

Research on construction management based on BIM-AR/VR technology

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Abstract. With the digital transformation of the construction industry, construction management built by BIM and AR/VR technologies has gradually become a crucial mean to enhance efficiency, reduce costs and promote environmental protection. This paper discusses the application of BIM combined with AR/VR in construction management, and demonstrates its advantages in project visualisation, collaborative communication and safety management through literature analysis. The combined technology can significantly improve the transparency and precision of project management, help managers better control construction progress and costs, optimise resource allocation, and reduce rework. At the same time, the introduction of AR/VR improves worker training, decreases the risk of accidents and promotes the intelligent and green development of construction management. Although the technology still faces problems such as data compatibility, applying BIM and AR/VR in construction management is promising with the integration of new technologies such as artificial intelligence.

1 Introduction

With the rapid development of information technology, construction industry is undergoing a digital transformation. In traditional construction management, cost, efficiency and environmental issues are the main challenges faced: works often lead to budget overruns and wasted resources; many projects still rely on manual operations and paper documents, which result in slow information transfer and inefficient decision-making; and waste from construction poses a threat to the environment and the health of construction workers. The combination of BIM and AR/VR is driving construction management in the direction of intelligence. This integration can better support the visualisation, informatisation and intelligent management of projects, helping managers to more accurately grasp the progress, cost and quality of the project, while also optimising the allocation of resources, reducing errors and rework during the construction process [1].

Alizadehsalehi et al. created a model which can enhance abilities to learn engineering and provided recommendations and a future roadmap for AEC educators to integrate BIM with VR [2]; similarly, Lozano-Galant et al. developed a low-cost AR tool for visualising BIM models applied to civil engineering education, and the results showed that the AR tool integration can enhance students' learning experience and improve their understanding of complex projects [3]; in terms of research, Gan et al. proposed an integrated BIM and VR-based approach to optimise the aerodynamic design and wind comfort of modular buildings

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by visualising Computational Fluid Dynamics simulation (CFD) simulation results, thus helping designers to make wiser decisions at an early stage [4].

The aim of this paper is to discuss the application of technology combining BIM and AR/VR in construction management. Assila et al. proposed a model combining technology that can achieve the goal of cost saving [5]; Panya et al. strengthened collaboration and communication in the process of information transfer through the combination of technology to increase the efficiency of construction management [6]; Chen et al. demonstrated the combination of technology attenuates the fire effects, thus achieving the purpose of protecting the environment and the building [7]. By analysing these cases, this paper focuses primarily on the construction management phase and explores the potential advantages and development prospects of integrating BIM into AR/VR technologies in this scenario.

1.1 Overview of BIM and AR/VR

Building Information Modelling (BIM), also called n-D modelling or virtual prototyping, is a revolutionary development which is constantly changing the architecture, engineering and construction (AEC) industry [8]. BIM advances the construction process and improves the integrated efficiency of the construction process by creating three-dimensional digital models that integrate the information in a construction project and provide a systematic management platform for the construction phase.

Augmented Reality (AR) is defined as an interactive experience in a real-world environment, linked to the real world via computer-generated data information; Virtual Reality (VR) is different in that it takes place in an artificial data environment, where the users are a part of this world in an immersive or non-immersive way [9].

BIM improves the accuracy and efficiency of the construction management by creating digital building models. However, some technical bottlenecks have gradually emerged in the long-term use of this technology: the lack of rendering accuracy of BIM models leads to the reuse of project resources, thus increasing costs; construction conflicts due to data incompatibility and model information inconsistency; and a lack of competence in environmental protection, where the lack of fluid data leads to wasted materials and casualties, thus increasing the burden on the environment. The combination with AR/VR effectively improves these aspects.

According to Seyman et al., there is an increasing preference for utilising VR/AR in BIM-based construction management [10]. Integrating BIM into emerging technologies like AR/VR is currently considered an effective solution to enhance construction management [11]. This technology not only plays a crucial role in communication efficiency and safety training, but also improves collaborative construction site management. AR/VR integrates the BIM model with the real environment, which improves the standard of visualisation of the building model and helps construction personnel to understand and collaborate more intuitively.

1.2 Comparative analysis of BIM-AR/VR combination

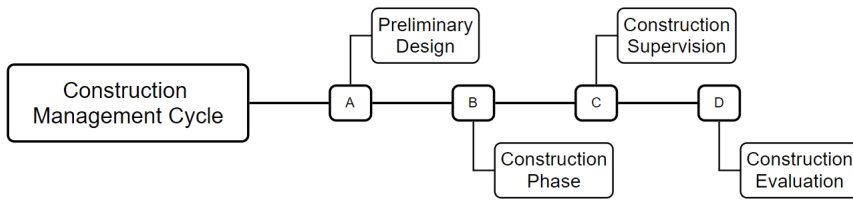


Figure 1. Construction management cycle (Picture credit: Original).

The integration of BIM and AR/VR not only improves construction efficiency, but also in an important position in project management, site supervision, and construction evaluation. The following is a comparative analysis of the changes before and after the combination of this technology during the construction management cycle in Figure 1.

In the design phase, BIM is able to generate 3D models that help designers and engineers obtain a comprehensive understanding of the project. However, with the gradual complexity of the building model, BIM gradually becomes difficult to fully demonstrate the construction situation in the real environment. With the introduction of AR/VR, the construction team can conduct simulation demonstrations in a virtual environment and anticipate construction problems in advance. This interactivity makes the design intent clearer and reduces rework due to misinterpretation.

On the construction site, binding BIM and AR/VR significantly improves the efficiency of teamwork. Project participants in traditional construction usually communicate with each other through paper drawings or 2D models, which can easily transmit error messages; AR can further enhance the visualisation of BIM models so that construction personnel can view construction progress and design models through the device and revise deviations in time; VR can also be used to train employees to familiarise themselves with the construction process and precautions in virtual environments, which can reduce the on-site incident Incidence rate.

In terms of construction supervision, BIM can track construction progress and resource usage through real-time data updates. Combined with AR/VR, project managers are able to visualise the status of the project through an immersive virtual experience, analyse the challenges that may be encountered during the construction process and make decisions accordingly. This data and real-time feedback-based decision-making enables managers to react more quickly, optimise resource allocation and ensure that projects are completed on time.

The combination of BIM and AR/VR also enriches the customer experience. By improving every aspect of the learning process, such as Ghanem's comparative analysis of AR/VR headsets, clients learning the technology are offered a more comprehensive range of options [12]. Technical details and construction processes that are difficult to understand can be displayed in AR/VR, allowing for an immersive 'tour' of a project that has yet to be built. This experience not only improves the client's confidence about the project, but also establishes the foundation for subsequent project negotiations and promotion.

In summary, this combination not only improves the efficiency and accuracy of buildings and structures, but also brings significant impacts in a variety of aspects such as on-site communication, project supervision and construction feedback and experience.

1.3 BIM-AR/VR technology applications

There are technical problems such as incompatible data formats and backward real-time rendering performance in the process of combining BIM and AR/VR, so it is very crucial to modify the quality of model data combining BIM and AR/VR devices.

Aung et al. proposed a mathematical algorithm on the basis of triangle mesh reconstruction [13]. This method optimises the overall model by reducing the number of vertices and triangles in the geometric model thereby reducing the transmission time and effort. The researchers conducted two tests on this algorithm as shown in the analysis of data in Tables 1, 2. The architectural model using this algorithm shows significant improvement and optimisation in terms of vertices, triangles and file memory by 56.7%, 67.9% and 73.4% respectively.

Table 1. Steel bridge model before and after optimisation (Aung et al., 2022).

Model	Type	Initial	Optimised	Improvement (%)
Steel bridge	Number of vertices	590942	255625	↓56.7
	Number of triangles	335564	107573	↓67.9
	File size (KB)	50535	13451	↓73.4

Table 2. Engineering building model before and after optimisation (Aung et al., 2022).

Model	Type	Initial	Optimised	Improvement (%)
Engineering building	Number of vertices	4183198	2235879	↓46.6
	Number of triangles	3231090	1336165	↓58.6
	File size (KB)	364761	124173	↓66.0

Through the application of this mathematical algorithm, the time and quality of combining techniques for on-site modelling and construction is significantly improved. A significant reduction in modelling time and improvement in the quality of the model leads to improved design and construction efficiency.

Keyu et al. also proposed a data transmission mechanism aimed at simplification using different polygon reduction methods [14]. It was validated that the mechanism can notably decrease the number of triangles in the model thus increasing the frame rate of the model transfer while improving the overall shape consistency.

2 Advantages of BIM-AR/VR in construction management

As AR/VR continues to evolve, their integration with BIM brings new possibilities for construction management. Integrating BIM with AR/VR demonstrates significant advantages in these three areas shown in Figure 2, which not only improves the granularity and transparency of project management but promotes the sustainable development of the

construction industry. This technological innovation lays a solid foundation for the future of construction management.

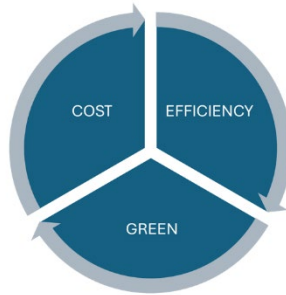


Figure 2. Three technical advantages (Picture credit: Original).

2.1 Cost

During the construction management phase, BIM provides comprehensive building information, including bill of materials, component specifications and construction steps. By creating accurate 3D models, construction teams can better understand the scale and complexity of a project; BIM also automatically generates cost budgets based on the model, avoiding cost overruns due to inaccurate budgets in later stages of construction. AR/VR can superimpose the BIM model on the real environment, allowing the construction team to identify potential problems in advance. Such foresight can significantly reduce cost losses caused by construction errors and material wastage.

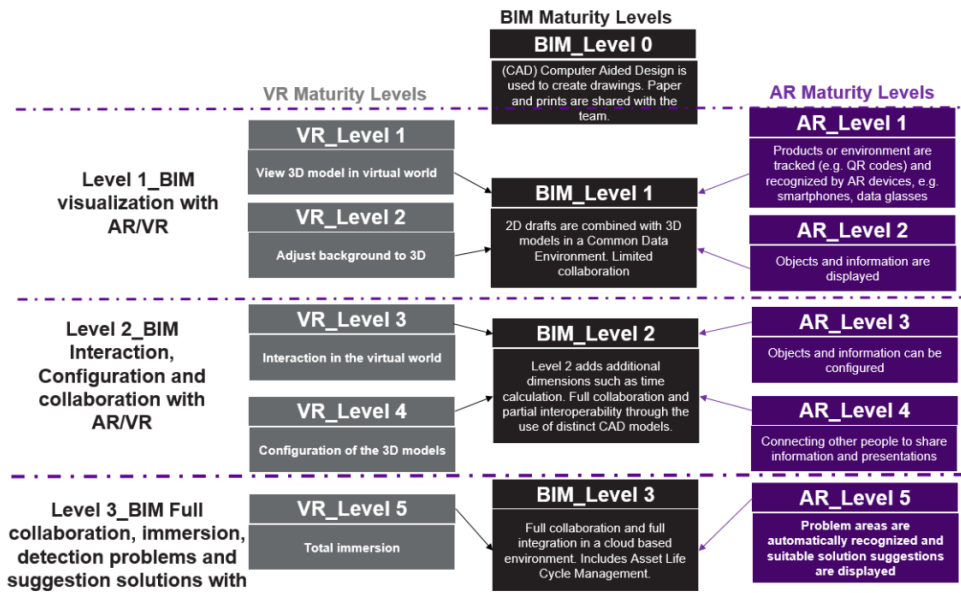


Figure 3. The recommended AR/VR maturity model for BIM [5].

Combination technology can also provide real-time project monitoring and data feedback mechanism, managers can quickly understand the construction progress and cost

consumption, Assila et al. proposed a model of the combination of technology as shown in Figure 3, aimed at assessing the maturity level of the existing progress, reducing the misrepresentation of progress and cutting corners [5]. This transparency allows the project manager to make timely adjustments and optimise resource allocation, thus reducing the cost of capital employed and the cost of delays; the technique also enhances the identification of hazards, and according to Afzal et al. on a series of case studies, the VR visualisation of 4-D BIM can be an effective solution to the challenge of workers working together in different language environments [15]; and Ankit et al. used this technology to create safety training scenarios to enhance the perception of machinery for people operating tower crane machinery in the field [16]; combined with the fact that the technology also plays a vital role in real-time interaction and communication during the training of the workers, Bao et al. researchers suggested a cross-platform framework with which the workers can access VR safety training courses to improve construction safety knowledge [17].

2.2 Efficiency

The coordination function of BIM can effectively motivate the industry to work together. This technique has shown significant improvements in the modelling design phase and field modification phase [18]. However, some communication problems between design, construction, operation and maintenance still need to be overcome in the management aspect [19].

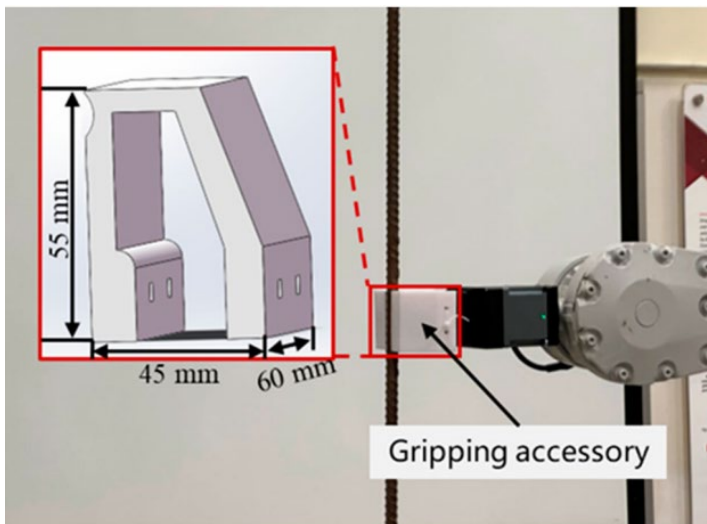


Figure 4. A designed gripping accessory [21].

Combined with AR/VR technology, it can enhance the interactive experience during the construction phase, enabling employees in different positions such as builders and technicians to obtain more detailed information about the BIM model when interfacing and confirming the information, and reducing conflicts of interest due to out-of-sync or incorrect information during the project. Panya et al. have confirmed the feasibility of this technology by combining the technology to improve collaboration and communication among construction project stakeholders by redesigning, maintaining the flow of information, and delivering the design in an effective way [6]. improved collaboration and communication between construction project stakeholders in rework, confirming the feasibility of the technique. However, the technology is still in the developmental stage, so there are many

potential problems, Sidani et al. concluded in their study that: combining technology is far from the expected state, such as connection and positioning problems, lack of non-geometric information and practical obstacles of applying AR technology in construction sites; for the connection and positioning problems [20]. Du et al. invented a clamping attachment as shown in Figure 4 that the technology is one of the research advances for this problem through the extension of BIM real-time technology to improve the accuracy of real-time operation of existing robotic arms through new algorithms [21]. This technology has a clear potential for health and safety in on-site construction, especially with the progression of assembly technology, the quality of materials has been uniformly guaranteed, so the reliability of on-site installation has become an assessment criterion for the building, and the efficiency of on-site management will be greatly improved if this technology continues to be developed instead of the errors of manual installation. Amin et al. also emphasised the importance of combining the technology research with a view to future. The technology can be better automated with the assistance of AI to improve efficiency [22].

2.3 Environmental protection

BIM can be modelled to provide detailed building information and resource requirements for projects to achieve the modern goals of green building and sustainability [23]. AR/VR can help BIM to update project information in real time and analyse which construction materials to use without compromising structural stability with less negative impact on the environment.

Incorporating technology can improve the safety of construction sites and thus indirectly protect the environment. Workers at construction sites are usually exposed to various dangers, such as collapses, equipment failures, and fires, which not only jeopardise the safety of the workers, but also cause damage to the surrounding environment. Incorporating technology can reduce the occurrence of accidents by obtaining real-time information about the hazards at the construction site. For example, Chen et al. proposed the impact of this technology on fire prevention, which efficiently extinguishing fires, also implies a reduction in environmental pollution, thus achieving the goal of sustainable development [7]; combining technology can also promote the design and implementation of green buildings, by comprehensively simulating the life cycle of a construction, and meticulously improving the design concepts and programs; designers could use this to observe the buildings' structure in details, while engineers and workers apply the combined technology to immerse themselves in the building's performance, understand the building's energy consumption and emissions, and select energy-efficient construction methods. The combined technology not only reduces environmental pollution during the operation of the building, but also provides data support for environmental practices during the construction management phase.

3 Conclusion

In an era of mainstream AR/VR development, combination of BIM and AR/VR has brought unprecedented changes to construction management in the construction industry. By offering real-time feedback on data, this technology enhances the transparency and visualisation of all aspects of the process, enabling project managers to quickly identify potential risks and optimise the decision-making process. Especially in terms of safety management, AR/VR technology greatly enhances employees' ability to perceive dangerous environments, and at the same time reduces the likelihood of accidents by providing safety training through realistic virtual scenarios; in addition, the combination of technology greatly enhances the interactive experience during the construction phase, enabling construction personnel to simulate operations in virtual environments, anticipate and rectify potential problems in the construction process beforehand, decline the rework rate. In addition, the combined

technology greatly enhances the interactive experience in construction phase, enabling the construction personnel to foresee and correct potential problems in the construction in advance through the virtual environment simulation operation, reducing the rework rate and improving the accuracy of the mechanical work so as to improve the efficiency; what's more, the combined technology also plays a pivotal role in the design and implementation of the green building, and promotes the achievement of the goals of energy saving, emission reduction and environmental protection by simulating and analysing the energy consumption pattern of the building, and better controlling the use and emission of the resources in the construction process.

Current research focuses on the case study of BIM and AR/VR, while in-depth research on the related algorithms is still limited, especially in improving the accuracy of data processing and optimising construction simulation decision-making there is a great potential. With the advance of Artificial Intelligence (AI), the combination of BIM and AR/VR will gain new breakthroughs. AI can analyse construction data, optimise energy consumption and material usage through machine learning algorithms, thus promoting the realisation of intelligent construction management, further improving efficiency, reducing costs and facilitating the sustainable development of green buildings.

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