BIM SAFE NZ
Safety Through Technology

Integrating Building Information Modelling and Health and Safety:

The building life cycle

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Executive summary

Building Information Modelling (BIM) is a valuable tool to support health and safety throughout the building life cycle. This report focuses on it use in the building operation and maintenance, and end-of-life stages.

Drawing on New Zealand and international research, the report identifies and illustrates various applications of BIM that can improve health and safety for building managers, workers and other building users. Case studies demonstrate the multitude of ways that BIM can be used to store, manage, monitor, and analyse building information and performance, and to plan, execute, and evaluate building activities.

BIM can provide valuable information and enhanced communication for health and safety management throughout the building life cycle. It can help to identify and mitigate hazards, optimize building systems and services, support emergency planning and response, and facilitate maintenance and repair. BIM can also be extended to enable automated and predictive monitoring, digital twins, and augmented reality to create safer and more efficient work environments.

The report recommends that building owners and managers should be aware of the benefits of BIM for health and safety, and that facilities management professionals should be involved in the BIM process from the early stages. The report also suggests that guidelines and standards should be used as much as possible to ensure the quality and consistency of BIM data and information exchange across the building life cycle.

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1. Introduction

1.1. Background

Building Information Modelling (BIM) is increasingly viewed as a valuable tool in the design and construction phases of a building, including in supporting the health and safety needs of those involved. However, these phases represent only a fraction of a building's life cycle, and involve only a small portion of the total number of people affected by the health and safety of the building. BIM can help to improve health and safety for far more people if it is used during the operation, maintenance, and renovation phases, as well as the demolition and disposal phases. In fact, BIM can support health and safety throughout the entire building lifecycle, from inception to decommissioning.

While it is difficult to put a figure on just how many people are involved in a building at different stages during the building lifecycle, some estimates of lifecycle costs for commercial buildings provide an indication of the likely proportions, suggesting that 85% of the lifecycle cost of a facility occurs after construction is completed. To go one step further, the 1:5:200 ratio is a popular (though contested) rule of thumb that states that if the initial design and construction cost of a building is $1, the maintenance and operating cost over the years is equivalent to $5, but the salary spent on people working in that building will be $200.

Although these specific values have been widely debated, the message stands—the ongoing cost of operating a building over its lifetime exceeds the initial expenditure, and the cost to a business of the people using the building far outweighs both. In addition to those working within a business, other people affected by the health and safety of a building during its ongoing operation and maintenance include visitors to the building, staff who service and maintain it such as cleaners and maintenance workers, tradespeople and other workers involved in renovation and refurbishment, and eventual deconstruction and demolition.

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 as well as relationships or connections between 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 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 draws on New Zealand and international research to explore the use of BIM in supporting Health & Safety during the building life cycle. The early part of the building life cycle is covered by two previous reports on BIM for H&S in the design stage (Okakpu et al., 2023), and BIM for H&S in the construction stage (Davies, 2023a); therefore, this report focuses on the subsequent parts of the building life cycle: building use, and end-of-life.

As much as possible, this report avoids duplication of material that has been covered in the previous reports. However, many of the BIM approaches for health and safety that are used in the building life cycle are the same as or very similar to those used in design and construction; this is true of renovation and demolition activities in particular. Where the literature has identified use cases in building operation or end-of-life that are distinctly different from those provided previously, illustrative examples have been included, even if the core technology or application is essentially the same as that described in previous reports.

Because of the rapid change taking place around BIM, artificial intelligence (AI) and Internet of Things (IoT), recently published research has been prioritised. Older research has been included where specific health and safety applications have been described that have not been more recently addressed.

1.4. Report structure

The discussion of the literature is organised by significant facilities management activities that take place once construction has been completed. The following sections present a range of activities or applications where BIM provides an opportunity to improve health and safety once the building has been handed over for operation. Given that design and construction have been covered elsewhere, the two remaining stages of the building life cycle have been identified as the focal areas for this report: 1) Building operation and maintenance and 2) Decommissioning and demolition.

The two stages are further subdivided into various aspects or approaches, each of which is described and supported by case studies to illustrate different applications of BIM. Many of these activities have overlapping concerns, which have generally been addressed in one of the sections only. For example, although demolition may often be necessary to enable renovations, it plays a much bigger role in the end-of-life stage of a building and so has not been discussed under the renovations section.

Because of the vast range of activities which take place in the built environment, and the resulting diversity of health and safety concerns, this report does not attempt to identify specific types of hazards that BIM could be used to support. Instead, more generic applications of BIM have been described, in the expectation that a reader will be able to envisage specific situations or hazard types from their own experience, that the described applications might align with.

2. Building operation and maintenance

2.1. Introduction

Building information modelling can assist facility managers to improve the health and safety conditions of a building during its operation, by providing valuable information about its physical and functional aspects. BIM can store and manage a large amount of data related to the building's design, construction and operation, making it easier for facility managers to access, update and maintain the building's assets and systems. BIM and associated technologies can be used to enable proactive and adaptive actions to support workers who manage and maintain the durability and efficiency of the building, as well as ensuring the well-being and comfort of everyone using the building. Communication for all building functions can be enhanced, and, as expressed by Hoeft and Trask (2022), "the increased cross-functional teamwork and democratization of information management enabled by BIM methodology-based solutions can be of tremendous value for safety throughout the building lifecycle".

2.2. Building records

An as-built model of a building contains a record of all elements that were added during construction, including critical information like make, model, and manufacturer of plant and equipment. This is important information to support facilities managers in their decision-making and risk assessment, so the model helps to plan and execute operations and maintenance activities safely and efficiently. Having a common source of information also enhances the communication and collaboration among the stakeholders, who can share and use the as-built model and relevant health and safety information in a structured and consistent way.

2.2.1. Central repository of building information

A BIM model functions as a database of information about a building, with the capacity to include a substantial amount of building information. As well as recording geometry and location of equipment and machinery in a building, BIM provides a structure to store and update operation and maintenance information, such as manuals for installation, operation and maintenance and warranty documents, which can be linked to the relevant equipment in the BIM models (Williams et al., 2019). BIM can also be used to manage inventory and maintenance records of the building equipment and facilities, and facilitate the inspection and replacement of damaged or faulty components. Wetzel and Thabet (2015) identify that although all of this information is already typically available within an organization, it is often stored in multiple locations and formats and so requires workers to invest considerable effort to consult everything required before starting a work activity. By bringing them all together into one connected system, BIM improves the likelihood that the appropriate safety records will be reviewed before work begins, thus contributing to safer work environments. Centrally collating this information into a BIM model also means it can be easily accessed, updated, and shared by different stakeholders, such as the designers, contractors, owners, operators, and facility managers.

2.2.2. Managing maintenance and inspection records

Maintenance and inspection records can help the facility manager to identify and mitigate potential hazards, risks, and accidents that may occur in the building. For example, the BIM data can provide information about the location, condition, and maintenance history of building components, such as fire alarms, sprinklers, emergency exits, etc. Further information can also be included to record other information that supports appropriate processes for maintaining the safety of the building, such as safety requirements, maintenance and inspection schedules (Fargnoli et al., 2019). The facilities management team can use this information to plan and schedule preventive maintenance, inspections, and repairs, as well as to ensure compliance with health and safety regulations and standards.

2.2.3. Connecting BIM and FM-specific tools

Where facilities management teams do not have the capability to use BIM tools directly, exchange formats such as COBie can be used to export information from the BIM model for use in specialised FM software (Matarneh, 2020). This allows the richness of information that is produced during the design and construction stages to flow through to the building operation, without significant changes to current practices in facilities management. However, those developing and managing the BIM process typically lack knowledge about the kind of information that the FM team requires and how to deliver this information effectively to the current FM systems, which poses a barrier to more effective transfer of information across the building life cycle (Rogage & Greenwood, 2020).

2.2.4. Case studies

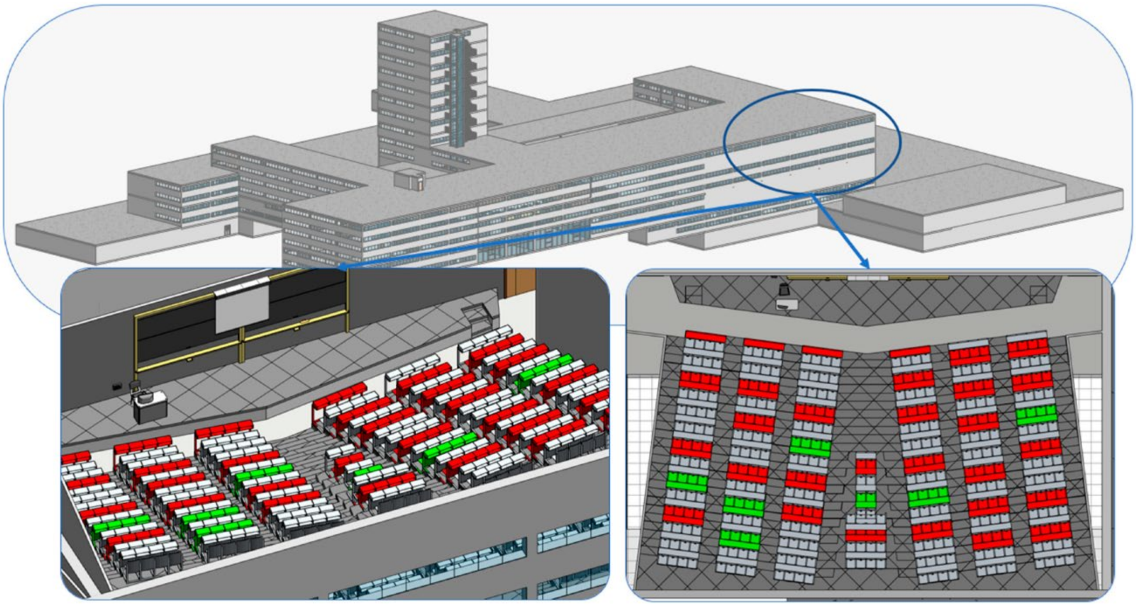
Once all the building information is brought together into a BIM environment, various interfaces can be used to access it for general use or specific purposes. Pan & Chen (2020) present an implementation that makes use of a BIM model as a building records system for reporting maintenance or repair. Users can scan the QR code of an object or building element requiring attention from a facilities manager (see Figure 1), which prompts them to complete a form describing the type of maintenance issue identified. The form is linked to the BIM model of the building, and the facilities manager is provided with the necessary details to quickly effect the required action, such as location, object type, maintenance information and serial numbers.

Figure 1 Scanning *of QR code to report a maintenance request*

Note: From “Facility maintenance traceability information coding in BIM-based facility repair platform” by N-H. Pan & K-Y. Chen, 2020. *Advances in Civil Engineering*, 2020, p.9. https://doi.org/10.1155/2020/3426563

This system ensures that problems are communicated without delay, and reduces the need for multiple visits to the site to diagnose the issue. It also helps the maintenance worker to be prepared and informed before performing the repair. As a result, there is less exposure to hazards, and a more secure and well-managed work environment. Pavón et al. (2020) present distinctly different use of BIM as a building records system in the operation phase of a building’s life cycle. Their research focuses on managing the movements and occupancy of building users during the Covid pandemic. The case study building used was a tertiary education building, and the tool developed was intended to facilitate social distancing and help avoid crowding. Based on information recorded in the BIM model, with the addition of student timetable data for room occupancy, the tool calculated the expected occupancy of all of the pathways and spaces in the building at a given time. This was provided as a visualisation to building users so they could make choices that would allow them to reduce their chance of infection. The tool also included a BIM-supported seat reservation system, which allowed students to book seats in classrooms and lecture halls to maintain social distancing. The link to the BIM model gave users the opportunity to view a visualisation of the room when they made their reservation (see Figure 2), and recorded their seating location in case their health status needed to be tracked. For facilities managers, the BIM-supported approach brought together a range of functions that were traditionally managed from separate formats.

Figure 2 *BIM-based seating registration system*



Note: From "Possibilities of BIM-FM for the management of COVID in public buildings." By R.M. Pavón, A.A. Arcos Alvarez & M.G. Alberti. *Sustainability* 2020, 12, 9974. https://doi.org/10.3390/su12239974

2.3. Monitoring building operations

A BIM model can be used as the basis for automated monitoring of a building and its performance. With the addition of sensors, cameras or other devices, monitoring can be carried out in real-time to ensure it performs within pre-determined parameters. This approach has many applications to the health and safety of building users.

2.3.1. Environmental factors

Environmental factors affecting the health and comfort of the building users can be monitored, such as temperature, humidity, lighting, air quality, noise, etc. The facility manager can use the BIM data to adjust and optimize the building systems and services, including heating, ventilation, air conditioning, lighting, etc., to create a suitable indoor environment for the users. The BIM data can also help the facility manager to identify and address any issues or complaints that the users may have regarding the building environment, such as thermal discomfort, poor lighting, odours, etc.

2.3.2. Hazard prevention

Monitoring can be used to detect and prevent potential hazards, such as structural defects, fire, gas leaks, or water damage, by comparing the sensor data with the BIM model and alerting the relevant stakeholders. This is particularly valuable where physical inspections and interventions can expose workers to risks. In these situations, remote monitoring and control of the building systems can create a safer working environment by reducing the need for site visits and hands-on activities.

2.3.3. Safety and security monitoring

Safety and security of building occupants can be supported through BIM and real time monitoring, through security and access control, such as preventing unauthorized entry, tracking the location and movement of people and assets, or verifying the identity of visitors, by using biometric, RFID, or facial recognition sensors. Although these systems can be operated independently of a BIM model, basing security on BIM data allows specific areas to be allocated different security conditions or classifications, and integrating security tracking with other aspects of building monitoring and performance.

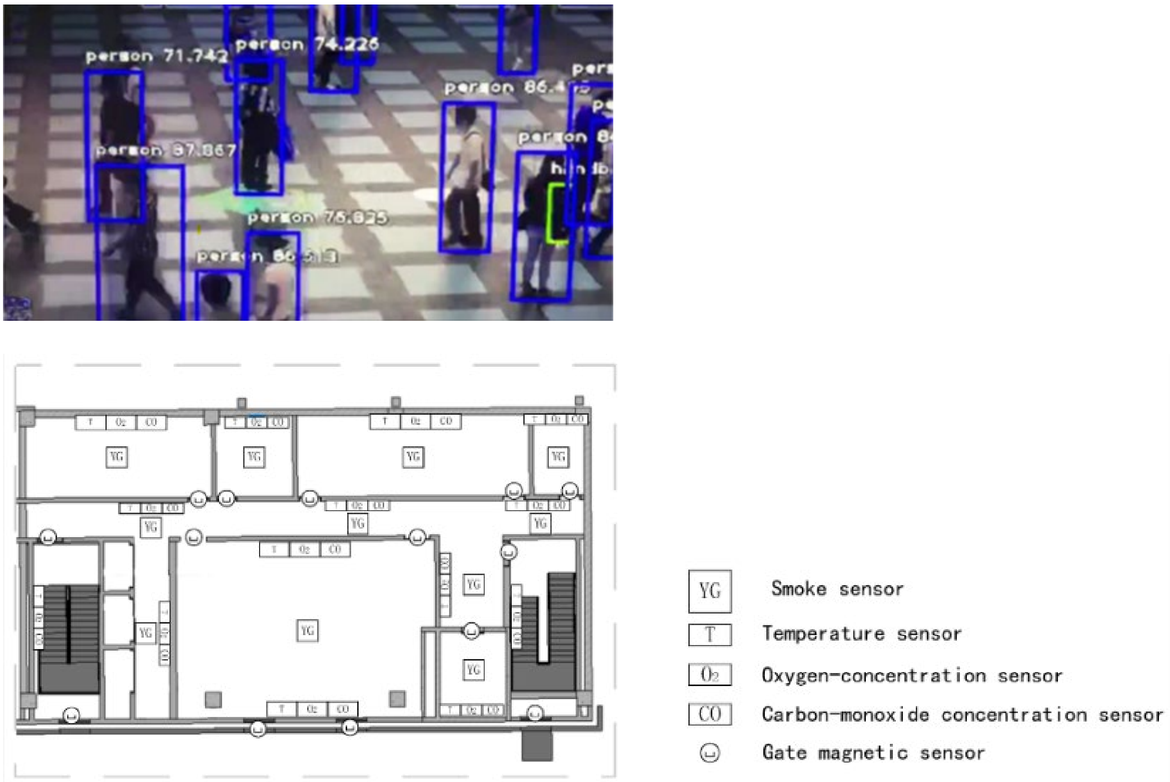
2.3.4. Digital twins

Digital twins add machine learning or artificial intelligence to the process to support predictive monitoring, where records of past performance and safety issues are used in conjunction with ongoing monitoring to identify factors that may lead to problems in the building. This approach can combine a variety of different data sources to detect problems that may not be indicated by individual sensors or monitoring devices. Maintenance or repair information can then be added to the model, with the resulting feedback loop helping to further refine the parameters for future application.

2.3.5. Case studies

Liu et al. (2020) demonstrated the use of BIM to enable automated building monitoring in a sports facility. Through the use of image recognition and sensors linked to a BIM model (see Figure 3), safety management staff were supported in identifying and responding to dangerous situations such as illegal intrusion, overcrowding, and fire. Once the sensors recorded conditions that met pre-identified danger levels, an alarm was triggered both in the affected spaces and in the 3D representation of the BIM model. The integration with the BIM model provides a 3D visualization of the location and its context, which enhances the situational awareness and decision-making of the safety management staff, and thus supports a prompt and coordinated response to the situation by allowing the safety management staff to understand the surroundings of the danger and handle it quickly and accurately.

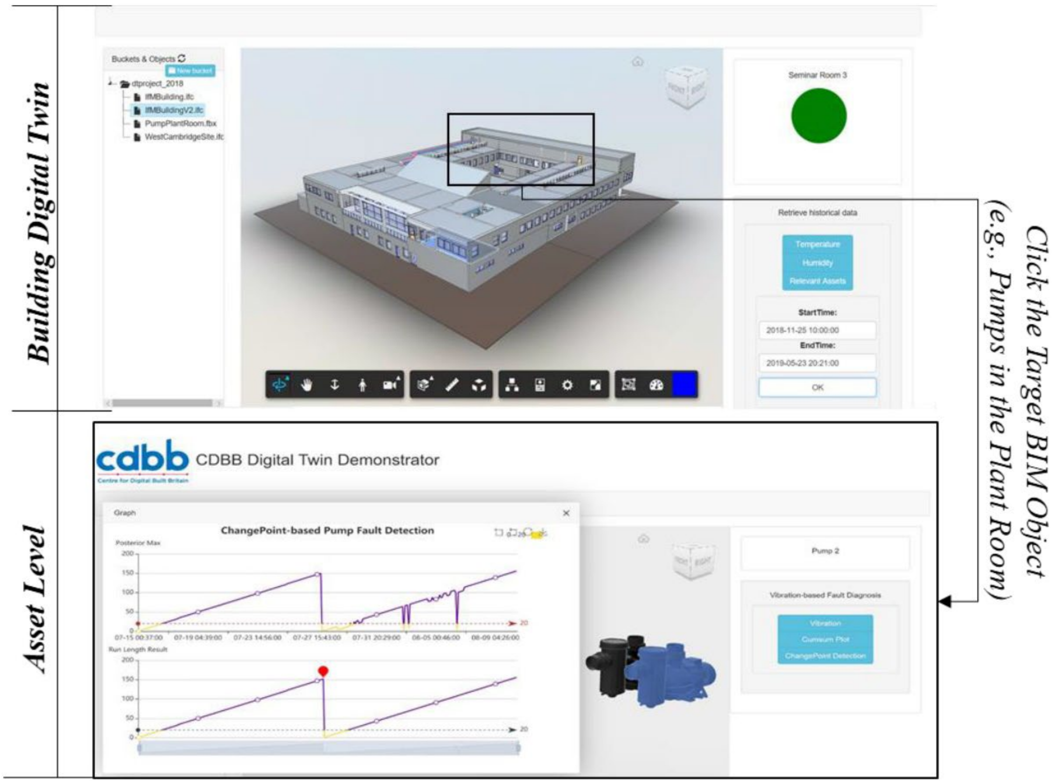
Figure 3 *Image recognition and sensor setup for identifying dangerous events*



Note: From "A framework for an indoor safety management system based on digital twin." by Z. Liu, A. Zhang, A., & W. Wang, 2020. *Sensors*, *20*(20), 5771. https://doi.org/10.3390/s20205771

Lu et al. (2020) provide an example of predictive monitoring using a digital twin to integrate data on the performance of building components. Their case study modelled the performance of two centrifugal pumps which form part of the heating and cooling system in a building. They used a BIM-based interface to connect data from sensors recording vibration and noise, as well as performance tracking of the pumps, and interpret the performance in the context of building use (see Figure 4). The system then compared the collected data against records of effective performance and failure characteristics of the equipment. Through early detection of faults, the system allowed facilities managers to take early maintenance measures and pre-empt a catastrophic failure that would have had health and safety implications for building occupants and maintenance workers.

Figure 4 *Representation of BIM model and monitoring data in a digital twin*



Note: From "Digital twin-enabled anomaly detection for built asset monitoring in operation and maintenance" By Q. Lu, X. Xie, A. Kumar Parlikad & J.M. Schooling. 2020. *Automation in Construction* 118, 103277. https://doi.org/10.3390/su12239974

2.4. Maintenance and repair

Perhaps the most valuable use of BIM to support safe maintenance and repair during the life of a building occurs at the design stage. By using BIM to facilitate safety-in-design processes, the needs of building users can be considered at the point where significant decisions are made. Automated processes can also be used in the design stage to check compliance with safety codes and recommendations, further ensuring the safety of building users during the operational life of the building. This use is detailed in Okakpu et al. (2023).

Other applications of BIM for maintenance and repair activities draw on its record-keeping and data management aspects. Maintenance tracking and record-keeping tools can be linked to BIM to facilitate the documentation required for ensuring plant and equipment is inspected, maintained and repaired as needed for safe operation. Augmented reality solutions also provide applications of BIM that can be used to support maintenance and repair by giving interactive and visual access to the information needed.

2.4.1. Case studies

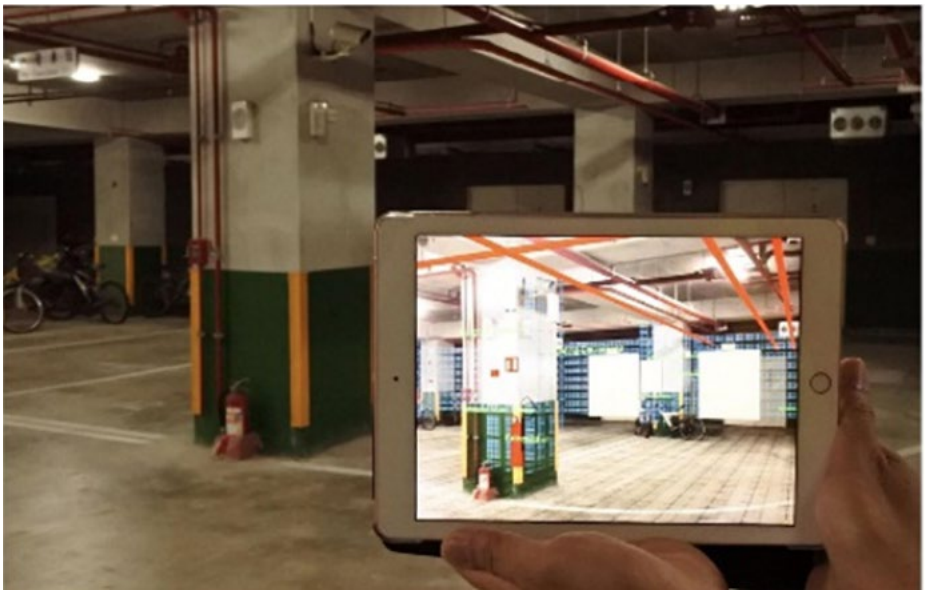
BIM can provide an information-rich environment for managing maintenance processes and guiding maintenance workers on what works need to be carried out and when. Ma et al. (2020) describe a system that integrates business processes into a BIM-based maintenance system. This allows a two-way exchange of information that contributes maintenance and operation data into decision making about business processes, and vice versa. Appropriate maintenance is an essential aspect of managing health and safety in the built environment, and this system not only helps building owners and managers to meet the needs of their assets, but also demonstrates that they have done so.

Figure 5 *BIM-based system for managing maintenance work orders*

Note: From “Data-driven decision-making for equipment maintenance” by Z. Ma, Y. Ren, X. Xiang & Z. Turk. 2020. *Automation in Construction, 112.* https://doi.org/10.1016/j.autcon.2020.103103

Chen, et al. (2020) provide an example of augmented reality in use for inspection and maintenance of fire safety equipment (FSE). Using a portable device, users were able to view data from the BIM model and a maintenance database overlaid onto their view of the building. Information was provided through the interface to assist the user to identify the type and location of the equipment, and review the elements that required inspection or maintenance (see Figure 6). The system also allowed notes or updates to be added through the interface to be recorded for future reference or to refer issues back to the facilities management team.

Figure 6 *Augmented reality interface showing location of fire safety equipment*



Note: From "BIM-based augmented reality inspection and maintenance of fire safety equipment" by Y-J. Chen, Y-S. Lai & Y-H. Lin. 2020. *Automation in Construction, 110.* https://doi.org/10.1016/j.autcon.2019.103041

2.5. Emergency management

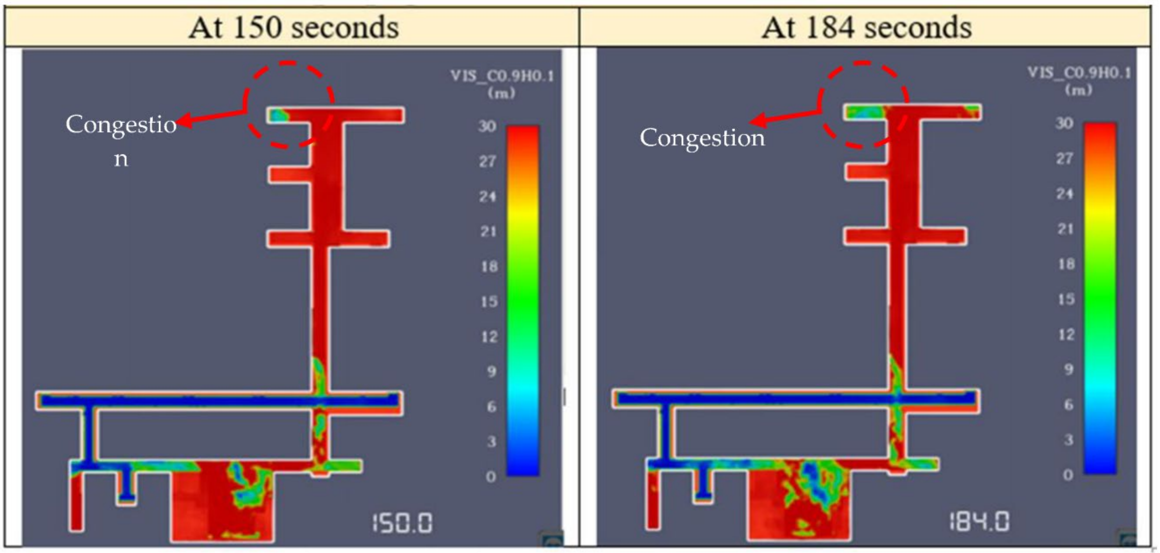
BIM can be used to store important information about the building which is useful in the event of an emergency. Key factors may be recorded in association with the geometry of the building, such as escape paths and the location of fire exits and the location and availability of emergency equipment. This information can be accessed by emergency responders before they enter a building, which can help ensure they have the most updated and accurate information, and support them in coordinating their actions, and monitoring the situation.

The digital model of the building can be used to enable spatial analysis and simulation of different emergency scenarios, such as fire spread, evacuation routes, and resource allocation. This can help emergency planners to assess the risks, identify the optimal solutions, and communicate the plans effectively. It can also be used in conjunction with virtual reality to allow building users and emergency responders to rehearse their actions in case of an emergency, and improve their familiarity with expected procedures. Analysis of users' responses in an interactive environment can also be used to help optimize evacuation plans and ensure they are effective in the event of an emergency.

2.5.1. Case studies

When renovation or maintenance works are planned, the BIM model can help to identify any impact it may have on escape paths or access to emergency equipment. Shams Abadi et al. (2021) provide an example of fire egress planning during renovation. They used the BIM model of the original building, with additional information specific to the renovation works such as space allocated to construction activity, blocked exits, obstructed routes, and occupant location and density during renovations. This information was used in conjunction with the construction programme to determine potential fire locations, to provide the basis for simulation of occupant behaviour during fire events. Aspects such as likely escape paths to emergency exits, congestion, visibility (see Figure 5) were simulated and modelled using BIM. The resulting information was fed back into the planning process for improving safety during the renovation works.

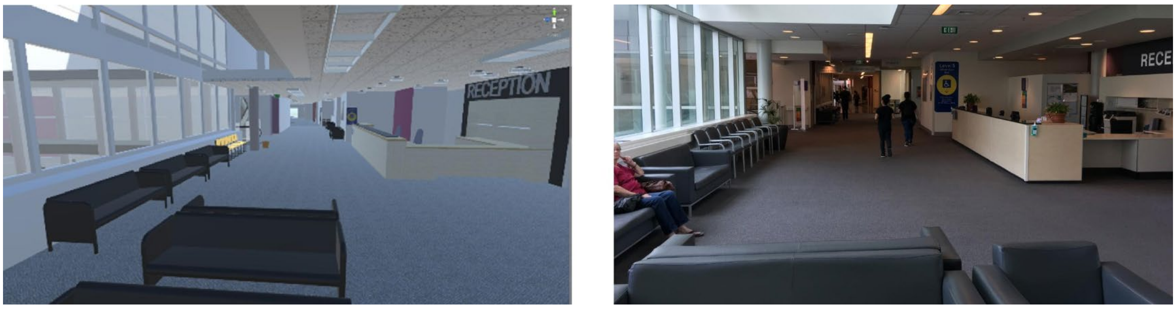
Figure 7 *Modelling of visibility at different stages of a fire evacuation*



Note: From "BIM-Based co-simulation of fire and occupants' behavior for safe construction rehabilitation planning" by S.T. Shams Abadi, N. Moniri Tokmehdash, A. Hosny, M. Nik-Bakht, 2021. *Fire*, 4, 67. https://doi.org/10.3390/fire4040067

Buildings such as schools, hospitals and other high-occupancy facilities are challenging to manage in emergency situations because it of the difficulty of carrying out drills for familiarise occupants with safety expectations in case of emergency or evacuation. In these situations, the use of a BIM model and virtual reality provides a training environment that mirrors the real situation. Figure 6 shows the representation of a hospital in comparison to the actual space, used by Feng et al. (2020) to create a gamified system to train workers and visitors in how to respond in case of an earthquake. The BIM model of the building was imported into a game engine to provide an accurate representation of the space, to familiarise users with the space and help them identify the appropriate reaction in different conditions.

Figure 8. *Comparison between virtual reality model used for emergency training and actual building interior*



Note: From "An immersive virtual reality serious game to enhance earthquake behavioral responses and post-earthquake evacuation preparedness in buildings" by Z. Feng, V. A. González, R. Amor, M. Spearpoint, J. Thomas, R. Sacks, R. Lovreglio & G. Cabrera-Guerrero. 2020. *Advanced Engineering Informatics*, *45*, 101118. https://doi.org/10.1016/j.aei.2020.101118

2.6. Renovation and refurbishment

Renovations often pose more risks than new construction, due to the need to work within the constraints of existing structures and services. The more information that is available about existing conditions, the safer and more efficient the process will be. Unexpected challenges may still arise during the process, but having information available in a BIM model can help in development of prompt and effective solutions to prevent injuries, delays, and waste. The use of BIM during a renovation project provides the same health and safety benefits that are seen in a full construction project, including supporting better project communication and interaction, aiding safety in design processes, informing safe work planning, and monitoring and recording safety processes. However, literature that specifically addresses health and safety in the renovation stage is extremely limited, and are covered in the previous report addressing the use of BIM for health and safety in construction (Davies, 2023a).

3. Deconstruction and demolition

At the end of a building's life, BIM can contribute to the planning and execution of decommissioning and demolition activities by providing information about the building structure, materials, and components, their characteristics, quantities, and locations. This information supports the health and safety management of the activities by helping those conducting the deconstruction to identify and mitigate the hazards, and plan, monitor and control the operations.

3.1. Managing demolition waste

One of the greatest risks to health and safety in the end-of-life stage of a building is the waste materials produced when it is demolished or deconstructed. These waste materials can include concrete, bricks, metals, wood, plastics, glass, asbestos, and other substances that may pose environmental and health hazards. This can have a negative effect on health and safety that goes even beyond the building itself, if hazardous materials are not disposed of appropriately. The hazards of improper disposal of asbestos-containing materials are well-recognised, but many other building materials have similar health and safety implications.

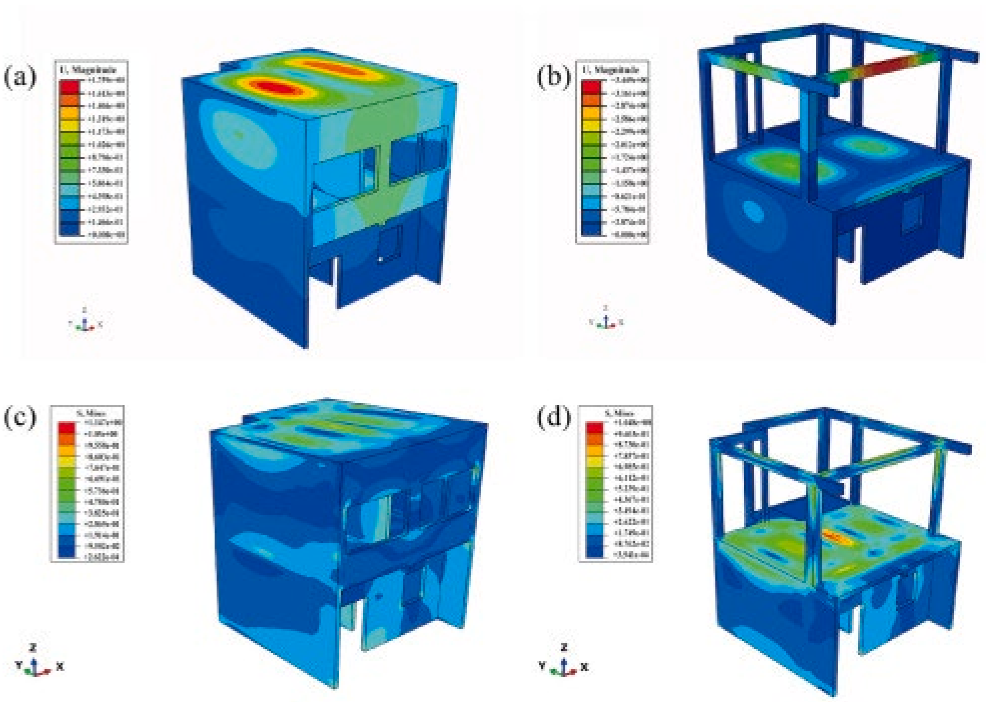
Because the BIM model of a building contains records on the materials and products that have gone into its construction, BIM can be used to survey the building and calculate volume and mass of each type of material used, as well as where they are located in the building (Hu et al., 2022). This facilitates thorough planning for the appropriate demolition approach and handling of waste materials, and allows additional hazards such as toxicity, flammability, corrosiveness, or radioactivity to be carefully considered. The BIM information can be extended through the use of a GIS to include information regarding the location of waste treatment plants and landfill sites so that transport can be minimised as well (Su et al., 2021). In common with most other studies on demolition waste, Su et al. (2021) focus on the use of BIM to minimise environmental impacts of demolition waste. However, the same approach is valid for a health and safety focus, and in many cases environmental impacts will have a health and safety element as well.

3.1.1. Case studies

Hu et al. (2022) present a method to create a BIM model of a to-be-demolished building using images collected by a combined unmanned aerial vehicle (UAV) and handheld camera system. The method includes camera motion path planning, feature points detection, dimension measurement, and material identification. The BIM model produced contains geometric, structural, and material information of the building elements, and can be used where an as-built BIM model is not held for a building, or to verify and update as-built documentation to account for dilapidation or modifications that have been made to the building since the original model was created. They presented an example of a 50-year-old residential building where the design data and maintenance records were no longer available. Challenges found by Hu et al. (2022) included the need for additional investigation of the building to identify where materials were contained inside the structure, for example reinforcement embedded in concrete was not identified by the photogrammetric approach used to create the BIM model but had to be manually added. However, for buildings which already have a relevant BIM model available, the demolition analysis can be carried out without the need for the preliminary model development.

Figure 7 shows the results of simulations carried out using the 4D BIM model, indicating structural deformation at different stages of the demolition process. This information was used to plan the appropriate demolition equipment and stages to ensure a safe process, and could also serve to brief workers on what to expect as demolition proceeded.

Figure 9 *Structural response modelling as part of simulating the demolition process*



Note: From "Smart building demolition and waste management frame with image-to-BIM." By X. Hu, Y. Zhou, S. Vanhullebusch, R. Mestdagh, Z. Cui, & J. Li. *Journal of Building Engineering* 49 (2022): 104058. https://doi.org/10.1016/j.jobe.2022.104058

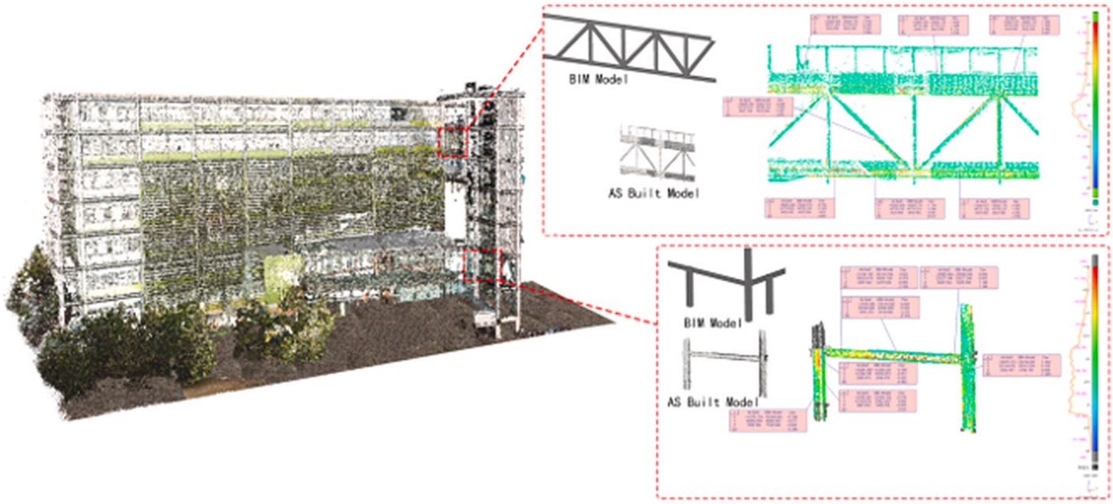
3.2. Planning for safe deconstruction

While demolition is a quick and destructive way of taking down a building, deconstruction is a process that involves greater care in taking a building apart to allow reuse or recycling of building components, and reduce waste. While still less prevalent, deconstruction is receiving increased attention for its environmental, economic, and social benefits. However, it adds significant challenges for safety. Deconstruction is a much slower process and more hands-on process than demolition, and requires workers to be more closely engaged in the activity. A significant safety factor is the lack of information on how a structure will perform once parts of it are removed during deconstruction. Structures are typically designed for the construction of the building and then its operational life, with little or no attention to end-of-life concerns.

3.2.1. Case studies

Xiao, et al. (2023) demonstrated the use of a BIM model using laser scanning and point cloud analysis to examine the steel structure of a building and identify sections that may be safely deconstructed for future reuse. The highly detailed BIM model allowed analysis of connection types and structural loads to produce a deconstruction sequence that allowed elements to be removed without unnecessary damage or risk. Figure 8 shows the outcome of an analysis identifying specific elements that could safely be removed from the structure. Ongoing scanning and monitoring during deconstruction could be fed back into the model to ensure decisions were made on the most complete set of data at each stage of the process.

Figure 10 *Analysis for deconstructability using point cloud model*



Note: From "Deconstruction evaluation method of building structures based on digital technology" by J. Xiao, L. Zeng, H. Xu, & H. Tang 2023 *Journal of Building Engineering*, Vol 66 10591, 19pp.

4. Requirements and recommendations

Across all of the applications of BIM for building operations and maintenance and end of life, the greatest barrier lies in the lack of forethought that typically goes into how BIM may be useful beyond the design and construction stages. The necessary solution to this is addressed in the report on BIM for health and safety in procurement (Davies, 2023b). The client or owner of the building needs to be aware of the ways BIM can contribute, so that appropriate BIM deliverables are produced for use throughout the life of the building (Munir et al., 2020). Early consideration of BIM processes and information management for the building in use increases the ability of facilities managers to take advantage of the opportunities it offers. "The involvement of FM professionals, therefore, is instrumental to creating complete and accurate building information that can be used for life cycle management." (Dixit et al. 2018, p479).

Interoperability and information exchange is an ongoing challenge all all stages within the building lifecycle because of the diverse applications and range of data formats available. At the project outset, better information exchange can be planned for if those involved in the early BIM establishment have knowledge of the facilities management tools used by building operators. However, in many case the data exchange processes will not be perfect or will need some further interaction to achieve the project goals. Using industry standards and guidelines wherever possible will help smooth this process (Tsay et al., 2022).

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