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A Review of the Integrated Application of Artificial Intelligence and Building Information Modeling

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Abstract. Under the background of digital transformation in the construction industry, Building Information Modeling (BIM) and artificial intelligence (AI) have become an important technical path to promote the intelligent upgrading of the construction industry. AI-BIM integration improves design efficiency, project control quality and building full lifecycle management capability. Fragmented data and poor interoperability hinder its widespread use. This paper conducts a literature review to summarise AI-BIM applications in automated design, construction management, operation and maintenance optimisation, and cross-stage collaboration. This paper further looks into how key technologies like machine learning, computer vision and NLP can be integrated. It also sums up current challenges and future research directions. Studies show that AI can improve BIM's ability in data processing, scheme design and smart decision-making. In the future, combining AI with digital twins and large language models will break existing limits and support the high-quality development of intelligent construction.

Keywords: Artificial Intelligence, Building Information Modeling, Integration, Digital Twin

1. Introduction

In contemporary society, the construction industry has long faced problems such as low production efficiency and disconnected information across different stages. With the growing adoption of digital construction, Building Information Modeling (BIM) has become the core tool for information management in engineering. Meanwhile, the rapid iteration of artificial intelligence (AI) provides a new technical path to address the problems of insufficient automation and low data utilization efficiency in traditional BIM applications. The deep integration of the two has gradually become a key research direction in the field of civil engineering.

A review of existing relevant research at home and abroad reveals that many scholars have demonstrated the application value of machine learning and computer vision technologies in the intelligent identification of construction risks and quality inspection. Some studies have also attempted to integrate generative AI into the BIM design process to achieve automated optimization of design schemes. However, most existing studies mainly test technologies for separate scenarios, and few works systematically sort out the full-life-cycle application framework of AI-BIM integration or the barriers to its practical use [1]. This paper reviews recent studies on AI-BIM integration, introduces practical application scenarios and core technical approaches, summarizes

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current major challenges, and discusses future research trends. It aims to clarify the main application scenarios, core technical methods, and practical bottlenecks of integrating AI and BIM, thereby providing useful references for future academic research and practical ideas for the intelligent transformation of construction companies.

2. Application scenarios of AI-BIM integration

2.1. Intelligent optimization and compliance checking in the design phase

2.1.1. Generative AI-assisted design and scheme optimization

The deep integration of AI and BIM supports automated and intelligent design optimization, offering a new technical approach for intelligent architectural design. For example, generative AI can use BIM models to iteratively adjust building layouts and structural plans. Meanwhile, machine learning tools can automatically check if the design results meet industry standards. This technology also helps optimize multiple factors, such as construction costs and carbon emissions. Ultimately, it greatly improves design efficiency and leads to more reasonable building plans [2]. Current research has demonstrated that BIM helps improve project quality, cut construction costs, and shorten project durations. It achieves these benefits by optimizing structural design, construction workflows, and later operational maintenance. Moreover, Tang [2] explored the main drawbacks of BIM application in structural engineering and put forward targeted solutions. These research outcomes offer solid guidance for the further integration of AI and BIM in structural engineering practice.

2.1.2. Automatic code compliance checking and multi-objective performance optimization

In practical engineering work, manual drawing review is usually inefficient and prone to errors. To solve this problem, Chen et al. proposed a machine learning-based method for automatic BIM standard inspection. This method analyzes model data based on the IFC standard and builds design rules through the LSTM neural network. It realizes automatic verification of civil engineering specifications and greatly improves drawing review efficiency [3]. Furthermore, combined with BIM data, AI can conduct multi-constraint scheme optimization considering construction cost, carbon emission, and construction difficulty.

2.2. Intelligent management in the construction and operation stages

2.2.1. Computer vision-driven construction progress tracking and safety warning

In the intelligent management of construction and operational stages, combining computer vision with BIM models can automatically monitor construction progress and issue alerts for potential safety hazards. AI technologies are also able to optimize construction schedules and manage on-site materials effectively. With the support of image recognition, construction quality can be examined automatically, enabling fine-grained whole-process project management.

AI analyzes BIM data to arrange reasonable construction procedures and avoid construction collisions, which ensures projects proceed as planned. Meanwhile, it adjusts material procurement and transportation schemes based on real-time construction progress. This method reduces material waste and avoids construction suspension caused by material shortages.

In terms of quality inspection, image recognition and machine learning can automatically detect common construction defects, including concrete cracks, unqualified steel bar binding, and incorrect

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component installation. This approach replaces traditional manual inspection work, reduces human errors, and greatly improves the efficiency of construction quality control [4].

2.2.2. Progress tracking and safety warning based on computer vision and BIM

At the quality inspection level, Xiong pointed out that BIM technology can integrate on-site monitoring data, achieve dynamic identification and early warning of construction safety risks, and enhance the on-site safety control level [5]. Based on this, computer vision algorithms are used to analyze the construction site images and compare them with the 4D BIM progress model to automatically identify progress deviations. At the same time, the system can issue real-time alerts for potential safety hazards such as high-altitude work and unauthorized operations, thereby forming an integrated intelligent control of progress and safety.

2.3. Life-cycle collaboration and cross-stage decision-making

The integration of BIM and GIS can fully combine the advantages of BIM's fine component information and GIS's spatial geographic analysis, build a three-dimensional digital foundation for urban infrastructure, support regional spatial planning, current status measurement and digital control, provide a standardized technical paradigm for urban renewal projects, improve the efficiency of planning verification and reduce the cost of engineering rework [6]. On this basis, if artificial intelligence algorithms are further introduced, intelligent analysis of multi-source spatial information such as BIM and GIS can be conducted, providing support for the identification of the operation status of urban infrastructure, risk prediction and cross-stage decision-making

3. Key AI technology integration pathways in BIM

3.1. Fundamental integration of machine learning and deep learning

Supervised and unsupervised learning are the basic AI algorithms used in BIM. They can automatically understand the components and engineering information inside a BIM model. This helps complete basic tasks such as classifying components, completing missing properties, predicting costs, and finding errors [7]. These algorithms can replace the tedious and labor-intensive manual work. They quickly find hidden engineering information in the BIM model and fill in missing data. This ensures the information is complete and builds a solid data foundation for future intelligent analysis and engineering decisions.

Convolutional Neural Networks (CNNs) are classic fundamental deep learning models. They can extract and recognize features from construction site images and image data of building components [8]. With its technical strengths, CNN can extract geometric information from BIM models. It also identifies features in on-site images and extracts hidden engineering details in the pictures. This method integrates AI algorithms with multi-source BIM data. It reduces errors caused by manual feature extraction. It enables integrated recognition, extraction and analysis of different types of engineering information, and supports construction cost prediction and construction scheme optimization.

3.2. Diversified integration of Natural Language Processing and generative AI

Natural Language Processing (NLP) serves as an important tool for connecting textual documents with BIM digital models. It can automatically parse unstructured text such as engineering

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specifications, design intent descriptions, and project operation logs. From these texts, NLP extracts key information including constraints and technical parameters. This enables automatic compliance checking of BIM models by converting scattered text materials into structured data that BIM models can recognize and use. Traditional BIM has difficulty directly reading text-based engineering documents. NLP helps overcome this limitation. It supports the integrated use of textual knowledge and digital models throughout the building lifecycle [9].

Generative AI offers a new path for innovative BIM applications. Technologies such as Generative Adversarial Networks (GANs) enable intelligent and automatic design of building schemes such as shear wall residential buildings. This method relies on the BIM platform for rapid 3D model construction. It learns features from existing engineering drawings and automatically produces structural design schemes. This greatly reduces the cost of manual modeling and improves design efficiency. It is a typical application of generative AI in BIM forward design scenarios [10].

3.3. Synergistic integration mechanism of AI and BIM

In terms of overall integration logic, combining AI technology with BIM is not just applying intelligent algorithms directly to 3D models. It goes through several steps, including engineering data collection, data preprocessing, model training, intelligent analysis and result feedback. BIM models supply structured data such as component attributes, spatial relations, engineering quantities and construction schedules for AI algorithms. Combined with site photos, sensor monitoring data and engineering documents, these form a multi-source heterogeneous dataset. Meanwhile, technologies such as machine learning, deep learning, computer vision and natural language processing extract features and analyze connections among different data. They support functions such as component identification, status monitoring, risk prediction and information extraction. The analysis results from the AI model are sent back to the BIM platform. This transforms traditional BIM from a digital tool mainly for information modeling into a platform with data sensing, intelligent analysis and decision-support functions.

4. Discussion

4.1. Challenges

The integrated application of AI and BIM faces two major limitations: data heterogeneity and insufficient standard interoperability. Construction engineering data from different projects, including models, monitoring records, and documents, are hard to unify. High-quality annotated samples are insufficient, and data preprocessing involves high costs. These factors reduce the training performance of intelligent models and limit their reusability across projects. In addition, poor compatibility between BIM software and AI platforms creates another barrier. Popular open standards such as IFC still have certain limitations in data conversion and semantic mapping. This easily leads to data silos and hinders cross-disciplinary and cross-system cooperation. Furthermore, the reliability and explainability of AI models in engineering scenarios still need further improvement. Construction projects vary greatly and operate in complex environments. Models trained on data from one specific project may not be directly applied to other engineering cases. Meanwhile, some deep learning models have opaque decision-making processes. For high-risk tasks related to structural safety and construction safety, professionals still need to verify and judge their prediction results.

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4.2. Future directions

Real-time decision-making driven by digital twins is an important development direction. For instance, by integrating on-site perception data with BIM models to build a digital twin system, dynamic simulation can be carried out during the construction, operation, and maintenance phases, supporting risk early warning and dynamic resource allocation, and promoting the upgrade of static BIM to real-time control. Additionally, large language models (LLMs) and knowledge graph-enhanced semantic intelligence also show great application potential in the construction industry. NLP and knowledge graph techniques can be used to examine engineering codes and design files. They build semantic connections between standard rules and building elements. On this basis, BIM models can automatically meet relevant regulatory requirements and reflect the core ideas of architectural design. In this process, text-based information can also be effectively matched with three-dimensional model data. Future studies are also needed to strengthen the combination of AI algorithms and open BIM standards. This approach allows engineering data and intelligent models to be shared and reused throughout different project stages, professional fields, and software systems.

5. Conclusion

In conclusion, this paper reviews the integrated development of AI and building information modeling. It systematically summarizes the practical applications of AI-BIM technology in three major scenarios, including design automation, construction and operation management, and whole life-cycle collaborative decision-making. This article also analyzes the integration approaches of mainstream AI technologies into BIM systems, covering machine learning, deep learning, natural language processing and generative artificial intelligence.

The research shows that artificial intelligence can effectively improve the data analysis capability, scheme generation efficiency and intelligent decision-making performance of BIM models. It promotes the transformation of the construction industry from static modeling to digital and intelligent development. Nevertheless, the current integration still faces several limitations, such as severe data heterogeneity, insufficient labeled datasets and poor cross-platform interoperability. With the continuous progress of digital twin technology, large language model and knowledge graph technologies, the deep integration of AI and BIM will demonstrate greater advantages in real-time monitoring, semantic reasoning and full-cycle collaboration, providing practical references for the intelligent upgrading of the construction industry.

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