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6D-BIM Applications to Enrich Circular Value Chains and Stakeholder Engagement Within Built Environments

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Abstract. Building Information Modelling (BIM) is a digitalisation tool that is widely adopted in construction industry. It is a three-dimensional digital replica of asset(s) such as buildings, which contain architectural information and building details (e.g. dimensions, materials, parts, and components). It has evolved from 2D CAD models (or blueprints) in the past to 3D CAD models embedded with information layers (e.g., construction time sequence or 4D-BIM), resulting in automation in construction. BIM has now been essential in various countries; for example, new UK BIM standards require asset owners to keep and maintain building information. BIM adopts an interoperable concept that can benefit the whole life-cycle assessment (LCA) and circularity of the built environments. Its applications extend to six dimensions (6D) where time sequence, cost and carbon footprint can now be reported in real time. These attributes are essential to stakeholders and critically help reduce any unexpected consumption and waste over the life cycle of a project. This study builds on the development of 6D BIM of an existing building to enrich circular value chains and stakeholder engagement. This paper highlights the development of 6D BIM, and, subsequently, the stakeholder interviews to address challenges, barriers, benefits, and effectiveness of 6D-BIM applications for stakeholder engagements across circular value chains. Snowballing sampling method has been used to identify stakeholder interviews to obtain new insights into the digital valorisation for stakeholder engagement. The outcome of this study will exhibit new insights and practical paradigms for BIM applications in built environments.

Keywords: 6D-BIM · Building Information Modelling · Circular Economy · Value Chain · Stakeholder Engagement

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1 Introduction

Circular economy (CE) is the global challenge that requires a cross value chain transition from linear economy (raw material extraction, production, use, land fill) to regenerative economy (extraction, production, use, reuse/recycling), as illustrated in Fig. 1. CE underpins the regenerative solution to resolve the climate issues by reducing raw material extraction, eliminating/minimising wastes, and then cutting down carbon footprints from raw material extractions and associated environmental impacts. The EU has introduced Circular Economy Action Plan [1], which embraces both the CE action and CE monitoring framework against science-based targets across circular value and supply chains [2]. It is very important to note that CE challenges cannot be resolved in isolation without the cooperation of every sector in every country around the world [3]. The new CE action plan announces initiatives along the entire life cycle of components and assets. It addresses how they are designed, promotes CE practices, encourages sustainable consumption, and aims to ensure that waste is minimised and the resources used are regenerative within the economy for as long as possible [1]. To scale up a widespread transition from linear to circular economy, value and supply chain actors must realise and closely collaborate across sectors for harmonized actions to enhance influence, promote inter-relationship, and overcome the barriers towards circular economy implementation [4]. Consequently, this study investigates the added value and capabilities of building information modelling (BIM) to improve and transform cross-functional stakeholder engagements across circular value chain within built environment sector.

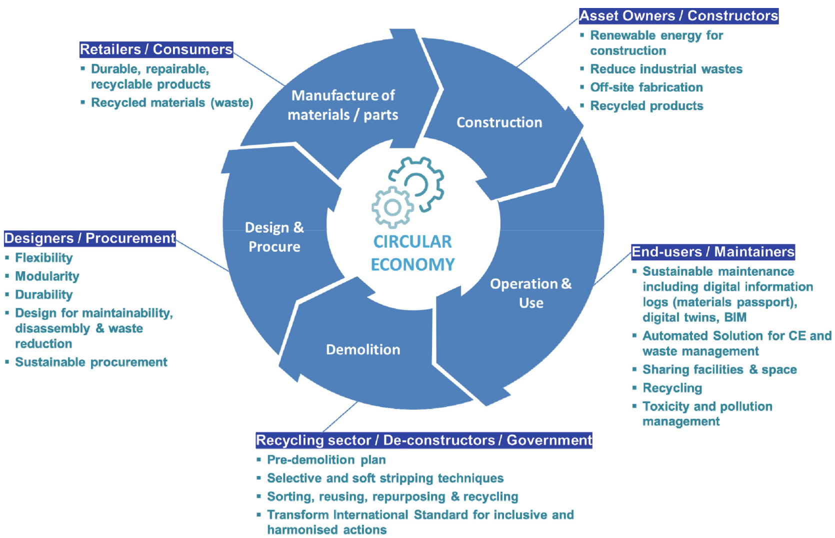

Fig. 1. Circular value chain and lifecycle management practices towards net zero. Stakeholders' interaction across value chain requires visualization and valorisation of data and information.

2 Digitisation Tools and Their Added Values

2.1 Building Information Modelling (BIM)

BIM is a digital platform to collect, create, archive, share and manage inventive data and information that can form 3D architectural model with full-scale dimensions. It can replicate and simulate digital information that is essential for construction, project management, monitoring and operation of a specific asset during the whole lifecycle [5, 6]. BIM embraces a coordinated digital dataset where relevant parties can access, visualize and share the information with respect to manufacturing, design, construction and operation as well as any necessary documents or contracts about the project. The modification or change within BIM environment will be immediately shared among stakeholders in the project or across value and supply chains [7, 8]. BIM (which can evolve to be a digital twin) emphasises the role and influence of all stakeholders within a project or a built environment boundary. It can analyse the capabilities of issues in construction, design, operation and maintenance at the early stages, which provides benchmarking targets for economical, environmental and social values of the assets. BIM is not simply a 3D architectural model but its adoption can make significant changes in resources workflow and project delivery process [9]. Currently, BIM adoption in the UK has been steadily increasing. However, recent requirements for British asset owners/investors to maintain and update building information has raised the importance of BIM and its associated skill training.

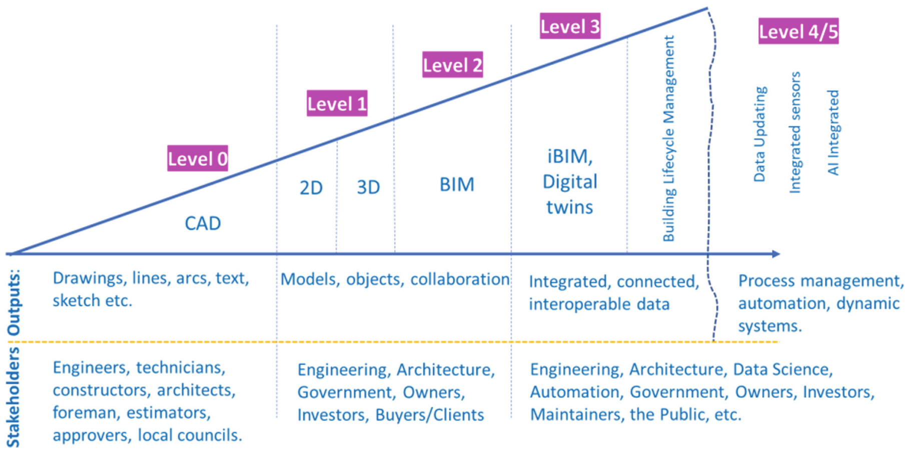

Fig. 2. Evolution of BIM metrics, outputs and maturity across circular value chain stakeholders, modified from [5].

BIM integration across value chain spans throughout the entire life cycle of a project or an asset. As shown in Fig. 2, digitisation evolution can be associated with stakeholders and life cycle stages of an asset (from design, production, construction, maintenance, and operation to deconstruction (or end of life management). Life cycle assessment (LCA) is then an integral part of BIM automation where several well-defined key performance indicators (KPIs) are regularly assessed and monitored in order to justify and benchmark a system's environmental, economic and social impacts (in accordance with EU CE Action Plan [1, 10]). On this ground, BIM can be evolved and improved to enrich the capacity and capabilities to determine various KPIs and enable several stakeholders and cross-functional parties to work collaboratively together and to exchange information in accordance with the BS Standard 19650-1 [8]. Table 1 illustrates the levels of BIM maturity and the classification at each level, which describes the types of collaborative work, tools and technology used to understand the process at each level (adopted from [5]). This displays the capabilities and added values of BIM across scales in practice.

Table 1. Level of BIM maturity and dimensions [5].

Classification	Description of capabilities and added values
Level 0 (CAD)	Unmanaged CAD, in 2D, with paper (or electronic paper or blue print) data exchange
Level 1 (CAD, Solids Work)	Managed CAD in 2D or 3D architectural format with a collaborative tool providing a common data environment with a standard approach to data structure and format. Commercial data separate
Level 2 (BIM)	A managed 3D architectural environment held in separate discipline 'BIM' tools with data attached; commercial data will be managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. The dimension of information can be further extended to 4D to include construction sequencing and 5D to include cost information associated with the sequence
Level 3 (Digital Twins)	A fully integrated and collaborative process enable by 'web service' or an interactive network (e.g. intranet, cloud, co-simulation, Navisworks link, etc.) and compliant with emerging industry foundation class standards. Generally, at least 6 dimensions (6D) of information will be integrated. In addition to physical dimensions in 3D (width, length, depth), the dimension of information will traditionally include 4D for construction sequencing, 5D for cost information, and 6D for project life-cycle management information or contractual arrangement. An additional information layer (i.e., 7D) can also incorporate carbon footprint, environmental impacts and toxicity information
Level 4 (Digital Twins)	Integration of inspection data (routine condition monitoring) or interactive real-time sensors (sensing for spontaneous actions, transient responses, ambient environments, crowdsensing or live human perceptions) in the BIM/Digital twins
Level 5 (Digital Twins)	Automation for decision making. A full integration of inspection data, real-time sensing data, and co-simulations for predictions (using constitutive and empirical models, numerical or analytical simulation methods, machine learning and artificial intelligence, data-driven physics informed techniques, etc.)

2.2 Demonstration I: 6D-BIM for Carbon Credit Assessment

Demonstration I, as illustrated in Fig. 3, highlights a specific BIM application within the context of railway station buildings using a Revit-based simulation of construction work for King's Cross station in London UK [11]. The 3D architectural BIM further adopts and transforms the King's Cross station building information into a 6D BIM. The 6D model contains a time and cost schedule with carbon emissions calculation, and renovation assumptions using Revit. The economic and environmental impacts can be determined in real time using Application Programming Interface (API). The project's outcome has already been exploited by re-construction stakeholders and asset owners. The carbon estimations in repair and maintenance stage can be reported for carbon offsetting. The BIM also allows future carbon credit calculations by assessing potential replacement options using low-carbon components and materials.

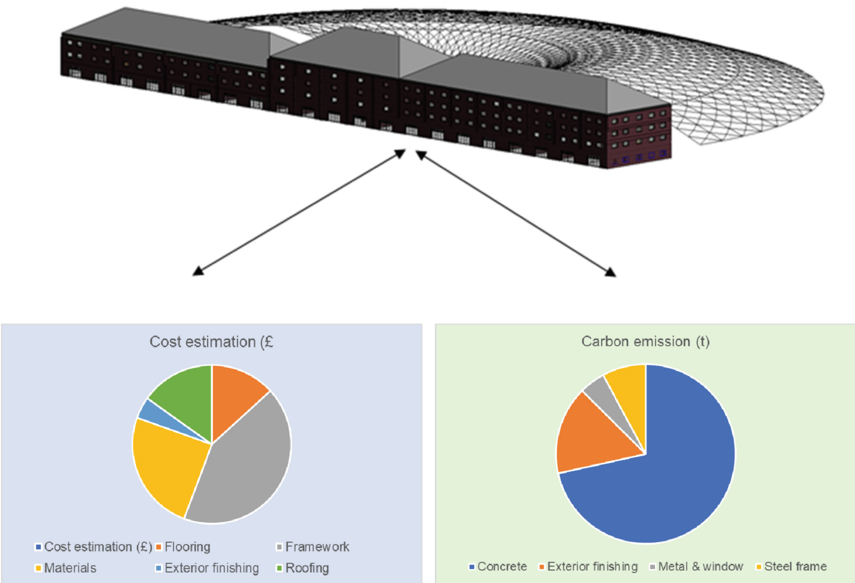

Fig. 3. A digital twin for sustainability evaluation of railway station buildings, adopted from [11]. King's Cross station in London UK has been used to demonstrate the real-time capability of 6D-BIM to determine lifecycle cost, carbon footprint.

2.3 Demonstration II: 6D-BIM for Net Zero Energy Building Improvement

Demonstration II, as displayed in Fig. 4, addresses the capabilities of 6D-BIM for determining technical and financial viability of Net Zero Energy Buildings (NZEB) for 'existing' buildings [12]. A number of suitable options for NZEB solutions can be tested and validated in BIM environments suitable for a specific geographical area. The 6D-BIM has been exploited by the developers to visualize NZEB options, promote collaboration among stakeholders, and accurately estimate associated costs and associated technical issues encountered with producing an NZEB in a pre-determined location. This demonstration also unlocks 6D-BIM capabilities to assess benefit/cost and apply renewable technologies to the existing building to improve energy efficacy.

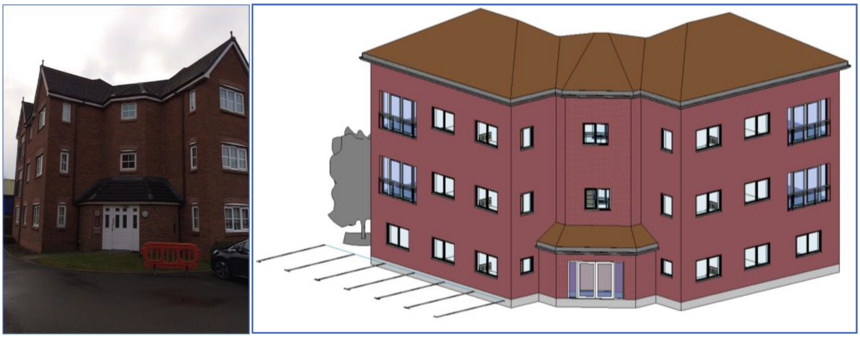

Fig. 4. 6D-BIM of an existing residential building in the UK to implement deep renovation options towards NZEB status, adopted from [12].

3 Methodology

To ensure an integrated approach toward circularity, representative stakeholders of all value chain elements will be invited to participate in closing the loop of supply and demand. Academic and industrial actors' involvement will enable the detection of specific Circular Business Models (CBMs) and related benefits in CE practices. For this purpose, this research adopts a quantitative survey approach using online questionnaires to investigate the effectiveness of BIM in the transfer of information between partners more efficiently, allowing them to develop new insights and make better-informed design choices. Accommodated by the real-world demonstration cases above, the questions have been designed to assess the quality of BIM's digital environment to enrich stakeholder engagement enabling participatory conversations on different aspects and interests necessary to develop viable business model developments focusing on value proposition, customer involvement and supply chain management. The outcome can facilitate an actionable and scalable BIM application and provide stakeholders with a digital monitoring tool for the benefits deriving from CE, as well as tracking CE performance indicators of Circular Business models. The investigation by online surveys will be conducted internationally across all value chain stakeholders. The non-personal data was collected anonymously without withholding personal information. All respondents had given consent for data collection. The data requested in this study was collected and processed by the researchers in accordance with the provisions of Regulation (EU) 2016/679 (the General Data Protection Regulation, GDPR) and all other applicable EU and UK privacy and data protection legislation. This study is GDPR compliant and has been approved by the University of Birmingham's IRB. In this study, 41 respondents in total have been collected from across the globe. The role of stakeholders will be used to classify and rank the responses derived from the online survey. Clear guidance has been provided to respondents, assuring anonymity to all to create a safe, fair, and inclusive environment.

4 Results and Discussion

4.1 Stakeholders and Their Understanding into BIM

BIM has been adopted in construction and architecture for nearly 2 decades in order to collect, create, archive, share and manage inventive data and information with an agreeable level of details (LOD). Accordingly, the public survey has been designed to embrace the BIM capabilities across value chain and lifecycle stakeholders. Figure 5 displays the role of respondents across all value chains. Most of them are in academia (27%), architecture, design and construction (22%), and asset ownership & investment (20%).

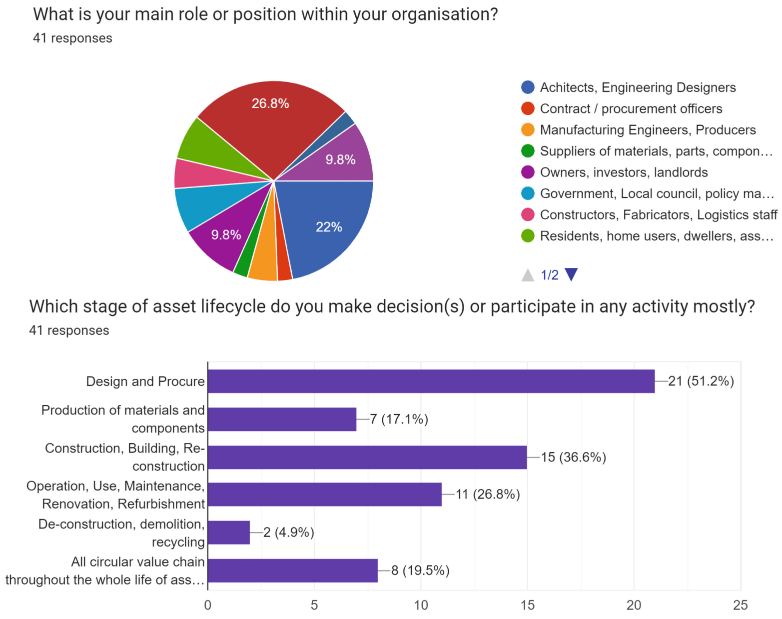

Fig. 5. Classification of respondents within the organisations across value chains.

Our survey results shown in Fig. 6 demonstrate that, in reality, BIM(s) may have been predominantly used in design and construction, but it does not effectively translate its application to engage with other stakeholders across value chains. Clearly, the role of technology enablers (e.g. BIM) in stakeholder engagement is significantly limited (i.e., >20% of response intensity).

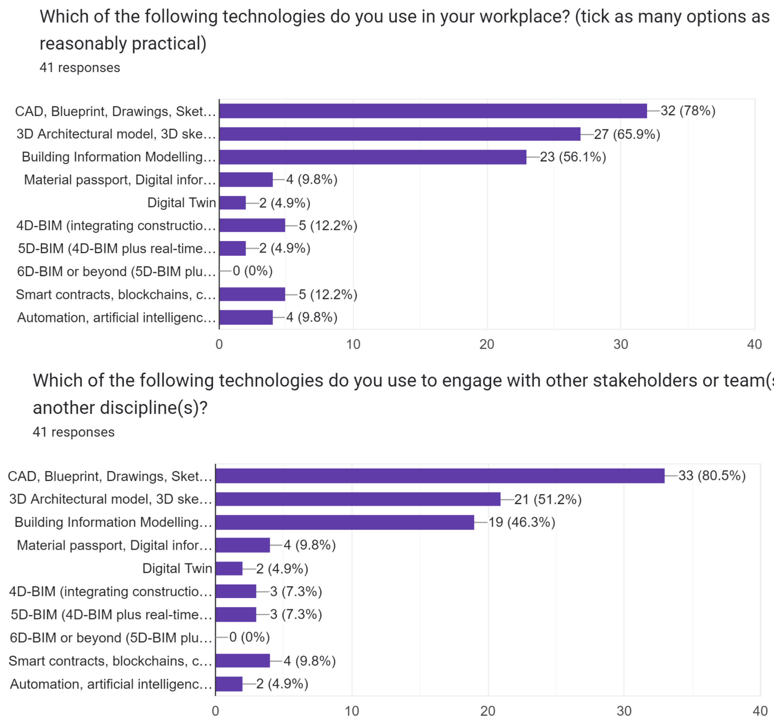

Fig. 6. Role of digitalisation technologies in stakeholder engagement across value chains.

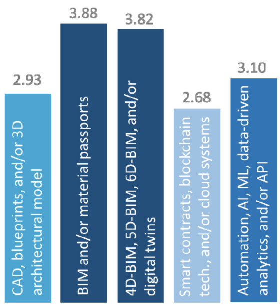

Fig. 7. Effectiveness and quality of digitalisation in stakeholder engagement (ranked out of 5.0).

4.2 Quality of BIM for Stakeholder Engagement

Figure 7 demonstrates the perceived quality and effectiveness of technology enablers in stakeholder engagement. Despite fewer BIM adoptions in practice, the respondents believe that BIM technologies (3D to 6D) can significantly improve the quality of stakeholder engagement. Surprisingly, smart contracts and blockchain do not seem to create added value to stakeholders across value chains. In Fig. 8, the actual BIM applications to enrich circular value chain is still ineffective, especially at the operations and end-of-life stages of lifecycle. This implies that it is necessary for every stakeholder to support and promote research and innovation that improves circular economy practices in sustainable asset management during both operations and end of life phases of lifecycle. The lack of circular economy innovation for existing building stocks is one of the key observed trends derived from the respondents' perception.

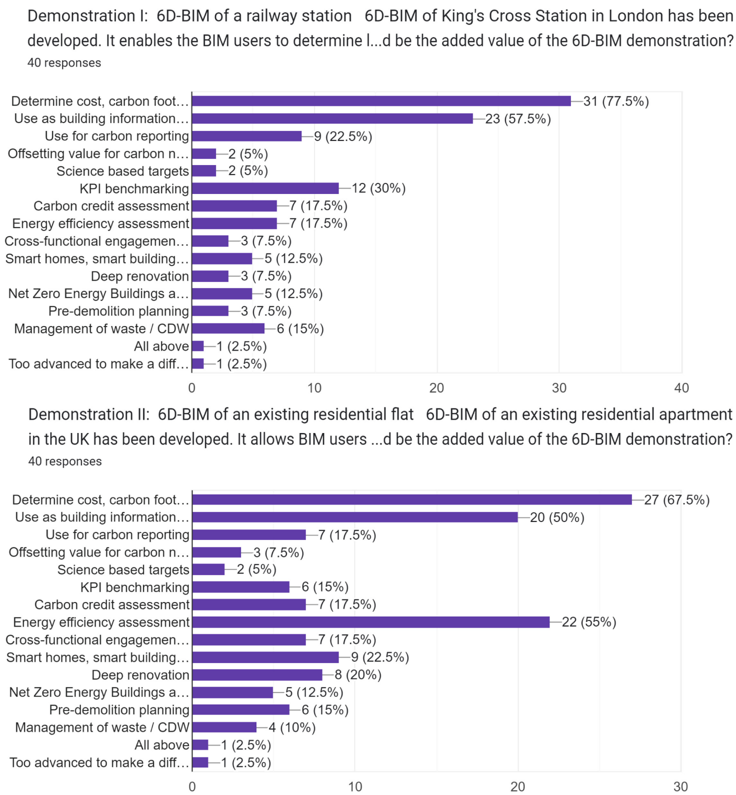

Fig. 8. Perceptions on added value potentials of digitalisation through use-case demonstrations.

5 Conclusion

BIM has been widely adopted in the construction industry, predominantly in architectural design and construction stage. Our study has carefully reviewed the state-of-the-art knowledge related to the application of BIM for stakeholder engagement. It shows a clear gap in the understanding into the quality of BIM to enrich circular value chains and stakeholder engagement. This study has thus conducted the stakeholder survey to identify challenges, benefits, and effectiveness of technology enablers (e.g., 3D to 6D BIMs) for stakeholder engagements. 41 experts worldwide have kindly provided new insights into the digital valorisation for stakeholder engagement. In contrast to market-wide perceptions, our results exhibit that the scale and scope of technology enablers is relatively limited when considering real-life application to enrich stakeholder engagement across circular value chain. This can severely pose the inability to meet net zero targets by built environment sector. All stakeholders must be united altogether to assure that circular economy is being implemented at every stage of lifecycle.

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References

1. European Commission (2023) Circular economy action plan. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
2. Science Based Targets (2023) Ambitious corporate climate action. https://sciencebasedtargets.org/
3. Kaewunruen S, Teuffel P, Cavdar AD, Valta O, Tambovceva T, Bajare D (2023) Comparisons of stakeholders' influences, inter-relationships, and obstacles in the implementation of circular economy on existing building sectors. Nat Sci Rep (submitted)
4. Fobbe L, Hilletofth P (2023) Moving toward a circular economy in manufacturing organizations: the role of circular stakeholder engagement practices. Int J Logist Manag 34(3):674–698
5. Kaewunruen S, AbdelHadi M, Kongpuang M, Pansuk W, Remennikov AM (2023) Digital twins for managing railway bridge maintenance, resilience, and climate change adaptation. Sensors 23(1):252. https://doi.org/10.3390/s23010252
6. Hardin B (2009) BIM and Construction Management. Wiley Publishing, Indianapolis
7. Beach T, Petri I, Rezgui Y, Rana O (2017) Management of collaborative BIM data by federating distributed BIM models. J Comput Civ Eng 31:04017009
8. BS ISO 19650-1 (2018) Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM)—Information Management Using Building Information Modelling. Part 1 Concept and Principles. British Standards Institute, London
9. UK BIM Framework (2023) The overarching approach to implement BIM in the UK (2023). https://www.ukbimframework.org/standards/
10. ISO 14064-1:2019 (2019) GHG Validation & Carbon Footprint Certification. International Standards Organisation, Brussels
11. Kaewunruen S, Xu N (2018) Digital twin for sustainability evaluation of railway station buildings. Front Built Environ 4:77
12. Kaewunruen S, Rungskunroch P, Welsh JA (2019) Digital-twin evaluation of net zero energy building for existing buildings. Sustainability 11(1):159