Integrating Building Information Modelling and Health and Safety: Procurement

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Executive summary

Building Information Modelling (BIM) has the potential to improve health and safety throughout the life cycle of a building or infrastructure project, and in a wider sense can be used to add value to a project in planning, design, delivery and operation. However, successful BIM use depends on the use of appropriate strategies at the outset of a project, to ensure BIM is considered as a central part of the procurement process.

Based on a review of international literature, this report summarises good practice and lessons learnt in procurement considerations for BIM. The literature is considered from two angles, first exploring the use of BIM within the construction procurement process to support health and safety improvements; and then considering aspects of the procurement process which need to be considered to enable BIM to be used effectively to support health and safety, as well as other project applications.

BIM has the potential to improve communication, visualisation and information management for project participants, and enables the use of tools such as reality capture and knowledge bases for better planning and decision making. BIM can also facilitate prefabrication and off-site manufacture, which can reduce health and safety risks on site. However, to realise these benefits, as well as many other health and safety improvements throughout the design and construction stages, the project procurement strategy needs to provide a clear framework for BIM implementation. BIM offers many opportunities to improve health and safety throughout the life cycle of a built asset, but the procurement stage is vital to enable them.

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1. Introduction

1.1. Background

Procurement is a key process that influences construction health and safety, as it defines project expectations, links all aspects of the design and construction process, and establishes the overall project strategy. Clients, as the initiators and purchasers of construction projects, have a major role in driving health and safety improvements. They make critical decisions on the selection of project stakeholders and determine the contractual relationships between them. The competencies and resources of these stakeholders ultimately affect the health and safety outcomes of the project.

Under the Health and Safety at Work Act 2015 (HSWA 2015), the client or contracting organisation has a duty to consult, cooperate and coordinate with all of the parties it contracts to the project, to ensure health and safety is managed appropriately throughout the project. The contracting PCBU ('person conducting a business or undertaking') cannot contract out of their health and safety duties or push risk onto others in a contracting chain, but a contract may include agreements regarding health and safety management processes by others, to ensure their expectations are met. However, it is still incumbent on the contracting party to monitor and manage the process to ensure that health and safety duties are being met.

Building Information Modelling (BIM) is invaluable as a tool to support PCBUs in meeting their obligations to identify, assess, communicate and monitor health and safety risks throughout the life cycle of a built asset. However, although awareness of the potential uses of BIM in the design and construction stages of a project is slowly increasing, its application to the procurement process has received little attention. Furthermore, the initial procurement stages of a project typically occur prior to any consideration of BIM for the project delivery, which presents a key challenge in optimising the value of BIM throughout other stages of the project. Consequently, client leadership is essential for BIM adoption and integration with health and safety management.

1.2. Terminology

In this report, the term *BIM* has been used in the sense defined by Eastman et al. (2011, p16) as "a modeling technology and associated set of processes to produce, communicate and analyse building models", whereas *BIM model* has been used to refer to the product of that process, i.e., the model created using the process of building information modelling.

Essentially, BIM provides a framework which allows buildings to be represented, not simply geometrically, but using objects which have information attached to them. The amount of information included determines the value of the model and the uses to which it may be put. Commonly used BIM terminology used in this report includes:

- 3D BIM - the three-dimensional representation of a building, with associated attributes. A 3D BIM model provides the capability of visual representation of the

building using static images, walk-throughs/fly-throughs, or integration into other interactive environments such as virtual reality (VR) and augmented reality (AR).
- 4D BIM - the 3D model with the addition of time-based information. The inclusion of scheduling data allows animations or simulations of the construction process.
- 5D BIM – a 3D or 4D model with cost data included.

Additional 'dimensions' of BIM have been proposed, but they are described differently by different organisations and are not widely adopted or recognised in the industry. In this report, health and safety has not been assigned a dimension but it has been assumed that health and safety information will be added to the BIM model at any level, depending on the project's requirements.

1.3. Sources and scope

This report seeks to make use of international research literature to explore the integration of BIM and health & safety in the context of construction project procurement. It is based on a Systematic Literature Review (Guo, et al., 2022) that was previously carried out for this project. However, the SLR identified only a very limited number of sources that specifically address aspects related to BIM-based safety in procurement. Accordingly, a more general perspective has been taken of construction health and safety, BIM and procurement. Much of the literature on procurement regarding BIM is not specifically focused on health and safety uses, and relevant connections have been inferred where required.

In addition to international research literature, two significant New Zealand sources have been used to connect international research to local practice; these are the New Zealand Government Construction Procurement Guidelines (MBIE, 2019), specifically the Health and Safety and Building Information Modelling sections, and the New Zealand BIM Handbook (BIM Acceleration Committee, 2019).

Two previous BIMSafe reports (Okakpu et al., 2023; Davies, 2023) addressed the applications of BIM to health and safety in a construction project, focusing on the design stage and construction stage respectively. The material covered in those reports introduce a range of BIM-enabled approaches to health and safety improvement, all of which may have implications for the procurement process. Unless the approaches have specific value for procurement activities that were not described in the original reports, they have not been duplicated here.

1.4. Report structure

The following discussion of the literature has been addressed in two parts: the ways in which BIM may be used to support a focus on Health and Safety within all aspects of project procurement; and the aspects of procurement that need to be considered to enable the use of BIM throughout the design, construction and operation of a building.

The three key stages of the construction procurement process, described in the Health and Safety section of the New Zealand Government Construction Procurement Guidelines

(MBIE, 2019) as Plan, Source and Manage, have been used as organising concepts within these two parts. The *Plan* stage requires the project brief to be developed and a procurement strategy to be determined, and the design of the project to be prepared. The *Source* stage involves selecting contractors and subcontractors and drawing up the contract. *Manage* involves monitoring health and safety throughout the construction phase of the project, and evaluating project outcomes and lessons learned at the conclusion of the project.

2. BIM and procurement for health & safety

According to the New Zealand Government Construction Procurement Guidelines (MBIE, 2019) the *Plan* stage of the construction procurement process requires the development of the project brief, followed by a decision on which procurement strategy will be followed for the project. The *Plan* stage also includes the design of the project. Although the use of BIM in design is relatively common, its application to health and safety is typically late in the design process. Early choices made on a project have a disproportionate influence on project outcomes, so it is important for health and safety to be considered as part of this early-stage decision making. BIM and associated technologies can provide valuable information to assist in this process.

In the *Source* stage, the procurement process is concerned with preparing documentation to inform the contracting process, setting out expectations and processes required for health and safety throughout the project (MBIE, 2019). It also involves assessing the health and safety capabilities of those parties considered for project involvement. BIM may be a useful tool in this stage, both to help the contracting party to communicate requirements or constraints to potential contractors, and for potential contractors to provide visualisations and examples that help to demonstrate the capability and maturity of their health and safety processes.

The third stage of the health and safety procurement process is *Manage*. During this stage the construction work is carried out and the main onus for ensuring health and safety is on the party carrying out the work. However, the contracting party still has a responsibility to carry out audits and inspections to maintain oversight of the work, and ensure it is performed according to the agreed standards. At the conclusion of the project, the final stage is to review the project as a whole and record lessons learned. From a procurement perspective, the main concern is to ensure the necessary project structure is in place to enable BIM. However, BIM also provides opportunities for facilitating information flows or supporting alternative procurement approaches, that have the potential to lead to health and safety improvements.

2.1. Reality capture

Reality capture uses digital tools such as laser scanning or photogrammetry to collect a detailed set of data points about existing objects, buildings or other site elements. These data points can then be converted into a 3D digital model and integrated with a BIM model to support other modelling activities. Reality capture and BIM can assist with health and safety in the *Plan* stage by providing accurate and detailed information about the existing conditions of a site or structure as input to procurement or design decisions, as well as in the *Manage* stage of a project where it can be used to facilitate site monitoring and to collect as-built information as part of project evaluation activities.

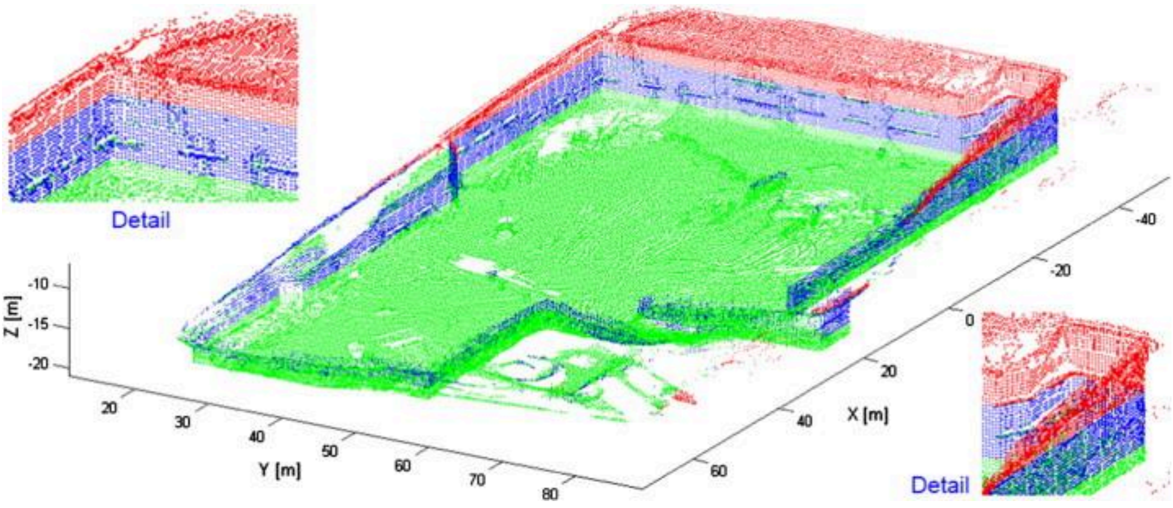
The primary benefit of reality capture for construction health and safety lies in the quality of information available for decision making, particularly in respect to the health and safety of workers during the construction stage (Fobiri et al., 2022). Projects that proceed according to design intent and previously planned construction methodology have a lower likelihood of health and safety incidents; unexpected conditions or additional unplanned tasks (particularly rework due to design or construction errors) are significant factors in accident occurrence (Pereira et al., 2020).

Reality capture can also be carried out at a distance from the site using cameras or laser scanners mounted on drones or robots, which provides a particular benefit where the site may be inherently hazardous. A local example of this is the use of a robot “dog” in Christ Church Cathedral (Christ Church Cathedral Reinstatement Project, 2021), to carry out a laser scan and 360° photographic survey to assist in the design and planning for stabilisation and rebuild, since the building was considered too dangerous for humans to enter after the Christchurch earthquakes.

2.1.1. Case study

Wang et al. (2015) provide an example of reality capture of a site environment being carried out to identify hazards and inform safety planning. In this case, laser scans were performed to collect 3D point cloud data from a construction site under excavation. Processing once the scanned data had been collected allowed the removal of temporary obstacles such as excavation equipment, and extraneous elements outside the area of interest such as trees, roads and surrounding buildings. Analysis of the resulting point cloud model allowed identification and visualisation of potential fall and cave-in hazards (see Figure 1). The data was also imported into a BIM model to provide an accurate representation of the site conditions to assist in the design and modelling of safety protective systems.

Figure 1. *Point cloud representation used to visualise cave-in hazards*



Note: From “Geotechnical and safety protective equipment planning using range point cloud data and rule checking in building information modeling” by J. Wang, S. Zhang & J. Teizer 2015 *Automation in Construction,* Vol. 49 Part B, pp. 250-261. https://doi.org/10.1016/j.autcon.2014.09.002

Although in this case study the data capture was conducted during the excavation stage of a project, i.e. once the project was already underway, the same principles apply to preliminary reality capture that may be beneficial at the outset of a project. If used for establishing initial site context, the elements that were considered extraneous in the case study (trees, other buildings, etc.) would provide important information to assist in decision-making around the need for specialist site development, whether for safety or other aspects of design, and to provide a realistic basis for design.

2.2. BIM-supported prefabrication

Prefabrication, and off-site manufacture in particular, has the potential to significantly reduce the hazard level of a construction project (Toole & Gambatese, 2008). On-site prefabrication allows alternative construction approaches to be used that may help reduce workers' exposure to hazards, for example, partially constructing services installations at ground level to reduce the amount of working at height required, or prefabricating sections of reinforcing cage on a trestle before lifting into place, to reduce muscular strain for workers. Off-site manufacture (OSM) offers additional health and safety improvements; site conditions are often constrained by other workers or equipment, have uneven working surfaces, moving vehicles and are exposed to the elements, factors which are not an issue in factory-based construction. OSM allows other efficiencies that may support worker safety, including the ability to use additional machinery and systems that may not be available or possible on site. Haslam et.al (2005) identified that a large proportion of site incidents could have been avoid through pre-fabrication, especially if the construction work had been moved off-site.

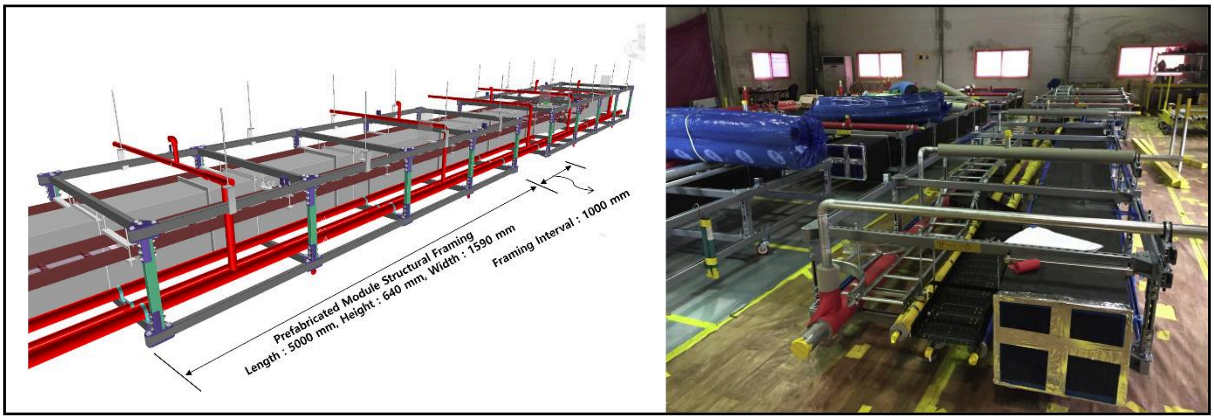
Using BIM as part of a prefabrication process provides significant benefits to a project. Key barriers to effective prefabrication include poor communication processes, lack of information sharing and inadequate project planning and scheduling (Sooriyamudalige et al., 2020). These are project aspects that BIM has been demonstrated to improve (Mostafa et al., 2018). The ability to rehearse construction methods and processes in BIM prior to activities taking place on site allows the integration of prefabricated elements into site works to be thoroughly coordinated, which facilitates the use of off-site manufacture even for complex building objects.

Decisions about the use of prefabrication need to be made early in the *Plan* stage of the procurement process, as it has significant implications on the subsequent planning and design of the project. Tang et al. (2019) emphasise the need for the contractual framework used in BIM projects to include clearly-defined and well-connected relationships between project stakeholders in OSM, further illustrating the importance of the procurement process in ensuring successful BIM use in a project.

2.2.1. Case study

Jang and Lee (2018) presented a case study of a multi-trade prefabrication activity which used BIM to support the coordination, manufacturing, and assembly of corridor racks for an automotive exhibition building. These racks consisted of a structural frame containing a complex arrangement of mechanical, electrical, and plumbing (MEP) systems components (See Figure 2). The pre-fabrication process delivered significant project benefits in terms of health and safety. The improvements included the much lower working height and ability of workers to work more comfortably without bending or reaching. Interference between workers of different trades was also avoided, which has health and safety, as well as productivity, implications.

Figure 2. *Corridor MEP racks in BIM model and factory manufacturing*



Note: From "Process, productivity, and economic analyses of BIM–based multi-trade prefabrication—A case study" by S. Jang & G. Lee, 2018 *Automation in Construction,* Vol. 89, pp. 86-98. https://doi.org/10.1016/j.autcon.2017.12.035

A notable finding from this case study was in relation to the level of planning and preparation necessary to enable the prefabrication work. In the project described, the BIM process of modelling, coordinating and re-modelling required for the off-site manufacturing was estimated to take an additional four weeks at the pre-construction stage compared with traditional construction processes. This additional time was needed to allow all clashes to be resolved and construction sequencing to be planned, before factory production commenced. The authors also identified that this form of off-site manufacture was only possible because the elements were fully designed prior to the construction stage, and noted that off-site construction is not suited to situations where design change is expected. Both of these observations highlight important factors that need to be considered as part of the procurement process.

2.3. BIM-connected health & safety knowledge base

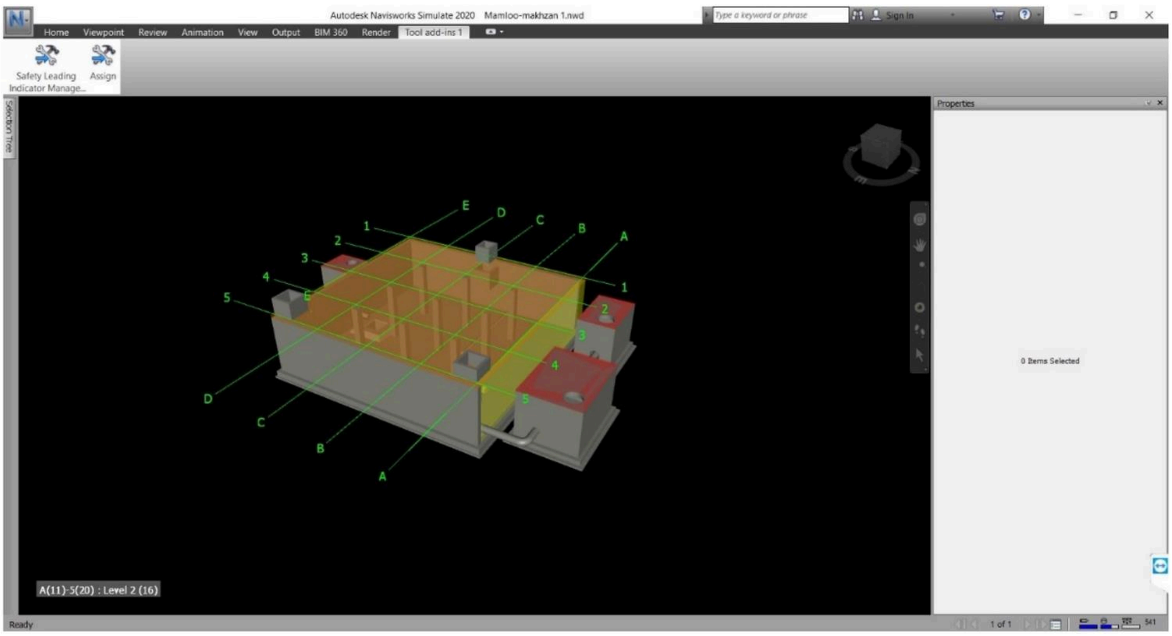
A knowledge base is essentially a facility that supports the collection, management and retrieval of information. A health & safety knowledge base is specifically targeted towards knowledge of safety-related information, and may be compiled using information drawn from expert practitioners, documents, and project best practice. The use of a safety knowledge base in conjunction with BIM opens up opportunities to manage safety information in a project, and to reuse that information on other parts of the project or on other projects, in the form of rules or prompts in the BIM model. These uses are most closely aligned with the *Plan* and *Manage* procurement stages because of their application to design and construction health and safety, and have been described in the context of automated rule-checking in Okakpu et al. (2023) and Davies (2023).

Depending on the information captured by the knowledge base, this approach can also be used to oversee the safety management process on a project, which aligns with the auditing and oversight activities described in the *Manage* stage of the procurement process. A knowledge base can be linked to locations or objects within a BIM model, and can be used to document safety activities or actions taken in relation to them.

2.3.1. Case studies

Dadashi Haji et al. (2022) used a BIM based knowledgebase to assess the impact of safety leading indicators. The safety knowledge base was formulated using interviews with experts, expert analysis of project documents and published literature, and lessons learnt from previous projects. The knowledge base items were allocated attributes in terms of spatial characteristics or connected activities, and provided an indication of likely hazards that could arise from a particular set of attributes. Activities during the construction process were also allocated attributes that indicated their vulnerability to a particular hazard. By combining this information in a BIM model, a 'heat map' was produced (see Figure 3) that provided a 3D representation of the building showing areas where hazards were most likely to arise.

Figure 3 *Heat map generated in a BIM model using a knowledge base of safety indicators*



Note: From "BIM-Based Safety Leading Indicators Measurement Tool for Construction Sites" by M. Dadashi Haji, B. Behnam, M. H. Sebt, A. Ardeshir & A. Katooziani, 2022 *International Journal of Civil Engineering,* Vol. 21, pp. 265–282. https://doi.org/10.1007/s40999-022-00754-9

Collinge et al. (2022) demonstrated the use of a safety knowledge base in the form of a safety risk library integrated into a BIM platform. To create the knowledge base, the research team used archive materials related to health and safety accidents, such as reports and press releases, to extract data that were categorised according to type of incident, locations and associated activities, among other factors. This was developed through workshops with industry experts to add potential mitigations or treatments to the situations described. Figure 4 provides an example of the type of structured data collected through this process. This resource was subsequently developed into a prototype that made the information available through a prompt interface within a BIM tool. This meant that while using the BIM model, the knowledge base could be called on to provide suggestions of actions that could be taken where a hazard was identified, and provide the benefit of previous knowledge to support decision making. Case study participants identified that the risk library was able to "positively impact design decisions, support selection of appropriate treatments to mitigate health and safety risks, and enable leveraging lessons learnt across previous projects" (p8).

Figure 4 *Example of matrix structure for risk and mitigation information*

Scenario Scenario 1: Floor with openings (150 < x < 3000)		Risk Fall: From open edge	Construction Scope In situ concrete
Building Element Slab	**Element Location** High-Level: Near Opening	**Associated Activity** Install construction	**Risk Factor** Physical: Opening

	Eliminate	Reduce	Control by subsequent design	Inform
Preliminary Design	Replace all openings required in floor slabs with precast service openings.	Cast in mesh in openings to reduce risk of person falling through.	Group small floor openings together to create one large opening.	Engage Strucutral Engineer with Architects to assist in design of handrail and guard elements.
	Avoid holes - consider alternatives to achieve design purposes.	Reduce hole sizes.	Locate floor openings away from passageways, work areas, & structure perimeter.	Engage with contractors and temp. works at appointment.
Detail Design	Avoid low walls in circulation areas.	Avoid trap hazards near openings.	Design permanent grating in opening to be installed when opening is created during construction.	Identify covering strong enough to support any loads likely to be placed on it - fix in position to prevent accidental dislodgment.
	Avoid hidden alcoves and offsets.		Specify guardrail systems around floor openings except at the entrance to stairways.	
Pre construction	Avoid risk of objects falling from holes/openings on workers below.	Provide requisite guardrails and toe boards at all slab openings.	Provide warning markings and/or colour change.	Inform contractor to design-in permanent cast-in sockets around floor openings to enable early installation of railings.
			Provide protective grate to support weight of person over opening.	Identify safe working load (SWL) of temporary covers in slab floor and specify fixings.
			Use safety nests fixed directly below the opening.	
Site work, Temp works, Change control	Securely fix cover with adequate safe working load (SWL) over opening with fixings requiring tool.	Ensure work is carried out only when weather conditions do not jeopardise the health and safety of workers.	Provide safe lighting levels, including access and depression.	Inform Site team of any activities when covers or guardrails need to be removed.
	Impact protective measures regularly.		Consider indicating pathways and adding tie-offs.	Site team required to highlight and report any changes on iste affecting the design.
			Every temporary floor opening shall be constantly attended by someone.	Contractor should identify all remaining opening/edges and check the selected permanent safety measures.

Note: From "BIM-based construction safety risk library" by W. Collinge, K. Farghaly, M.H. Mosleh, P. Manu, C.M. Cheung & C.A. Osorio-Sandoval, 2022 *Automation in Construction,* Vol. 141, Article104391. https://doi.org/10.1016/j.autcon.2022.104391

3. Enabling BIM for health and safety

In order to meet the requirements of HSWA (2015), it is accepted that health and safety needs to be an integral part of any construction procurement process. Achieving this begins with establishing a health and safety strategy early, as part of the project brief. Similarly, effective BIM use needs to be considered from the outset of a project, and include the full range of BIM uses and users. Decisions made at the start of the project affect all future project stages, and consideration of BIM at an early stage will support better communication and help avoid interoperability issues between project stakeholders (Abd Jamil & Fathi, 2018). Consequently, the procurement process is fundamental to integrating BIM into health and safety processes on a project.

3.1. Client role

A lack of client demand for BIM has been widely identified as a significant limiting factor in BIM uptake, in New Zealand as well as internationally (Hall et al, 2022; Vass & Gustavsson, 2017). Without a client providing explicit expectations and support for BIM implementation across the wider project, it is common for parties to limit their use of BIM to suit their own specific needs, without considering other stakeholders (Dakhil et al., 2019). This situation was described by Vass & Gustavsson (2017, p607) as “a kind of limbo,” where clients expect designers and contractors to take the lead on BIM within a project, whilst contractors in particular are waiting for direction from the client to enable them to use BIM more fully. As a result, many of the potential benefits of BIM go unrealised, in health and safety as well as for other project objectives.

Many clients do not have the knowledge or experience to specify BIM requirements within a project, and have limited understanding of how to manage BIM throughout the construction process. This may lead to a limited definition of BIM requirements at the procurement stage which, as a consequence, may flow on to a poor connection between the design, construction and operational stages of a project (Pidgeon & Dawood, 2020). Even where the client has the necessary knowledge, different project participants often have differing interpretations or expectations of BIM within a project, depending on their specific areas of expertise and concern, and the uses of BIM with which they are familiar (Abbasnejad et al., 2021). To overcome this, the BIM section of the New Zealand Government Construction Procurement Guidelines (MBIE, 2019) recommends the involvement of a BIM specialist early in the project to ensure that BIM needs are considered as part of the project definition. Additionally, it has been noted that the use of BIM to improve project performance in health and safety is often limited by project participants falling back on traditional approaches that they are more familiar with (Ganah & John, 2015); this aspect may therefore not be as well covered as it might be, even with a BIM specialist involved. This places a responsibility onto the client or client representative to ensure that health and safety expectations are communicated to those providing input into the brief and project strategy.

3.2. BIM framework and project definition

As is the case with any project data, project participants need to determine protocols for exchanging BIM data with other project parties. Joyce and Houghton (2014) specify three sets of protocols that need to be considered: what each party is required to do in creating data; the rights each party has to use project materials they have created or have been given by others; the responsibilities each party has for issues arising from exchange or use of data. While these protocols are not specific to the use of BIM for project health and safety requirements, they clearly align with the HSWA (2015) requirements that all contracting parties consult, cooperate and coordinate in delivering their responsibilities.

The New Zealand BIM Handbook (BIM Acceleration Committee, 2019) sets out a process and supporting documents for defining a project from a BIM perspective. This begins with a project BIM brief. The BIM brief sits alongside and is interconnected with the project brief, but is specifically geared towards defining the use of BIM during the design and construction stages, and the management of the digital asset (the BIM model) that results from the process. This document sets out the client's expectations and priorities on the project and establishes standards for the use and provision of BIM on the project. If the client expects BIM to be used as an enabler for health and safety improvements on the project, this would be specified in the project BIM brief (London et al., 2020).

In order to coordinate and manage the various parties to the project, a BIM Execution Plan (BEP) is a key document that outlines how BIM will be used, including the scope, level of detail, roles, deliverables, processes and protocols for BIM. A separate BEP may be prepared for the design, construction and operation phases, to set out the changing BIM objectives and processes as the project progresses.

Outside the NZ context, an increasingly important resource is the ISO 19650 series of international standards, which set out high level principles for using BIM to plan, produce and manage information throughout the lifecycle of a project. These documents are driving a process of alignment for other BIM documents and processes internationally to unify and clarify project approaches to BIM (ANZ Guide, 2019), and will form a central reference for future revisions of the NZ BIM Handbook.

3.3. BIM contractual issues

A misalignment exists between typical construction procurement processes and BIM, which can limit the potential benefits of BIM throughout the project life cycle or create challenges for BIM implementation. Key issues are that developing a BIM strategy generally begins with the design stage, and design consultants tend to be procured concurrently. This may place a BIM manager in the position of firming up the project scope, from a BIM perspective, at a point where other consultants may have already been procured on a basis that is not coherent with the developing BIM strategy (Abd Jamil & Fathi, 2018). Aibimnu and Papadonikolaki (2020) identify that successful BIM implementation depends on coordination among the various tasks and disciplines within the project, and establishing a shared understanding between the various parties at an early stage is an important component of that.

Successful BIM projects have been conducted within a range of contractual frameworks, achieving benefits in health and safety as well as other successful construction outcomes. Collaboration in BIM is largely dependent on a range of intangible, “soft” factors such as organisational culture, participants’ social skills, and trust (Oraee et al., 2019). However, it is widely recognised that the benefits of BIM are greater if the procurement strategy is designed to support collaboration (MBIE, 2019). Ragab and Marzouk (2021) highlight that informal approaches to collaboration are quickly sidelined if disputes arise, and parties tend to fall back on traditional adversarial approaches if collaborative processes are not defined as part of the contract.

3.3.1. Design-Bid-Build (DBB)

In the traditional design-bid-build (DBB) model, designers and constructors are contracted separately to the client to carry out their project contributions separately. The design process is completed before the project construction is sent out to tender. Main contractors negotiate with sub-contractors and suppliers to put together a proposal for the construction approach and cost of the works. Elements that need to be considered in relation to BIM are the status and completeness of BIM models and the responsibility for managing the BIM process. From a BIM perspective, the separation of design and construction BIM modelling is an inhibitor of successful BIM use, and may result in models not being handed over or modelling outputs by the different parties that do not meet the needs of others in the project (Holzer, 2015). DBB also presents challenges for consideration of health and safety during the design stage. The designers who are conducting any safety in design exercise are unlikely to have the construction knowledge necessary to make decisions related to construction methodology, which reduces the scope of design changes that could potentially improve construction health and safety. As a result, close attention needs to be paid to the BIM capabilities of the parties, and especially to their willingness and ability to collaborate within the structured contractual relationship, so that information and decisions can be shared where appropriate.

3.3.2. Design-Build (DB) and Early Contractor Involvement (ECI)

From a BIM perspective, design-build (DB) is a more collaborative framework that sees a single contractual relationship between the client and the team responsible for both design and construction of the project. This may be in the form of a joint venture, or may be led by either the design side or construction side. In either case there is shared ownership of the BIM model, with both design and construction teams contributing to information development (Holzer, 2015). Early contractor involvement (ECI) is a slightly different model where a contractor is engaged alongside the design team to provide the benefit of their knowledge and experience as part of the design process. This can help improve buildability and allow optimisation of designs for materials and construction methodology and sequencing. It also brings construction expertise into the safety in design process, which can be captured in the BIM model of the design to be transferred through to the construction stage.

3.3.3. Integrated Project Delivery (IPD)

Under an integrated project delivery (IPD) framework, each project participant plays a role in contract management, design and construction decision making. This connected approach to the project aligns strongly with the collaborative working ideal of BIM processes, with information sharing taking place using BIM. IPD also supports a mutual and coherent process for the development of the BIM model (Holzer, 2015). The IPD approach allows project participants who are typically involved in later stages of the project to engage earlier in the process, adding their expertise to decisions around design and construction. One key benefit of this is the availability of all parties to contribute to health and safety design and planning, and for their contribution to be captured in the BIM model for all to make use of as required.

3.4. Cost of BIM

The cost of BIM and who should bear it is a factor that must be considered as part of the procurement process. A barrier to wider uptake of BIM has been that the parties may not gain benefit from the use of BIM that is proportional to the resources and effort that they put into the modelling process, but the value may be realised by a different project stakeholder. As explained by Zheng et al., (2017), "designers' contributions to BIM actually provide handsome benefits to clients and contractors." Clash detection and design coordination is an application of BIM that has been widely grasped, but Ragab and Marzouk (2021) identify that responsibility for dealing with any inadequacies of design identified in this process is often not defined. This often leads to ad hoc resolution of clashes, which causes additional cost, commonly borne by the contractor. Clients may therefore benefit substantially from BIM modelling carried out by designers and contractors, obtaining a resolved as-built model of their building for use in operation and maintenance, that is often not formally specified as a project output and is not recognised in the project's payment structure.

Costs of implementing BIM may also be substantial, especially if a previously unfamiliar tool or software is required as part of a project. The cost to an organisation or team goes well beyond the direct setup costs of software and hardware, with training costs and time implications, and the loss of productivity due to unfamiliarity of processes (Nnaji & Karakhan, 2020).

3.5. Project evaluation and lessons learnt

Although not focused specifically on health and safety aspects of BIM implementation, Aibimnu and Papadonikolaki (2020) argue that recording the time and effort investment in BIM activities provides a valuable source of data for process improvement. They suggest that it also helps to identify the interdependencies between BIM tasks and activities. Given the way in which health and safety requirements are embedded within every aspect of the building lifecycle, this type of analysis could be very beneficial for improving BIM strategies in this area.

4. Conclusions

BIM can aid in communication, visualisation and information management to support decision making around health and safety in the construction procurement process. Tools such as reality capture and knowledge bases extend the information available for project definition and planning. The use of BIM for prefabrication and off-site manufacture opens up an additional procurement route that can have significant health and safety benefits.

Despite the opportunities offered by these factors, however, a more important consideration during procurement is to ensure that systems and structures are in place to enable the use of BIM for health and safety throughout the life cycle of the building. For BIM to be successfully used in a project, whether for health and safety or for any of its many other applications, the procurement strategy needs to provide clear definition of project requirements and processes, including factors such as ownership of models and modelling responsibility, and how costs associated with BIM are to be managed.

Employment of a BIM specialist may be necessary from an early stage of a project, to help inform the client of potential uses and requirements of BIM, and to create a unified procurement process where BIM is developed in a consistent manner from the outset. Although collaborative contractual arrangements have been described as more suited to BIM implementation, the relationships and capabilities of the project participants may have a greater impact than the form of contract, and need to be specified and evaluated alongside other project considerations. The New Zealand BIM Handbook (2019) provides a suite of templates and examples of BIM planning documents that support the process of implementing BIM on a project.

BIM offers many opportunities to improve health and safety through the procurement, design and construction stages of the construction project, and throughout the operation, maintenance and eventual renovation or demolition of a built asset. However, the procurement stage is vital to enable them through a well-defined BIM framework for the project.

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