BIM in Construction and Operations

Executive Summary

The modern construction sector is working under extreme pressure to execute projects with greater certainty of schedule and budget while maintaining total compliance with the stringent environmental performance requirements. Conventional project management, based on data silos and disconnected workflows, is insufficient in addressing these competing needs, resulting in constant overruns and waste. This report provides a critical analysis of how Building Information Modelling (BIM) functions as an integrated platform to address these challenges during the construction phase fundamentally. The analysis of the report is structured around three synergistic themes. It then examines BIM in terms of Project Schedules and cost certainty, stating that BIM-facilitated 5D processes would not only enable the control of costs and schedules but also make cost and schedule management active and dynamic rather than fixed and predictive. BIM transfers quantities and costs to a federated model, directly enabling real-time analysis of the effects of changes and providing unprecedented financial transparency. Second, the report examines the processes of optimising construction operations using BIM, including 4D sequencing and 4D clash detection. It takes a harsh judgment of the 4D BIM not as a visualisation tool but as a collaborative planning platform. Here, it is possible to optimise construction logic, eliminate spatiotemporal conflicts, and validate complex methodologies to maximise project schedule reliability. Finally, the report broadens the concept of project performance to include environmental metrics by examining BIM's utilisation in sustainability and waste reduction. It examines how accurate model-based measurement and prefabrication processes can have a dramatic impact on material waste. Moreover, it examines the new role BIM can play in embodied carbon tracking during the procurement process and the principles of a circular economy that can be implemented through Design for Deconstruction, making sustainability central to construction activities.

Contents

Introduction

The construction industry is at a tipping point, as governments, investors, and the public are pressuring the industry to improve its chronically low productivity while mitigating its significant environmental impact. In the past, uncertainty has been the hallmark of project delivery, as experience has shown that schedule delays and cost overruns are inevitable components of a complex and fragmented process (Eastman et al., 2018). Nevertheless, increased client demands and the regulatory background, including the UK's Net Zero targets, require a shift towards a new paradigm based on performance and guarantees (UKGBC, 2019). The conventional methodology, whose design, cost, schedule, and sustainability are often separated and frequently set in opposition to each other as distinct and mutually hindering streams of work, is inherently immature to this challenge.

This report analyses how the concept of Building Information Modelling (BIM) can deliver the combined data backbone needed to break down such silos, which in turn allows for an all-inclusive approach to managing construction activities. The main contention is that BIM enables the transition to proactive performance optimisation as opposed to reactive problem-solving. It will be discussed through a critical examination of three interlinked themes that define modern, high-performance construction.

BIM for Project Schedules and Cost Certainty is the first direction of the investigation, examining how 5D BIM transforms the financial management of a project, a previously fragmented estimation process, into a live, model-integrated control system. Building on this, the report examines the operational mechanisms of optimising construction operations using BIM for 4D sequencing and 4D clash detection, evaluating these as tools for collaborative planning and risk mitigation that directly enhance schedule reliability. Finally, the analysis broadens to consider environmental performance, assessing how to utilise BIM in sustainability and the reduction of waste by enabling precise material management, embodied carbon tracking, and circular economy principles during the construction phase.

By synthesising these elements, this report will conclude that BIM's primary value in construction lies in its capacity to create a unified data environment where time, cost, and sustainability are managed as interdependent variables, empowering teams to deliver projects with engineered certainty.

BIM for Project Schedules and Cost Certainty

Financial uncertainty is a chronic ailment in construction, stemming largely from the disconnect between design information, quantity take-offs, and cost estimation (Hardin & McCool, 2015). In traditional workflows, quantity surveyors perform manual or semi-automated take-offs from 2D drawings, a process that is not only laborious and prone to error but also creates a static cost plan that is difficult to update when designs inevitably change. BIM-enabled 5D processes, the linking of cost data to the 3D model, offer a fundamental solution to this challenge.

From Manual Take-offs to Model-Driven Quantification

Automation of the Quantity Take-Off (QTO) procedure is the most immediate advantage of BIM in cost management. As a case study of a road project developed in Norway, Fürstenberg et al. (2024) show how, using the data of categorized quantities read directly out of IFC-serialized domain models and mapped into standardized cost items, up to 40% of the BoQ could be generated reliably with every revision, saving manual measurement requirements and human theory that might accompany them. However, the critical value of this approach lies not just in its initial accuracy but in its dynamic nature. When a design change is made in the model, for example, altering a wall specification, the associated quantities update automatically, allowing for an immediate and transparent assessment of the cost implications. This is a stark contrast to the traditional process, where design changes trigger a time-consuming and often contentious re-measurement and re-pricing exercise.

However, as Stanley and Thurnell (2014) emphasize, 5D BIM is by no means a cure-all i.e. quantity take-offs are only as reliable as the data embedded in the model. If the BIM objects lack full specification, contain omissions or errors, or are inconsistently coded, the resulting estimates will be flawed which is a classic garbage in, garbage out scenario. If models from different disciplines are not correctly structured or lack the necessary data parameters, the resulting QTO will be unreliable. This underscores the importance of a well-defined BIM Execution Plan (BEP) and robust collaborative practices (MO3) to ensure all project team members produce models fit for the purpose of 5D analysis.

The Role of 5D BIM in Dynamic Cost Management

True 5D BIM extends beyond a simple QTO by integrating the model with resource libraries, unit costs, and the construction schedule. This creates a dynamic cost management tool that allows for sophisticated what-if scenario planning during the construction phase (Cheung et al., 2018). For example, if a specific material becomes unavailable, the project team can quickly model an alternative, and the 5D system can automatically calculate the impact on both cost and schedule.

Figure 1: 5D BIM Dashboard (Dysert, n.d.)

This capability, illustrated in Figure 1, transforms the role of the commercial manager from a historical cost reporter to a proactive cost advisor. On the Royal Adelaide Hospital megaproject, the team leveraged 5D BIM within their BIM-based construction network to coordinate and control an exceptionally high level of design complexity. By structuring over several of interface points and sequencing model authoring from LOD 200 through to LOD 300, the Engineering Services Coordination Manager was able to harness the virtual model to track changes, detect clashes and arbitrate design decisions in real time, dramatically reducing the potential for misalignment, disputes and cost overruns (Mignone et al., 2016). This demonstrates that when implemented effectively, 5D BIM provides the financial certainty and data-driven decision-making capabilities that modern, complex projects demand.

Optimising construction operations using BIM for 4D sequencing and 4D clash detection

While 5D BIM addresses cost certainty, 4D BIM—the integration of time—is the key to achieving schedule reliability. Traditional Gantt charts, while useful, fail to represent the critical spatial component of construction. They struggle to explain the interaction between logistics and sequencing the daunting logistics of activities on a busy site. 4D BIM has addressed this aspect through the ability to visualise the building process using a simulation program, which has transformed the schedule into a collaborative planning and risk reduction tool.

4D Sequencing as a Collaborative Planning Tool

In a nutshell, 4D sequencing is the practice of connecting the separate components of a 3D modeling of a building to the related tasks within the project schedule to generate a visual schedule that even the owners, designers, architects, and the site crews can easily comprehend and work interactively (Awe et al., 2025). But the best it has got is that it can be used as a collaborative planning tool (MO3). With the help of the 4D model, in the course of the planning workshops project teams will be able to experiment and prove various construction sequences, optimise resource provision, and define the most effective construction logic.

In the case of the Queen's Wharf Brisbane project, 4D BIM was employed during the two-and-a-half-year demolition and excavation phase. The extraction of more than 400,000 m^3 of material in and around the Queen Wharf Road and William Street live public roads allowed the project team to optimize the program and communicate clearly to the regulators and local bodies by the use of a model-based visual representation (Peter Gordon, 2019; Queen’s Wharf Brisbane, 2021). This demonstrates that 4D is not merely an output for presentation but an interactive environment for optimising the construction plan itself, thereby increasing its feasibility and reliability.

Mitigating Risk through 4D Clash Detection

At its core, 4D clash detection moves beyond the static, geometry-only checks of 3D systems by embedding time into the model and explicitly simulating both permanent and temporary site elements as they evolve. Yoo et al. (2022)'s rule-based 4D-BIM framework, for example, incorporates schedule data alongside spatial rules to generate a lightweight BIM that highlights hazard zones over time. Their system models not just structural components but also temporary formwork, crane-reach envelopes, material-delivery zones, and exclusion areas then uses predefined rules to flag where any of these collide in space and time before execution . This analysis can pre-emptively identify critical on-site risks, such as two subcontractors scheduled to work in the same tight space simultaneously, a crane's load path conflicting with a temporary structure, or an access route being blocked by a materials delivery.

Critically analysing this practice (MO1), the primary challenge lies in the level of detail required. For 4D clash detection to be effective, the BIM model must be sufficiently developed to include these temporary works, and the schedule must be detailed enough to reflect real-world operational sequences. Implementing combined location-based scheduling and 4D CAD requires substantial upfront effort—defining consistent location hierarchies, splitting and tagging BIM objects, and integrating schedule data across disciplines. Yet, as demonstrated in the Luleå cultural-centre case, this investment lets teams spot spatial and sequencing conflicts (e.g., congested work zones and hazardous task overlaps) in the model phase, avoiding on-site disruptions, rework, and safety risks (Jongeling and Olofsson, 2007).

Utilising BIM in Sustainability in construction and the reduction of waste

In the face of the climate crisis, the definition of project performance has expanded beyond time and cost to include environmental sustainability. The construction industry is a major contributor to resource depletion and waste generation, with estimates suggesting that up to 30% of materials delivered to a site can end up as waste (Osmani et al., 2008). BIM provides a powerful data-centric platform to address this inefficiency.

Lean Construction and BIM-Enabled Waste Minimisation

The principles of Lean construction, centered on the elimination of waste, are directly reinforced by BIM's precise, model-driven quantity takeoffs. In one healthcare-project case study, integrating BIM with pull-planning and an IPD delivery model reduced material waste by 6% through more accurate ordering and just-in-time supply (Gokberk Bayhan et al., n.d.). Furthermore, by facilitating off-site prefabrication (as discussed in the DfMA context), BIM enables a shift to manufacturing environments where material usage can be optimised and waste streams can be managed far more effectively than on a traditional construction site.

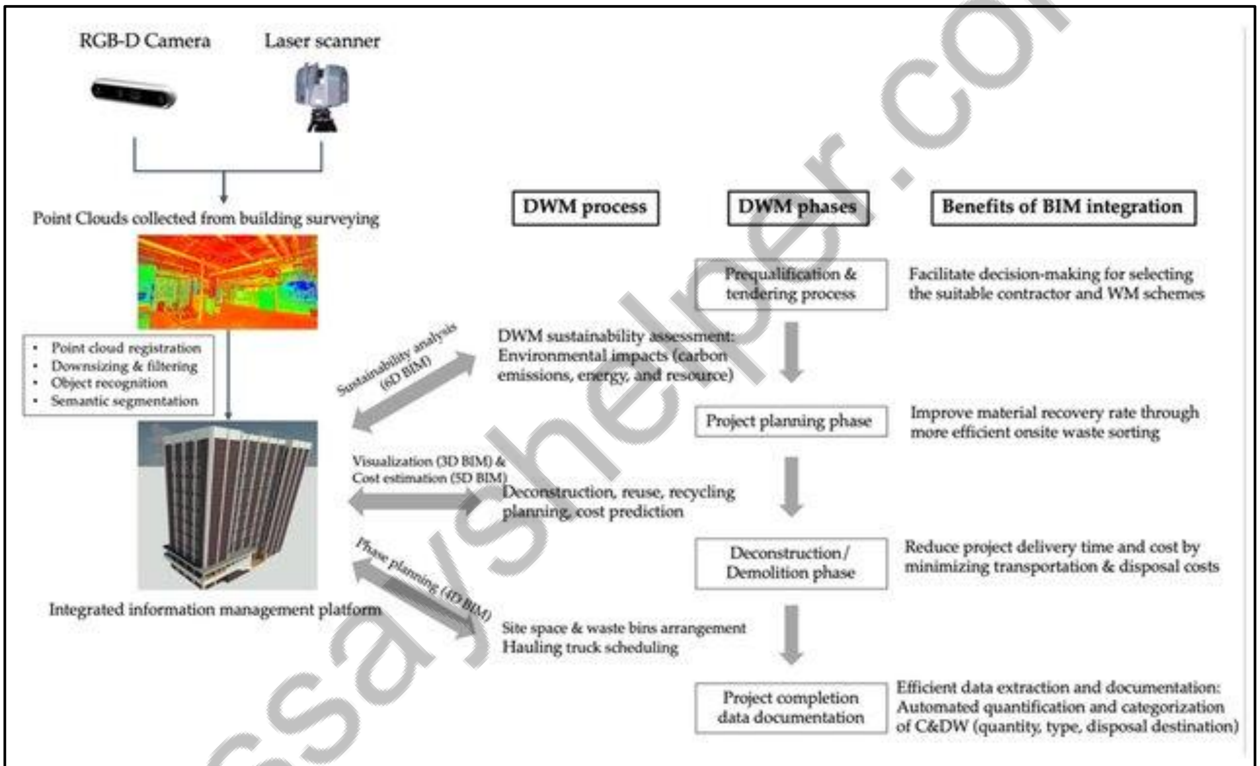

Figure 2: BIM-Based Waste Tracking (Han, Kalantari and Rajabifard, 2021)

Moreover, clash detection plays a crucial role in waste reduction. Every on-site clash that is resolved through demolition and rework generates significant material waste. By identifying and resolving these clashes in the virtual environment before construction begins, BIM directly prevents this form of abortive work and its associated waste (Won & Cheng, 2017). As illustrated conceptually in Figure 2, BIM provides the data needed to move waste management from a reactive disposal activity to a proactive minimisation strategy.

Embodied Carbon Tracking and Designing for a Circular Economy

Beyond operational waste, BIM is emerging as a critical tool for managing a building's whole-life carbon footprint. During the construction phase, this is particularly relevant for tracking embodied carbon, the emissions associated with the manufacturing and transportation of materials. By enriching BIM objects with Environmental Product Declaration (EPD) metrics and embedding all assembly-level material compositions in a lightweight classification catalogue, our plugin computes an up-to-date embodied-carbon total (kg CO_2e) as each procurement decision is finalised (Parece, Resende and Rato, 2024). This enables the intelligent choice of materials based on cost, performance, and carbon footprint.

Moving ahead, BIM supports the approach to a circular economy, specifically Design for Deconstruction (DfD), which involves disassembling a building to reuse its components at the end of its life. A BIM model, when populated with as-built data about the types of materials used, connections to them, and expected end-of-life performance, becomes an active source of information for assessing recoverability and making informed decisions when designing deconstructable structures (Akinade et al., 2017). The digital record, prepared and certified at the construction stage, is invaluable as the material recovery in the future becomes easier, making construction demolition waste a resource rather than waste as the material loop is closed. This crucial futuristic application demonstrates the capability of BIM in developing assets that are not only effective in use but also responsible during the end-of-life cycle.

Conclusion

The analysis of BIM schedules and cost certainty, operational optimisation of operational environments, and its sustainability illustrate that it is worthwhile because it can produce a consolidated and data-rich environmental output for a project. This integrated approach directly counters the fragmentation and uncertainty that have long hindered the construction industry's performance. BIM enables teams to engineer certainty into the construction process by offering a platform to deliver dynamic financial control, collaborative logistical planning and proactive environmental control.

Analysis shows that 5D BIM is more than an estimating tool, as it is transformed into a live cost control system. Similarly, 4D simulation is more than a visualisation tool, becoming an invaluable operating system where advanced optimisation and de-risking of complex operation sequences can be developed. Furthermore, BIM's role in sustainability moves beyond a design-phase consideration, offering tangible mechanisms for waste reduction and embodied carbon management directly within construction operations.

Nevertheless, this report also states that these advantages do not occur automatically. They depend on the mature adoption of collaborative practices (MO3), new digital skills being learnt, and the leadership willing to invest in the resilient processes and quality data that are the foundation of an effective digital delivery strategy. The bottom line is clear to top management: BIM is not a technology to assign but a business strategy to be driven. It is the staple model of project delivery that answers the tripartite call of the modern world: on time, on budget, and with a tangible sense of care towards the environment.

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