Hoboken.

Kiridena, S. and Sense, A. (2016), "Profiling project complexity: insights from complexity science and project management literature", *Project Management Journal*, Vol. 47 No. 6, pp. 56-74, doi: 10.1177/875697281604700605.

Koseoglu, O. and Nurtan-Gunes, E.T. (2018), "Mobile BIM implementation and lean interaction on construction site: a case study of a complex airport project", *Engineering Construction and Architectural Management*, Vol. 25 No. 10, pp. 1298-1321, doi: 10.1108/ecam-08-2017-0188.

Landeta, J. (2006), "Current validity of the Delphi method in social sciences", *Technological Forecasting and Social Change*, Vol. 73 No. 5, pp. 467-482, doi: 10.1016/j.techfore.2005.09.002.

Liao, L., Teo, E.A.L. and Low, S.P. (2017), "A project management framework for enhanced productivity performance using building information modelling", *Construction Economics and Building*, Vol. 17 No. 3, pp. 1-26, doi: 10.5130/ajceb.v17i3.5389.

Liao, L., Teo Ai Lin, E. and Low, S.P. (2020), "Assessing building information modeling implementation readiness in building projects in Singapore: A fuzzy synthetic evaluation approach", *Engineering Construction and Architectural Management*, Vol. 27 No. 3, pp. 700-724, doi: 10.1108/ecam-01-2019-0028.

Liao, L., Zhou, K., Fan, C. and Ma, Y. (2022), "Evaluation of complexity issues in building information modeling diffusion research", *Sustainability*, Vol. 14 No. 5, p. 3005, doi: 10.3390/su14053005.

Lu, Y., Luo, L., Wang, H., Le, Y. and Shi, Q. (2015), "Measurement model of project complexity for large-scale projects from task and organization perspective", *International Journal of Project Management*, Vol. 33 No. 3, pp. 610-622, doi: 10.1016/j.ijproman.2014.12.005.

Luo, L., He, Q., Jaselskis, E.J. and Xie, J. (2017a), "Construction project complexity: research trends and implications", *Journal of Construction Engineering and Management*, Vol. 143 No. 7, 04017019, doi: 10.1061/(asce)co.1943-7862.0001306.

Luo, L., He, Q., Xie, J., Yang, D. and Wu, G. (2017b), "Investigating the relationship between project complexity and success in complex construction projects", *Journal of Management in Engineering*, Vol. 33 No. 2, 04016036, doi: 10.1061/(asce)me.1943-5479.0000471.

Mani, S., Ahmadi Eftekhari, N., Hosseini, M.R. and Bakhshi, J. (2022), *Sociotechnical Dimensions of BIM-Induced Changes in Stakeholder Management of Public and Private Building Projects*, Construction Innovation.

Martins, L.L. and Schilpzand, M.C. (2011), "Global virtual teams: key developments, research gaps, and future directions", in *Research in Personnel and Human Resources Management*, Emerald Group Publishing.

McAuley, B., Hore, A. and West, R. (2017), "BIM innovation capability programme of Ireland".

Merschbrock, C. and Munkvold, B.E. (2014), "How is building information modeling influenced by project complexity?: a cross-case analysis of e-collaboration performance in building construction", *International Journal of e-Collaboration*, Vol. 10 No. 2, pp. 20-39, doi: 10.4018/ijec.2014040102.

Merschbrock, C., Hosseini, M.R., Martek, I., Arashpour, M. and Mignone, G. (2018), "Collaborative role of sociotechnical components in BIM-based construction networks in two hospitals", *Journal of Management in Engineering*, Vol. 34 No. 4, 05018006, doi: 10.1061/(asce)me.1943-5479.0000605.

Mesa, H.A., Molenaar, K.R. and Alarcón, L.F. (2016), "Exploring performance of the integrated project delivery process on complex building projects", *International Journal of Project Management*, Vol. 34 No. 7, pp. 1089-1101, doi: 10.1016/j.ijproman.2016.05.007.

Mignone, G., Hosseini, M.R., Chileshe, N. and Arashpour, M. (2016), "Enhancing collaboration in BIM-based construction networks through organisational discontinuity theory: a case study of the new Royal Adelaide Hospital", *Architectural Engineering and Design Management*, Vol. 12 No. 5, pp. 333-352, doi: 10.1080/17452007.2016.1169987.

Monarch, I. and Wessel, J. (2005), "Autonomy and interoperability in system of systems requirements development", *Paper presented at the 16th IEEE International Symposium on Software Reliability Engineering*, Chicago, IL.

Morin, E. (1992), "From the concept of system to the paradigm of complexity", *Journal of Social and Evolutionary Systems*, Vol. 15 No. 4, pp. 371-385, doi: 10.1016/1061-7361(92)90024-8.

Naveed, F. and Khan, K.I.A. (2022), "Investigating the influence of information complexity on construction quality: a systems thinking approach", *Engineering Construction and Architectural Management*, Vol. 29 No. 3, pp. 1427-1448.

Noble, H. and Smith, J. (2015), "Issues of validity and reliability in qualitative research", *Evidence-Based Nursing*, Vol. 18 No. 2, pp. 34-35, doi: 10.1136/eb-2015-102054.

Onungwa, I., Olugu-Uduma, N. and Shelden, D.R. (2021), "Cloud BIM technology as a means of collaboration and project integration in smart cities", *Sage Open*, Vol. 11 No. 3, 21582440211033250, doi: 10.1177/21582440211033250.

Oraee, M., Hosseini, M.R., Papadonikolaki, E., Palliyaguru, R. and Arashpour, M. (2017), "Collaboration in BIM-based construction networks: a bibliometric-qualitative literature review", *International Journal of Project Management*, Vol. 35 No. 7, pp. 1288-1301, doi: 10.1016/j.ijproman.2017.07.001.

Oraee, M., Hosseini, M.R., Edwards, D.J., Li, H., Papadonikolaki, E. and Cao, D. (2019), "Collaboration barriers in BIM-based construction networks: a conceptual model", *International Journal of Project Management*, Vol. 37 No. 6, pp. 839-854, doi: 10.1016/j.ijproman.2019.05.004.

Page, S.E. (2010), *Diversity and Complexity*, Princeton University Press.

Papadonikolaki, E. (2018), "Loosely coupled systems of innovation: aligning BIM adoption with implementation in Dutch construction", *Journal of Management in Engineering*, Vol. 34 No. 6, 05018009, doi: 10.1061/(asce)me.1943-5479.0000644.

Papadonikolaki, E. and Wamelink, H. (2017), "Inter-and intra-organizational conditions for supply chain integration with BIM", *Building Research and Information*, Vol. 45 No. 6, pp. 649-664, doi: 10.1080/09613218.2017.1301718.

Patacas, J., Dawood, N. and Kassem, M. (2020), "BIM for facilities management: a framework and a common data environment using open standards", *Automation in Construction*, Vol. 120, 103366, doi: 10.1016/j.autcon.2020.103366.

Peterson, F., Hartmann, T., Fruchter, R. and Fischer, M. (2011), "Teaching construction project management with BIM support: experience and lessons learned", *Automation in Construction*, Vol. 20 No. 2, pp. 115-125, doi: 10.1016/j.autcon.2010.09.009.

Pitsis, A., Clegg, S., Freeder, D., Sankaran, S. and Burdon, S. (2018), "Megaprojects redefined– complexity vs cost and social imperatives", *International Journal of Managing Projects in Business*, Vol. 11 No. 1, pp. 7-34, doi: 10.1108/ijmpb-07-2017-0080.

Preidel, C., Borrmann, A., Mattern, H., König, M. and Schapke, S.E. (2018), "Common data environment", in Borrmann, A., König, M., Koch, C. and Beetz, J. (Eds), *Building Information Modeling*, Springer, Cham, available at: https://doi.org/10.1007/978-3-319-92862-3_15

Rahimian, A., Hosseini, M.R., Martek, I., Taroun, A., Alvanchi, A. and Odeh, I. (2022), "Predicting communication quality in construction projects: a fully-connected deep neural network approach", *Automation in Construction*, Vol. 139, 104268, doi: 10.1016/j.autcon.2022.104268.

Sacks, R., Koskela, L., Dave, B.A. and Owen, R. (2010), "Interaction of lean and building information modeling in construction", *Journal of Construction Engineering and Management*, Vol. 136 No. 9, pp. 968-980, doi: 10.1061/(asce)co.1943-7862.0000203.

Sacks, R., Gurevich, U. and Shrestha, P. (2016), "A review of building information modeling protocols, guides and standards for large construction clients", *Journal of Information Technology in Construction*, Vol. 21 No. 29, pp. 479-503.

Sauser, B., Boardman, J. and Gorod, A. (2009), "System of systems management", *System of Systems Engineering: Innovations for the 21st Century*, pp. 191-217, doi: 10.1002/9780470403501.ch8.

Schimanski, C.P., Pradhan, N.L., Chaltsev, D., Pasetti Monizza, G. and Matt, D.T. (2021), "Integrating BIM with Lean Construction approach: functional requirements and production management software", *Automation in Construction*, Vol. 132, 103969, doi: 10.1016/j.autcon.2021.103969.

Senescu, R.R., Aranda-mena, G. and Haymaker, J.R. (2013), "Relationships between project complexity and communication", *Journal of Management in Engineering*, Vol. 29 No. 2, pp. 183-197, doi: 10.1061/(asce)me.1943-5479.0000121.

Shirowzhan, S., Sepasgozar, S.M., Edwards, D.J., Li, H. and Wang, C. (2020), "BIM compatibility and its differentiation with interoperability challenges as an innovation factor", *Automation in Construction*, Vol. 112, 103086, doi: 10.1016/j.autcon.2020.103086.

Snowden, D.J. and Boone, M.E. (2007), "A leader's framework for decision making", *Harvard Business Review*, Vol. 85 No. 11, pp. 68-149.

Solihin, W. and Eastman, C. (2015), "Classification of rules for automated BIM rule checking development", *Automation in Construction*, Vol. 53, pp. 69-82, doi: 10.1016/j.autcon.2015.03.003.

Succar, B. (2009), "Building information modelling framework: a research and delivery foundation for industry stakeholders", *Automation in Construction*, Vol. 18 No. 3, pp. 357-375, doi: 10.1016/j.autcon.2008.10.003.

Succar, B. and Kassem, M. (2015), "Macro-BIM adoption: conceptual structures", *Automation in Construction*, Vol. 57, pp. 64-79, doi: 10.1016/j.autcon.2015.04.018.

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

Travaglini, A., Radujković, M. and Mancini, M. (2014), "Building information modelling (BIM) and project management: a stakeholders perspective", *Organization, Technology and Management in Construction: An International Journal*, Vol. 6 No. 2, pp. 1001-1008, doi: 10.5592/otmcj.2014.2.8.

Uhm, M., Lee, G. and Jeon, B. (2017), "An analysis of BIM jobs and competencies based on the use of terms in the industry", *Automation in Construction*, Vol. 81, pp. 67-98, doi: 10.1016/j.autcon.2017.06.002.

Vass, S. and Gustavsson, T.K. (2017), "Challenges when implementing BIM for industry change", *Construction Management and Economics*, Vol. 35 No. 10, pp. 597-610, doi: 10.1080/01446193.2017.1314519.

Vidal, L.A. and Marle, F. (2008), "Understanding project complexity: implications on project management", *Kybernetes*, Vol. 37 No. 8, pp. 1094-1110, doi: 10.1108/03684920810884928.

Vidal, L.A., Marle, F. and Bocquet, J.-C. (2011), "Measuring project complexity using the analytic hierarchy process", *International Journal of Project Management*, Vol. 29 No. 6, pp. 718-727, doi: 10.1016/j.ijproman.2010.07.005.

Vogel, C., Zwolinsky, S., Griffiths, C., Hobbs, M., Henderson, E. and Wilkins, E. (2019), "A Delphi study to build consensus on the definition and use of big data in obesity research", *International Journal of Obesity*, Vol. 43 No. 12, pp. 2573-2586, doi: 10.1038/s41366-018-0313-9.

Yang, Y.N. (2003), "Testing the stability of experts' opinions between successive rounds of Delphi studies".

Zomer, T., Neely, A., Sacks, R. and Parlikad, A. (2021), "Exploring the influence of socio-historical constructs on BIM implementation: an activity theory perspective", *Construction Management and Economics*, Vol. 39 No. 1, pp. 1-20, doi: 10.1080/01446193.2020.1792522.

(The Appendix follows overleaf)

Appendix 1

Dimension	Project complexity factors (provenance of complexity)
Context	Unusual type of design process
	Demand of creativity
	Scope for development
	Institutional configuration
	Significant on public agenda
	Degree of project flexibility (in scope, process, organisation . . .)
	HSSE issues
	Decision making process challenges
	Repetition of similar type of projects
	Internal politics Issue (ambiguity, hidden information)
	Environment complexity (networked environment)
	Cultural configuration
	Form of contract
	Overlapping office hours
	Stability project environment
	Experience with parties involved
	Project drive
	Commercial newness of the project (new partners, teams etc.)
	Conflict between stakeholders
	Level of competition between stakeholders
	Lack of support (top management, users, staff members etc.)
	Organisational degree of innovation
	New laws and regulations
	Local laws and regulations
	Level of competition
	Environment of changing technology, economy and nature
	Functional role
	Degree of obtaining information
	Interaction between the technology system and external environment
	Organisational risks
	Neighbouring environment (including the site access/location)
	Geological condition/difficulty of location
	External politics issue
	Union power
Belonging	Quality requirements
	Cost restraints (cost and financing)
	Specific requirements/standards
	Capability (knowledge, experience, education, training etc.)
	Technical capability of team
	Unknown/poorly defined requirements
	Bespoke software or hardware
	Trust in stakeholders
	Team transparency, empathy (the personal and intangible matter that improves cooperation)
	Project Manager competencies
	Technological degree of innovation
	Risk of highly difficult technology
	Technological newness of the project
	Highly customised products
	Responsibility and Accountability
	Requirements capture

(*continued*)

Table A1.
Project complexity factors extracting from the literature review

Dimension	Project complexity factors (provenance of complexity)
Autonomy	Availability of people, material and of any resources due to sharing
	Level of interrelation of between phases
	Team/partner cooperation and communication
	Levels of management are involved in project decision-making
	The amount of overlap and interactions
	Dynamic and evolving team structure
	Dependencies with the environment
	Interdependencies between sites, departments and companies
	Interdependencies of objectives/interests
	Process interdependence
	Stakeholders interrelation/interdependencies
	Interdependencies between actors
	Specifications interdependence
	Interdependence between components of the product
	Technological process dependencies
	Resource and raw material interdependence
	Dependencies between schedules
	Interdependencies of information systems
	Number of governmental people who involved in projects
	Combined transportation
Connectivity	Interconnectivity and feedback loops in the task and project networks
	Face to face relationship between project team members
	Number of interfaces in the project organisation
	Relations with permanent organisations
	Capacity of transferring information
	Level of processing information
	Goals/interests alignment
Emergence	Dynamics of the task activities
	Uncertainties of scope
	Uncertainty and clarity of objectives or goals
	Uncertainty in technical methods
	Information uncertainty
	Clients with unrealistic goals
	Market uncertainty

(*continued*)

Table A1.

Dimension	Project complexity factors (provenance of complexity)
Diversity	Variety of financial resources
	Variety of organisational skills needed
	Variety of the project management methods and tools applied
	Variety of resources to be manipulated
	Diversity of tasks
	Diversity of inputs and/or outputs
	Variety of the interests of the stakeholders
	Diversity of staff (experience, social span . . .)
	Variety of the stakeholders status
	Cultural variety
	Number of different languages
	Multiple time zones
	Variety of hierarchical levels within the organisation
	Variety of organisational interdependencies
	Variety of technological dependencies
	Variety of the technologies used during the project
	Variety of technological skills needed
	Multiple participating countries/location
	Geographic location of the stakeholders
	Variety of information systems to be combined
	Variety of the product components
	Client transparency, empathy (the personal and intangible matter that improves cooperation)
	Multiple suppliers, contractors, vendors, etc.
Size	Number of decisions to be made
	Duration of the project
	Number of deliverables/disciplines
	Number and quantity of resources
	Number of activities
	Largeness of capital investment
	Number of the project management methods and tools applied
	Number of different occupational specialisations
	Number of inputs and/or outputs
	Largeness of scope (number of components etc.)
	Size in CAPEX (Capital expenditures)
	Number of stakeholders
	Number of companies/projects sharing their resources
	Number of formal units and departments involved
	Number of objectives
	Number of investors
	Staff quantity
	Number of structures/groups/teams to be coordinated
	Number of hierarchical levels
	Number of information systems

Source(s): Bakhshi (2023)

Table A1.

Appendix 2

Complexity factor	Consensus %	Median	IQD	Mann–Whitney Z	Significant p-value
Repetition of similar type of projects	57	7	2.00	0.515	0.606
Commercial changes	71	8	1.00	0.369	0.712
Degree of flexibility in BEP	85	9	1.00	1.125	0.260
Unusual type of design	85	9	1.00	0.455	0.650
Previous experience	85	9	1.00	0.895	0.371
Significance on public agenda	85	9	1.00	0.789	0.430
Institutional configuration	100	10	0.00	0.567	0.571
Local laws and regulations	100	10	0.00	0.224	0.823
Levels of management	71	8	1.00	0.700	0.484
Interdependence of objectives	85	9	1.00	0.156	0.876
Dependencies on technology vendors	85	9	1.00	0.741	0.459
Interdependence between BIM models	100	10	0.00	0.782	0.434
Technological changes in the BEP	57	7	2.00	0.292	0.770
Level of development (LOD) in EIR	85	9	1.00	0.224	0.823
Specific requirements/standards	85	9	1.00	0.369	0.712
Project Manager competencies	100	10	0.00	0.515	0.606
Technical capability of the teams	100	10	0.00	0.369	0.712
Capacity of transferring information in the CDE	100	10	0.00	0.455	0.650
Organisational skills of the team members	57	7	2.00	0.895	0.371
Variety of culture and language	57	7	2.00	0.789	0.430
Geographic location of the stakeholders	85	9	1.00	0.567	0.571
Variety of data formats	85	9	1.00	0.224	0.823
BIM maturity level in BEP	100	10	0.00	0.700	0.484
Diversity of tasks in BEP	100	10	0.00	0.156	0.876
Variety of procurement methods	100	10	0.00	0.741	0.459
Multiple project locations	100	10	0.00	0.782	0.434
Unknown/poorly defined BEP	57	7	2.00	0.292	0.770
Information uncertainty	85	9	1.00	0.224	0.823
Number of stakeholders	57	7	2.00	0.369	0.712
Largeness of CAPEX	57	7	2.00	0.515	0.606
Number of companies	85	9	1.00	0.369	0.712
Number of task teams	100	10	0.00	0.455	0.650
Number of handover deliverables	100	10	0.00	0.895	0.371
Duration of the project	100	10	0.00	0.789	0.430

(*continued*)

Table A2.
Final expert consensus on BIM-enabled project complexity factors

Complexity factor	Consensus %	Median	IQD	Mann–Whitney Z	Significant *p*-value
Cronbach's Alpha: 0.820					
Kendall's W: 0.260					
Chi-Square (X^2)*:* 19.200					
X^2 *– Critical Value* (p = 0.05)*:* 14.091					
Degrees of Freedom (Df): 7					
Significant p-value: 0.012					

Note(s): This table summarises the percentage of consensus among participants for each variable, along with the Median, Interquartile Deviation (IQD), Mann-Whitney Z score, and significance *p*-value. The percentage of consensus indicates the agreement level among experts. The Median represents the central tendency of the ratings, while IQD shows the variability. The Mann-Whitney Z score and its significance *p*-value assess the differences between groups, with p-values less than 0.05 indicating significant differences. Summary statistics provide an overall measure of reliability (Cronbach's Alpha) and agreement (Kendall's W), with Chi-Square and its significance confirming the robustness of the findings

Table A2.

Corresponding author
Javad Bakhshi can be contacted at: Javad.Bakhshi@unisa.edu.au