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8D-BIM models in construction: Enhanced occupational safety for construction works

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Abstract: Building Information Modelling (BIM) is a key tool supporting innovative approaches in the area of sustainable and ecological construction. Through the use of digital technologies such as BIM, it is possible to accurately plan and optimize construction processes resulting in efficient resource management, reduced energy consumption and minimized waste. BIM also allows for better collaboration between project teams, which supports the integration of sustainability efforts throughout the building lifecycle, from design, realization to operations and maintenance. In addition, the use of BIM can improve occupational health and safety (OHS) on construction sites. With detailed 3D models and simulations, potential hazards can be identified before work begins, construction site organization can be better planned and dangerous situations can be avoided. This facilitates risk management and also ensures safer working conditions for all participants in the construction process.

Keywords: Building Information Modelling, BIM, construction simulation, occupational health and safety, project coordination

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Introduction

The architecture, engineering and construction (AEC) industry is experiencing rapid changes in information technology (IT) due to digital transformation, bringing

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new opportunities and new challenges (Rafsanjani & Nabizadeh, 2023). The implementation of building information modelling (BIM) in the construction industry increases the efficiency of design, communication, management activities and redefines the roles of the project teams. Architects, engineers and building managers must adapt their tasks to work with digital data, requiring new technical and coordination skills (Chen et al., 2024). The philosophy of building object information modelling (BIM propaedeutics) aims to help this transformation and simplify work processes (Borkowski, 2024). The circular economy in construction, as a disruptive aspect, can be supported by digital technologies, particularly BIM technology, in terms of, among other things, increasing knowledge about the sustainability of the materials used as well as improving site safety (Banihashemi et al., 2024). Furthermore, improvements in the health and safety is vital for the construction industry. Introduction of BIM safety models in the design and planning stages can bring essential support to the health and safety performance of construction projects. The concept of Design for Safety (DfS) has been widely discussed in academic literature (Farghaly et al., 2022; Manu et al., 2019; 2021). DfS is an approach that focuses on incorporating safety considerations from the building design stage to minimize risks onsite. As part of the 8D-BIM concept – safety during design and construction – DfS is gaining prominence as a key element to identify and reduce risks using digital models and simulations. By integrating DfS into the BIM process, potential hazards can be detected, site organization can be better planned and safer working conditions can be created that directly impacts risk management and safety improvements for all participants in the construction process. This study examines the 8th dimension of work safety in BIM, while proposing a working methodology that can be used in coordinating and managing work safety in construction projects.

1. Dimension of nD-BIM technology

The aim of BIM is to provide efficiency in construction project processes and assist with better collaborative working (Holzer, 2011). BIM has altered the way buildings are designed, operated and maintained. As a result, BIM models allow for early detection of design faults and health and safety hazards (Adam et al., 2022).

Following the main fundamentals of BIM technology, a three-dimensional model of the building (3D-BIM) is developed, which, after saturating with parameters regarding the elements, is the starting point for developing further dimensions of the technology (Biswas et al., 2024). The modelling of a building is based on the use of parametric objects representing structural elements, which contain not only geometric attributes, but also information about the physical properties of the materials used (Sacks et al., 2004). The programmes that enable model development include various types of libraries of parametric families of building components, such as walls, slabs or columns. During the design process, for each branch: architectural, structural or installation, the designer selects the necessary objects and adjusts them to the design accordingly. Importantly, the parameter values of the objects can be modified according to the needs of the project, during its development, even after its completion, and new parameters can also be added at later stages of design as well as implementation. In this way, on the developed BIM model, the user can change and adjust model components according to new or alternative requests at any stage of the project and at any point in the life cycle of a construction object.

The nD-BIM model is obtained from the parametric modelling procedure (3D-BIM) and is the starting point for further analysis (Charef et al., 2018). The parametric BIM model can be used in multidimensional terms, as it allows for a set of processes related to the design, implementation, maintenance and management of a construction facility. Multidimensionality is often referred to as nD-BIM dimensions. Thus, the 3D-BIM model represents a set of 3D parameters used in all branches of the project (architecture, engineering, construction and installations) (Reynold et al., 2023; Yang et al., 2024). The 4D-BIM model deals with the construction work simulation of a facility, planned according to an established method of planning and scheduling of the construction projects (Jupp, 2017). The 5D-BIM model makes it possible to forecast construction costs and to significantly reduce material costs by reliably estimating these costs, based on a rigorous quantity survey before the execution phase begins (Aragó et al., 2021). The 6D-BIM model deals with research and simulation of energy and sustainability during the design phase and in the use phase (Montiel-Santiago et al., 2020). The 7D-BIM model, on the other hand, deals with the management and maintenance of a building throughout its operational life (Gao & Pishdad-Bozorgi, 2019). The multidimensionality of the models is shown in Figure 1.

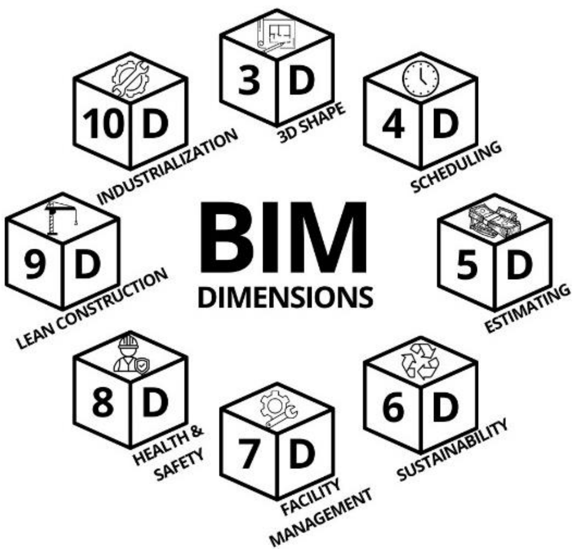

Fig. 1. Multidimensionality of nD-BIM models (*own research*)

2. Dimension 8D-BIM

In addition to the 7 defined dimensions of BIM technology, innovative directions for its development are currently being identified, in terms of three new dimensions of BIM, including: 8D-BIM: safety during design and construction (Collinge et al., 2022), 9D-BIM: lean construction (EL Mounla et al., 2023) and 10D-BIM: construction industrialization (BorjeGhaleh & Sardroud, 2016).

The proposed 8D-BIM dimension includes human safety in construction and supports preventive measures such as hazard detection in construction (Cortés-Pérez, 2020).

This paper aims to formulate a definition of a new eighth dimension of BIM technology, focusing on the integration of site safety with the process of modelling information about construction objects. For the proposed new dimension of BIM, minimum requirements, standards for levels of geometric detail and information related to construction site safety are proposed, which must be met by the developed 8D-BIM model. The new BIM dimension, defined through a set of parameters, will help ensure minimum quality standards for BIM models that comply with current health and safety regulations. Through the developed standards, levels of detail related to the identification and analysis of risks in the context of construction site safety will be defined. The new dimension of BIM will be a critical tool for designers and engineers, supporting them in ensuring a safe working environment on construction sites. The introduction of these innovations will improve safety onsite and the efficiency of the entire construction process. Using data to develop accurate virtual job site models with elements that affect job safety will allow for a better understanding of the impact of construction projects on job safety.

Construction site safety can also be monitored using solutions based on a combination of BIM and virtual reality (VR) technologies. Monitoring construction sites with cameras is becoming increasingly important for occupational safety performance, bringing innovative perspectives on preventing and reducing occupational and health risks in construction.

3. Health and safety in construction projects

The severity and number of fatal occupational accidents in the construction industry remains high compared to other industries (Czajkowska & Ingaldi, 2023; Sankar & Anandg, 2024). The increasing digitization of the construction sector has shown potential for improvement in construction site safety planning and hazard prevention.

The most effective method is to mitigate construction accidents during the design phase of construction lifecycle (Ibrahim et al., 2022). The potential to influence construction safety decreases as the schedule progresses, as shown in Figure 2. The benefits of use of BIM, at the early stages of construction project lifecycle include: early detection of errors in design, simulation of the sequence of activities and schedule optimization. BIM models can also support feasibility studies, cost appraisal, sustainability analyses and construction site planning.

The 8D-BIM adds occupational safety information to the geometric model of the building, at the design and construction stages. It enables the modelling of permanent building elements, but also the required temporary structures and work undertaken onsite, namely fences, storage areas, scaffolding, machinery, signs, temporary structures, protective railings, etc.

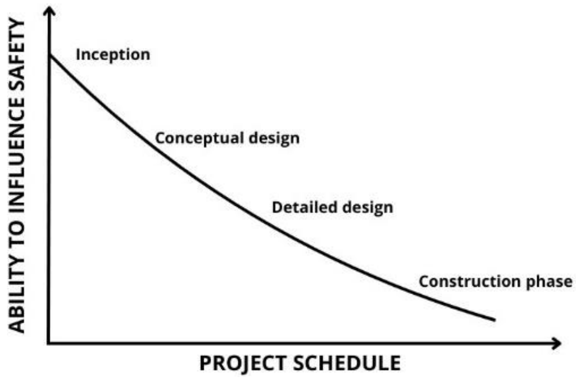

Fig. 2. Impact on occupational safety as the schedule progresses (*own research*)

All elements can be brought into the virtual environment. As a result, 8D-BIM models offer an opportunity to synchronise construction activities with simulation and visualization of construction works. Worksite safety can also be improved by using collision detection at the design stage (Pogorelskiy & Kocsis, 2024). The analysis of design clashes makes it possible to reduce possible inter-industry conflicts, while improving the planning and sequencing of construction activities, as well as levelling out possible necessary rework due to late detection of incompatibilities. As a result, a safer construction environment can be achieved.

4. Safety during design and construction (8D-BIM)

The development of a three-dimensional spatial model of the building object (3D-BIM) is the first stage of the process. The model can be developed in any modelling software (e.g., Autodesk Revit, Tekla, ArchiCad and others) based on concepts, guidelines or, in the case of construction objects ongoing reconstruction, expansion, modernization, archival technical drawings or designs provided by users or owners (Szóstak & Kierski, 2023).

In the second phase, modelling of the surroundings is required, i.e., the context of the construction site, in terms of the development of the construction site, administrative, hygiene and sanitary facilities, storage areas for construction materials, traffic routes, construction machinery, etc. This complements the architectural BIM model. Consideration of the surrounding elements supports analysis of logistics and construction activities that affect work safety, such as the rotation of general construction workers, construction equipment, and the loading and unloading of materials, which allows analysis of available space and identification of relevant constraints.

One of the key benefits of BIM models is the ability to spot 'clashes' at an early stage of the project development. Therefore, the next step is the “clashes detection”. In this phase, activities aimed at detecting collisions (the overlap of two or more object) are carried out. Collisions, in the form of inconsistencies, can be resolved and approved directly by the software user, such as minor geometric inaccuracies that occurred during modelling while some might require more in-depth analysis and new design. Once the irregularities in the model, resulting from clash detection have been resolved, it is possible to conduct a walk-through of the site – a visual simulation. A "visual" inspection with the use of virtual reality offers another opportunity to spot any potential hazards and plan preventive actions.

In the next step, the 3D-BIM model of building and site is linked with a construction schedule. As a result, a 4D-BIM model is developed enabling step-by-step simulation of the project development.

4D-BIM models allow the identification of possible health and safety hazards related to worker health and safety on the construction site, such as falls from heights, ground burial in an excavation, exposure to chemical and biological hazards, crushing, and hazards during installation and/or removal of structural elements. Additionally, linking static 3D-BIM models with a schedule allows for the identification of hazards related to the sequence of a planned works. Whenever a safety hazard cannot be eliminated at the source, it is necessary to implement measures to reduce the hazard. These safety measures fall into two categories: collective and individual protection measures. Collective measures include the implementation of protective railings, protection of openings in the ceiling, proper use of ladders, etc. These elements can be added to the 3D-BIM model. Figure 3 shows an example of a balustrade modelled in a construction facility.

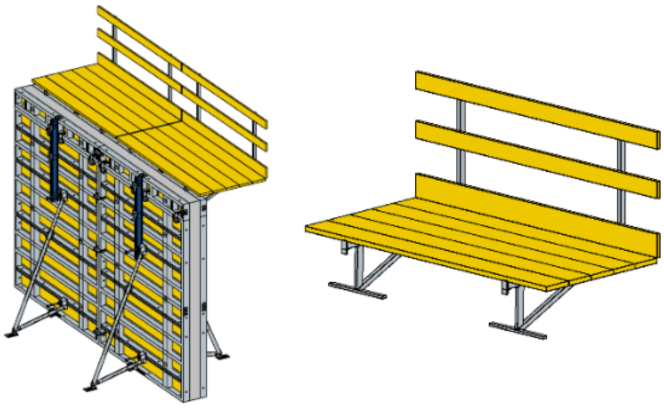

Fig. 3. Model of safety railing (*own research*)

If collective measures are insufficient to reduce risks, individual protective measures should be implemented, including safety helmet, safety shoes, warning vest, gloves, goggles, earplugs, masks, visors, etc.

As the project model evolves from spatial visualization (3D-BIM) through scheduling integration (4D-BIM) to safety and risk management, additional dimensions in BIM offer increasingly sophisticated capabilities to support occupational health and safety on construction sites. By linking the 3D-BIM model with various project phases, project teams can analyze and anticipate potential hazards at each stage, implementing necessary preventive measures to mitigate risks. Moving beyond these initial dimensions, advanced applications of BIM, such as 8D-BIM, specifically target comprehensive safety planning and monitoring through innovative digital solutions (Sepasgozar et al., 2023). The integration of 8D-BIM introduces powerful tools for managing safety in real time, allowing for proactive adjustments and supporting enhanced safety outcomes across the construction lifecycle.

In the future, the application of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) could significantly enhance the safety functions of 8D-BIM on construction sites (Ooi et al., 2023). AI could enable automatic risk analysis and forecasting onsite, facilitating early prevention of potential hazards. Meanwhile, the use of IoT sensors integrated with BIM models could provide real-time data on site conditions, such as temperature, wind speed, worker and machinery locations, detection of non-compliance with personal protective equipment requirements, or the absence of collective safety measures (e.g., missing protective railings). This would enable more dynamic safety management. Integrating these technologies with 8D-BIM holds the potential not only to increase worker protection but also to optimize the entire safety management process.

Conclusions

BIM technology is an innovative approach to planning, designing, implementing and managing construction projects. BIM technology can be used to develop three--dimensional, spatial models of construction objects (3D-BIM), which, supplemented with new information, can be expanded to further dimensions, from 4D-BIM to 10-BIM.

This research focuses on the stages of development of 8D-BIM: Safety during design and construction. This dimension allows for the analysis of safety risks associated with carrying out construction work on a site and allows for early risk reduction before construction and increased awareness of health and safety issues. BIM models offer a visual simulation of a construction object, a virtual walk through the construction site, where it is possible to identify potential risks and implement appropriate preventive measures. Ongoing research indicates that there are potential benefits to be gained from using the 8D-BIM model.

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