CHAPTER 3

Building Information Modelling

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Abstract From its origins as a computer-aided three-dimensional modelling tool, Building Information Modelling (BIM) has evolved to incorporate time scheduling, cost management, and ultimately an information management framework that has the potential to enhance decision-making throughout the whole life-cycle of built assets. This chapter summarises state-of-the-art BIM and its benefits. It then considers the particular characteristics of deep renovation projects, the challenges confronting their delivery, and the potential for using BIM to meet the challenges. This includes the application of Artificial Intelligence (AI) and Machine Learning (ML) to BIM models to optimise deep renovation project delivery. The prospects for this are encouraging, but further development work, including the creation of ontologies that are appropriate for renovation work, is still needed.

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3.1 Introduction

'BIM' can refer to an item (i.e., a building information model) as in its description by the US National Institute of Building Sciences as 'a digital representation of the physical and functional characteristics of a facility' (National Institute of Building Sciences, 2021). BIM can also be the process of managing construction information. This is defined by Hamil (2022) as '[…] creating and managing the information on a project throughout its whole life cycle'. Succar and Kassem (2015) have observed that BIM is a byword for digital innovation in construction. The concept of BIM first emerged in the early 1990s when earlier Computer-Aided Design (CAD) and 3D CAD software systems evolved into object-oriented 3D design tools containing geometric as well as non-graphical data. The term first became used in the early 2000s, notably in a white paper by Autodesk (2002). Nearly two decades after its first coinage as 'BIM', it has become a framework for managing information across the whole life cycle of projects as evidenced by the ISO 19650-1:2018 and ISO 19650-2:2018 standards and other related standards and guidance.

However, BIM has not permeated every part of the industry (Hamil & Bain, 2021) and there has been a temptation to 'cherry pick' convenient elements of the technology, leaving many wider aspects of BIM overlooked and their benefits unexploited (Georgiadou, 2019). There is also uncertainty over what BIM adoption actually means. Industry surveys predominantly reflect the use of BIM software, while academic studies tend to elicit the opinions of individual survey respondents. This has prompted attempts to measure BIM maturity. These range from the early Bew-Richards model comprising four levels of BIM (BSI, 2013) to more detailed multi-component approaches initiated by Succar (2009), further developed by Succar and Kassem (2015) to measure the maturity of countries or markets. Despite all the efforts, barriers to BIM adoption still remain. Begić and Galić (2021) found the most prominent of them to be resistance to change, required investment in software and skills, and cybersecurity concerns.

The remainder of this chapter is structured as follows. Section 3.2 explores BIM's benefits by examining its various applications through the project life cycle. The problems of delivering deep renovation projects are reviewed in Sect. 3.3, and then Sect. 3.4 considers how BIM can offer solutions. Section 3.5 considers some of the remaining challenges, and Sect. 3.6 offers a perspective on how current and future developments in BIM can overcome these challenges. Finally, Sect. 3.7 presents some concluding remarks.

3.2 BIM Applications, Benefits, and Beyond

BIM originated as an enhanced 3D design tool but soon began to offer a wider range of functional applications that extended its range of use cases: so-called BIM dimensions. These offer the prospect of a unified model that can enable the efficient and effective sharing of data between different functions and throughout the project life cycle.

Table 3.1 presents a (non-exhaustive) list of the commonly recognised BIM dimension. In reality, once they go beyond 4D BIM, where a time schedule is linked to a 3D physical BIM model, these so-called dimensions

Table 3.1 Commonly recognised BIM 'dimensions'

Dimension	*Description*	*Uses/benefits*
3D BIM	A digital object-oriented representation with physical and functional information. Allows integration of multiple designs (architectural, structural, services, etc.)	Complements the distributed building design process. Enables parametric design, automatic code compliance checking, visualised renderings and 'walk-throughs', clash detection/resolution, and generation of off-site fabrication
4D BIM	BIM for scheduling and project delivery. Involves linking a time schedule to the 3D model to enhance and visualise construction planning techniques	Improves project management and communication between members of the project team through informative animations of the construction process
5D BIM	'5D BIM' offers automatic quantity take-off (QTO), cost management and analysis	Evaluation of the cost implications of design decisions and support for bidding, procurement, cost management, and accounting

Note: Further uses (safety, accessibility, security) have been proposed, with no consensus on terminology (Charef et al., 2018). The term 'nD model' reflects the range of possibilities (Aouad et al., 2006)

Table 3.2 Metaphoric 'dimensions' debated in literature

Dimension	*Description*	*Uses/benefits*
6D BIM	BIM for environmental sustainability. Incorporates information on embodied carbon, energy use, resource efficiency	Real-time feedback on the implications of design decisions, enabling detailed analysis of an asset's future performance
7D BIM	Focus on managing the operational life cycle of a built asset. The output to the owner or end user is in the form of an asset information model (AIM)	Can be linked to Building Management Systems (BMS) for functions such as predictive maintenance, facilities management, and building performance

are simply applications. As Koutamanis (2020) points out, time can realistically be considered a dimension, whereas cost (5D), sustainability (6D), or life cycle (7D) are metaphors. The terminology is nevertheless retained here as it is still widely recognised. Stepping aside from the BIM dimensions, a more inclusive coverage of the applications and uses of BIM is represented by the PennState BIM uses (2023) or the concept of model uses of Succar et al. (2016) (Table 3.2).

Related literature suggests that BIM can generate a number of organisational benefits. According to Georgiadou (2019), they include design optimisation, improved on-time delivery, cost efficiency, quality assurance, collaboration and communication, and sustainability. Ghaffarianhoseini et al. (2017) also add technical superiority, interoperability, information capture, improved cost control, whole-life applicability, the potential for integrated procurement, and reduced conflict and better communication and coordination within the project delivery team. Attempts to quantify the value of such benefits using, for example, a return on investment (ROI) approach are necessarily context-specific. This is confirmed by Sompolgrunk et al. (2021) that found a huge variance in reported ROIs. Positive results were predominantly associated with schedule reduction/compliance, increased productivity, and reduction in requests for information, change orders, and rework.

As highlighted in Begić and Galić (2021), BIM is a vital element in the transformation to 'Construction 4.0', where innovations such as the Internet of Things (IoT), blockchain, and artificial intelligence (AI) and modern methods of construction (MMC) will play an increasing role in the built environment, and built assets will have a golden thread of information showing how they have been built and how they are performing (Hamil, 2022).

The digital and object-oriented basis of BIM allows it to interact with other digitally driven systems which can represent either inputs to a BIM model (e.g., the retrospective modelling of existing facilities through point-cloud surveys) or outputs (e.g., the automated manufacture of building components from their design). Other examples include the integration of BIM with blockchain to overcome challenges related to provenance, accuracy, transparency, security, and ownership of model information (Li et al., 2019). Furthermore, an opportunity for transforming the management of built assets comes with the concept of the 'digital twin'—a cyber-physical system where live data flows from sensors[1] in the physical asset (e.g., a building) into its counterpart digital model (De Luca et al., 2021). Conversely, the physical twin can be controlled from the model to enable operation, maintenance, monitoring, diagnostics, prediction, and simulation. These activities can focus on such important issues as energy use, carbon emissions, and planned maintenance.

3.3 Deep Renovation Projects: Key Challenges

The delivery of construction projects in general can be complex and demanding and presents well-documented challenges to the control of cost, schedule, and quality. This situation becomes even more acute in the case of renovation projects, which are inherently more uncertain.

Planning and execution of deep renovation[2] projects are currently driven by judgement and experience rather than standardised solutions (Amorocho & Hartmann, 2021; Lynn et al., 2021). Such projects typically disturb existing building occupants, whose presence, conversely, disrupts construction logistics, schedules, and budgets. Deep renovation projects, which aim at maximising energy efficiency in the renovation process (Shnapp et al., 2013) are even more problematic because of their extended impact on the fabric, services, and even structure of a building (Fawcett, 2014). McKim et al. (2000) reported that renovation projects were twice as susceptible to delay and suffered four times the cost overruns of new construction work. Their conclusion was that conventional

[1] Chapter 2 in this book provides more details on the use of sensor networks in the context of deep renovation projects.

[2] Chapter 1 in this book provides a detailed definition of Deep Renovation.

time and cost control techniques were inadequate for such projects. Alongside the uncertainties surrounding the work itself is the safety and well-being of building occupants. Chaves et al. (2016) have highlighted disruptions involving: (a) utilities (gas, electricity, telecoms); (b) access; (c) use of space by both occupants and contractors; (d) problems with internal environmental quality (noise, dust, vibration, and debris); (e) external environmental quality; and (f) transport and parking spaces. To mitigate such issues and allow project teams to plan, organise, and efficiently realise renovation tasks, Killip et al. (2013) have suggested the adoption of new technologies and optimised processes: approaches that are epitomised by BIM-based applications. BIM benefits are much reported in literature but rarely in relation to renovation projects.

3.4 The Potential for BIM in Deep Renovation Projects

In their state-of-the-art review of design decision-making for sustainable renovation projects, Passoni et al. (2021) stress the need for multi-criteria decision methods, optioneering, and pre-validation of proposals. Although their work relates to the *design* of sustainable renovation projects, the conclusions apply equally to their delivery. In both cases digital tools based on BIM can be employed to identify, optimise, validate, and communicate different renovation scenarios, in terms of cost, time, and effectiveness in meeting the required functionality and quality of the resulting work.

A foundation for using BIM in most renovation projects is employing a laser scanner to capture point-cloud data that can then be processed to create a 3D BIM model (Wang & Kim, 2019). The retro-constructed geometric 3D BIM model can then be semantically enriched to enable further functionalities. Thus the 'scan to BIM' or 'mapping' stage can provide the basis for the application of BIM in renovation projects as described by D'Oca et al. (2018) in their review of related European Horizon 2020 projects. The captured as-built BIM models can be used for building condition assessment that can underpin the prioritisation of renovation options. For example, Sebastian et al. (2018) describe the use, based on the initial scanned model, of software applications for assessing conditions and analysing and prioritising renovation interventions on the basis of their energy performance. Acampa et al. (2021) have also shown how BIM-based decision support systems have been used to generate such optimal renovation scenarios.

BIM enables a common data environment (CDE) for information exchange between the various design consultants, connecting energy simulation and prediction (Garwood et al., 2018; Pinheiro et al., 2018), life cycle costing (Edwards et al., 2019; Sharif & Hammad, 2019) and its parametric modelling capacity enables quicker and more cost-effective design optimisations (Abanda & Byers, 2016; Corgnati et al., 2017).

From a project delivery perspective, BIM can enhance the management of project schedules through 4D BIM (Jupp, 2017; Sheikhkhoshkar et al., 2019) and budgetary control using '5D BIM' (Lee et al., 2016). The benefits of doing so include more critical assessment of options, more effective coordination and work sequencing, improved tracking and review, enhanced utilisation of space and resources, control of waste, and improved communication (Gledson & Greenwood, 2017). In deep renovation projects, these benefits are amplified. In fact, the uncertainty inherent in renovation work requires flexible approaches, and in this respect, the ability of BIM-based simulations of time and cost to evaluate different renovation scenarios offers great potential (Chaves et al., 2016).

Finally, from a communication perspective, the use of BIM simulation and visualisation can be useful in mitigating disruption to (and by) occupants (Passoni et al., 2021). Crucially, BIM simulations of time and cost can enable users to share and clarify the perception of the renovation process with all stakeholders, including building occupants who are unlikely to fully understand traditional drawings and schedules. The ability to use visualisation to demonstrate design and construction decisions and their consequences in time and space, including any different options that are available, can clearly facilitate good relations and better cooperation with owners and occupiers. This, in turn, should assist the renovation process.

3.5 Immediate Challenges in the Adoption of BIM Solutions

The prospects for the use of BIM in deep renovation projects are encouraging, but there remain challenges, some of which are related to interoperability and workflow. As observed by De Gaetani et al. (2020), the multidisciplinary nature of construction design attracts the use of different types of authoring software, file formats, or (even if formats are the same) different file format versions. Thus, additional effort may be required for file exchange. The development of time- and cost-related models from initial 3D design models is typically performed later in the project process by the contractor. Here the inherent advantage of BIM is the opportunity to extract objects from the design model to generate scheduled activities and budget items. As identified by Park and Cai (2015), this process involves four phases:

1. Extracting object information from the 3D model
2. Defining the appropriate work (WBS) or cost (CBS) breakdown structures for the project
3. Linking the elements of these with the objects in the BIM model
4. Generating the schedule or cost models themselves

In theory, this process could be automated (ElMenshawy & Marzouk, 2021), but this depends on the interoperability between the applications used and the degree of coordination with the original design. Design-oriented 3D BIM models are rarely set up to facilitate the subsequent production of schedule and budgetary tools. As a result, significant manual effort, involving the splitting or aggregating of objects, is required to link the elements of the 3D model to the relevant time and cost parameters. Such interoperability and workflow challenges must be overcome to unlock the full efficiencies of information transfer enabled by BIM adoption.

3.6 Further Developments and Challenges

Furthermore, the availability of BIM models for delivering renovation projects presents an opportunity to exploit advances in Artificial Intelligence (AI) and Machine Learning (ML). Mulero-Palencia et al. (2021) raise the possibility of applying AI and ML to BIM models of deep renovation interventions. Their focus is on the development of algorithms for diagnosis (at the preliminary analysis stage of a project) and optimisation (at the design simulation and optioneering stage), but there are implications for all stages in the life cycle of deep renovation projects.

A current barrier to doing so is the lack of ontologies that are appropriate for renovation work. Ontologies are fundamental requirements for formalising specific domain knowledge including concepts, relations, and constraints and are thus an essential basis for producing machine-readable code that can support process automation (Hartmann & Trappey, 2020). As noted by Amorocho and Hartmann (2021), BIM-based tools for design, planning, and project management are normally targeted at new construction and comprehensive ontologies for renovation activities are not currently available. Amorocho and Hartmann (2021) have developed a limited example ontology that was restricted to the installation of common renovation products, such as windows, HVAC components, and external thermal insulation panels. However, no ontology currently exists for the general case of renovation projects, and further development will be necessary to capture the potential of BIM-driven AI solutions.

3.7 Conclusion

This chapter summarises the state-of-the-art on BIM with a specific emphasis on its potential in deep renovation projects. In the course of domestic renovation works, disruptions to users and occupants are inevitable. This and the uncertainties inherent in this type of work make the delivery of such projects challenging—particularly in adhering to time and cost plans. Deep renovations are especially problematic in this respect. The use of BIM would not only enable the integration of condition assessments with subsequent building design, but also permit the automatic extraction of design information to generate schedules and budgets and to control them. Based on BIM, other technologies, such as AI and ML, could be applied to generate standardised and optimised solutions for the delivery of deep building renovation projects.

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