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The Control of Civil Engineering Projects Based on Deep Learning and Building Information Modeling

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ABSTRACT

The aim of this study is to enhance the quality of civil engineering project management and optimize project control in order to ensure adequate construction resources and facilitate seamless project progression. By integrating building information modeling (BIM) technology with deep learning techniques, optimal control was examined at various stages of civil engineering project management. A simulation test was performed on a selected gymnasium engineering project, focusing on cost and resource control aspects. The findings revealed that, as the project advanced, the planned cost exceeded the actual cost by nearly 100,000 yuan in the final stage. The combination of BIM technology and deep learning model prediction substantially reduced the cost and material budgets of the engineering project. Data analysis showed that the average positioning error of the convolutional neural network algorithm for the project model was below 2%.

KEYWORDS

Building Information Modeling, Civil Engineering, Deep Learning, Optimized Control

INTRODUCTION

Under the influence of high standards and requirements of national policies, the management of civil engineering projects in the new era is facing new development opportunities and challenges. In actual civil engineering project management, inadequate management work and frequent occurrences of unreasonable allocation of engineering resources not only affect the quality of civil engineering project construction, but also have a negative impact on the development of the construction industry. Civil engineering project management requires effective control over various departmental processes to ensure the overall quality of project construction and to minimize construction costs. In the new era, intelligent control methods have provided new technical support for various industries, and modern civil engineering is also developing towards digital construction. Following the trend of the times, artificial intelligence machine learning technology has promoted sustainable development in the field of civil engineering and construction. Facing the challenge of optimizing control in engineering project management, utilizing deep learning methods combined with building information modeling

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(BIM) technology presents a new development opportunity and research direction for the current construction industry.

Intelligent optimization is a process of seeking the optimal solution or the best strategy under specific conditions in an automated and intelligent manner by using a combination of Artificial Intelligence (AI) techniques, optimization algorithms, and computer science methods. The main goal of intelligent optimization is to find the best decision or solution in a complex problem to achieve a specific goal or optimization criterion.

Building Information Modeling (BIM), a revolutionary technology in the construction industry, has transformed the way building projects are planned, designed, and executed. BIM integrates geometric, spatial, and temporal multi-dimensional information into a digital representation of a building project. This collaborative platform enables project parties to efficiently manage and visualize the entire construction process, facilitating better communication and coordination between project teams.

A key aspect of construction project management is scheduling, which involves allocating resources, setting milestones, and optimizing task sequences to ensure efficient project execution. Traditional scheduling methods often struggle to cope with the complexity of modern construction projects, leading to project delays, cost overruns, and overall productivity loss. In this context, combining deep learning methods with BIM offers a promising way to optimize construction project scheduling.

Deep learning techniques, as part of artificial intelligence, have achieved remarkable success in areas such as computer vision, natural language processing, and recommender systems. Applying these advanced methods to construction project scheduling can take advantage of the rich data available in BIM models and historical project records. By processing and analyzing this data, deep learning algorithms can learn complex patterns and dependencies to generate more accurate and dynamic project schedules.

This research aims to explore and propose a BIM-based framework for construction project scheduling optimization using deep learning methods. The main focus is on developing models that can predict project duration, identify critical paths, and allocate resources efficiently. Utilizing historical project data and real-time updates from the BIM model provides construction project stakeholders with a more informed decision-making tool that helps to proactively adjust the project schedule as needed.

The significance of this research lies in its potential to improve project planning and execution capabilities, resulting in cost savings and improved project outcomes. In addition, by combining deep learning with BIM, this study can help drive the digitization and process optimization of the construction process and promote wider adoption of advanced technologies in the industry.

LITERATURE REVIEW

Tsai et al. (2014) investigated a new methodology for critical success factors (CSFs) that can be used to further develop research for more effective evaluation of buildings. Jung et al. constructed a BIM application framework for evaluating the value of BIM applications, assessed the level of practical application of BIM technology in three levels and six dimensions, and illustrated the driving reasons for increasing the value of using BIM technology.

Sing et al. (2011) constructed a theoretical architecture of a multi-participant collaborative work platform based on BIM technology and clarified the specific technical requirements for realizing collaborative work based on BIM technology from the perspective of practical application. The specific technical requirements for realizing BIM technology-based collaborative work are clarified from the perspective of practical application.

As one of the national basic industries, the construction industry can promote the construction of the national economy. The management and control of construction civil engineering projects is an inevitable requirement for the current development of the construction industry and a research hotspot in recent years. Luong et al. (2021) proposed a new multi-objective differential evolution algorithm based on opposition to solve the time-cost quality trade-off problem. This new algorithm used opposition-based learning techniques for group initialization and generation jumps, and opposition numbers were used to improve the exploration and convergence performance of the optimization process. He analyzed a numerical highway construction project case, explained the use of the algorithm, and demonstrated its ability to generate nondominant solutions.

Ahmed (2018) demonstrated that utilizing augmented reality and virtual reality could effectively and efficiently solve various construction management problems. Research found that augmented reality was successfully applied to construction project scheduling, progress tracking, worker training, safety management, time and cost management, as well as quality and defect management. The construction industry had the ability to use augmented reality and virtual reality technology as tools to save time and cost.

Roman et al. (2022) described an advanced method for creating a unified information model in architecture, which combined architectural, design, engineering, cost, and depreciation models of building objects, and proposed some issues related to enterprise restructuring business processes. The research results showed that building methods could improve the efficiency of enterprise management processes in digital construction. Koseoglu et al. (2018) emphasized the synergistic effect between BIM and lean concepts based on a case study analysis of facts and data. In complex projects, a comprehensive approach was needed to successfully manage design and construction information through accurate modeling, collaboration, and integration, covering various disciplines throughout the entire project lifecycle. The research results had a significant impact on the understanding of BIM as a new working method in Turkey's construction industry.

In recent years, intelligent technology, as an emerging technology in the construction industry, has played a significant role in resource optimization and control, and more and more people are paying attention to this technology. Huang et al. (2019) reviewed the application and development of artificial intelligence in civil engineering in recent years, including intelligent algorithms, big data, and deep learning. It could be seen that the research direction and difficulties of artificial intelligence in civil engineering in the past few years were mainly focused on structural maintenance and management, as well as design optimization. Yao et al. (2020) proposed a method based on machine learning algorithms, called deep reinforcement learning, to learn better maintenance strategies and maximize the long-term cost-effectiveness of maintenance decisions through repeated experiments. In this method, each single-vehicle road segment could have different treatments. By taking the long-term maintenance cost-effectiveness of the entire section as the optimization objective, the deep reinforcement learning model could learn to make better strategies to improve the cost-effectiveness of long-term maintenance. By implementing the optimization maintenance strategy generated by the developed model, road conditions could be controlled within an acceptable range.

These studies had certain reference significance for the optimization control of civil engineering management projects, but most of them were explored from a theoretical level. In the construction of civil engineering projects, grasping the key points of project construction, ensuring the safety of project construction, and effectively utilizing resources are key factors in project management and construction. Intelligent automation technology can accurately analyze the data of various parts of engineering projects, thus improving the level and efficiency of engineering project management.

INTELLIGENT OPTIMIZATION CONTROL OF CIVIL ENGINEERING MANAGEMENT PROJECTS

Optimization and Control Measures for Building Civil Engineering Projects

Civil engineering project management refers to the planning and management of materials, personnel, production progress, construction situation, and other aspects at the construction site, to ensure the sustainable development of civil engineering project operation. The sustainability of project operations, including financial, social, and environmental sustainability, is one of the prominent issues that needs to be addressed today (Chawla et al., 2018). Civil engineering projects are relatively complex, and ensuring the implementation of project engineering is the most important issue in civil engineering management. Civil engineering projects are also directly related to large construction enterprises. In order for enterprises to achieve high economic benefits, they must effectively control and manage civil engineering projects. Civil engineering project management should also follow the principles of scientificity and rationality. Scientific management methods should be adopted for engineering project management, with reasonable construction processes and scientific engineering project operation processes. Civil engineering management should also adhere to the principle of cost-effectiveness. Building civil engineering construction not only meets people's needs but also generates economic benefits. Only through scientific and rational management can more economic benefits be obtained. At the same time, the principle of standardization should be upheld. For the construction of civil engineering projects, there should be standardized principles, including departmental and personnel management at the construction site. For the current stage of civil engineering project management, there are still several management issues.

Firstly, in the design of civil engineering projects, if each design element is not fully accurate and fully considered, it would lead to deviation from and failure to meet the original construction requirements, thereby reducing construction quality. The second issue is that there is a significant difference between the cost budget of the engineering project and the actual cost of the project. The increase in construction costs has caused economic pressure on the engineering project. In addition, insufficient preparation of equipment and building materials for engineering projects can also affect construction progress. The issue of engineering progress is crucial in both practice and theory. From a practical perspective, improving project progress is a key part of the project management process, which can ensure the smooth completion of the project (Habibi et al., 2018). The control system of engineering projects lacks a unified management mechanism, and there is no unified engineering project management standard for each link. In addition, the professional skills and management awareness of the staff are poor, which not only leads to frequent safety accidents, but also cannot ensure the construction quality of engineering projects. After research, it has been found that management personnel in the construction industry lack the professional knowledge needed to manage civil engineering projects, resulting in low management quality. It is difficult to detect problems in a timely manner and they do not use scientific methods to solve them. This causes civil engineering construction projects to fall behind schedule. (Sresakoolchai & Kaewunruen, 2021).

The management of civil engineering projects has a huge impact on the entire engineering construction, and analysis of the control and management measures for civil engineering projects should focus on the following needs: increase management efforts, improve management systems, coordinate and supervise, and optimize resource allocation. Firstly, it is necessary to increase management efforts. In the on-site scheduling of civil engineering projects, in order to ensure the safety of civil engineering construction, it is necessary to improve the professional level of engineering project management, improve the safety system of its management site, and enhance the safety awareness of civil engineering project personnel. Improving the management system is also very important for the management of civil engineering sites (Hou et al., 2021). It is necessary to not only manage water and electricity equipment, but also ensure the smoothness of construction site roads to ensure smooth construction. Improving the management system of civil engineering projects plays a crucial role in the quality of engineering construction.

The role of coordination and supervision is to prevent waste of engineering resources and reduce the occurrence of safety accidents. Project management needs to be strengthened, while the supervision procedures for engineering projects need to be improved to create a good civil engineering construction environment for construction enterprises, thereby improving their economic and social benefits. Finally, it is necessary to optimize the allocation of enterprise resources. In order to achieve more scientific and reasonable allocation, the personnel and resource allocation of civil engineering projects must be optimized to improve the operational efficiency of engineering projects, comprehensively achieve management, and make project operation more stable. Civil engineering construction is a relatively complex and extensive project that requires multi-dimensional optimization control. Its control system must effectively and uniformly manage all processes of the engineering project and establish a complete management system.

Project Optimization Control of BIM

Building Information Modeling (BIM) is a methodology that integrates digital modeling and management techniques. It covers the fields of architecture, civil engineering, and infrastructure, and it is designed to create, maintain, and share full lifecycle data for building projects (Chan et al., 2018).

BIM integrates the building's original geometry, attribute information and relationships, and relevant data, such as time and cost, by creating a virtual three-bit building model in a digital environment. This allows the entire project team to share consistent information and work collaboratively throughout the design, construction, and maintenance process.

More than just a 3D model, BIM includes information about the spatial location of building elements, materials and construction, specialized systems (e.g., electrical, plumbing, HVAC, etc.), schedules, cost estimates, and more. By adding this information to the model, BIM enables more accurate analysis and decision support (Ahmed, 2018).

BIM's advantages include providing pipe-only, visualized building design and planning, which helps all parties to better understand and communicate the design intent, and facilitating collaborative work and cooperation among project participants, which improves efficiency accuracy. BIM can automatically perform clash detection, identify potential problems during design, construction, and operation, and provide solutions (Hu & Castro-Lacouture, 2019). BIM integrates a wide variety of building project data, thereby providing comprehensive project information and decision support. BIM is an integrated methodology and tool that provides a more efficient, accurate, and collaborative approach to construction project management through digital modeling and management. The optimization control of BIM technology for civil engineering projects can be analyzed from the perspectives discussed in the following sections.

Optimization of Civil Engineering Project Plan

In planning and controlling decisions and processes, the randomness of projects is receiving increasing attention. Attention to the planning phase of engineering projects should be focused on improving existing project control technologies and developing new methods for automated data collection, processing, and generation of more integrated project plans (Pellerin & Perrier, 2019). Traditionally, project management practices based on strict planning and control should be applied to construction projects (Larsson et al., 2018). During the planning stage of civil engineering projects, BIM technology can be used to calculate the specific impact of design changes on project investment reports in real time and plan different solutions. Enterprises can choose the best engineering project solution based on their own needs (Parsamehr et al., 2023). The application of BIM and geographic information systems can integrate building structures into the surrounding environment, visualize different information, and support decision-making in risk management (Lee et al., 2020). Whether from the perspective of environmental benefits or economic benefits, BIM technology can conduct real-time analysis based on actual situations and provide multiple solutions for enterprises to choose from (Zabin et al., 2022).

Optimization of Civil Engineering Project Design

Regarding the design of engineering projects, it is important to note that the increasing size of the project structure and the diversified development of engineering buildings have increased project complexity as well. Traditional two-dimensional design techniques can no longer meet the design requirements and cannot optimize the design of engineering projects (Pan & Zhang, 2023). BIM technology can optimize the construction of difficult structural parts of buildings, such as roofs and curtain walls, and coordinate them using visualization technology (Rahimian et al.,2020). After effectively optimizing these special and complex structural parts, BIM technology can significantly reduce project costs and improve the progress of civil engineering projects, as shown in Figure 1.

Construction Optimization of Civil Engineering Projects

The construction stage is the most important implementation stage of civil engineering projects. If this stage cannot be effectively controlled, it would have a significant impact on the safety and progress of the engineering project. BIM technology can perform three-dimensional or four-dimensional image simulation. Four-dimensional simulation of BIM is more effective in visualization and scheduling control than traditional planning (Husin, 2019). The construction progress of civil engineering projects and the progress of each node can also be demonstrated, and the construction progress of the project can be simulated in advance. Reasonable construction plans can be formulated based on the simulated data, thus reducing the waste of human resources and reducing the construction cost of the engineering project, as shown in Figure 2.

In the context of modern building management, effective project delivery relies on a large amount of data, and easy access to key construction management data remains a major obstacle due to implementation challenges (Cheng et al., 2020). With the continuous advancement of civil

Figure 1. BIM design optimization

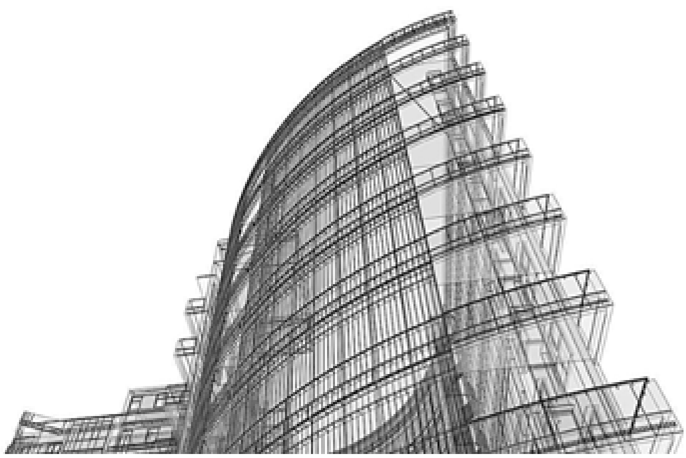
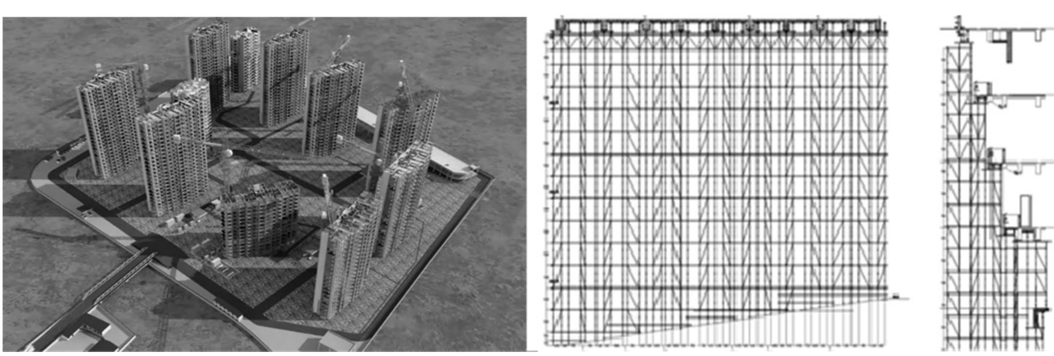


Figure 2. BIM construction optimization



engineering projects, management personnel are unable to promptly grasp all information, resulting in an increase in the overall complexity of the project. It is necessary to rely on certain scientific and equipment assistance, and BIM optimization tools need to be combined with intelligent technology to provide the best optimization control effect for the project. This article introduces the methods of deep learning.

Combination of Deep Learning and BIM

Deep learning is a type of machine learning that is improved on machine learning algorithms and has a deeper neural network structure that can handle more complex models. For BIM technology and deep learning, its data can be transformed into a form that is easy for people to understand and utilized to help enterprises make reliable decisions. In civil engineering project management, the planning stage, design stage, construction stage, and operation and maintenance stage generate a large amount of data and there are many data streams when optimizing using BIM technology in each stage. Combined with deep learning algorithms, it can be used for recommending design components and checking rationality in engineering projects (Kor et al., 2023). It can also be applied in scenarios such as environmental monitoring and construction personnel safety protection during the construction phase. Deep learning plays a significant role in data classification and prediction of civil engineering projects. In the field of actual engineering projects, testing the structural performance of the project is a very important step that can improve the efficiency of engineering structure monitoring and improve the safety of its civil engineering management, thus binding energy with BIM technology to optimize the management of civil engineering projects. Convolutional neural networks in deep learning utilize abstract algorithmic models that simulate the working principles of brain structures. They have powerful functions of learning, memory, and association. The complexity of civil engineering project structures makes it difficult to express changes in the architectural structure and characteristics of engineering projects through logical relationships. Convolutional neural networks have strong nonlinear mapping ability and adaptive learning characteristics, which can be combined with BIM technology to optimize civil engineering projects.

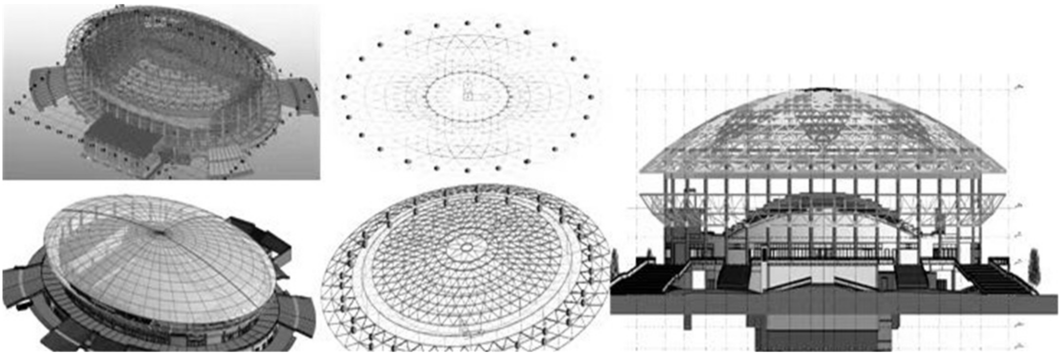
According to the principle of convolutional neural networks, civil engineering projects use convolutional neural network methods for structural analysis and preliminary design. This mainly applies to the extraction, induction, and nonlinear modeling capabilities of convolutional neural networks. By establishing a mapping function relationship between input and output variables, pattern matching, classification, recognition, and calculation are carried out. Finally, BIM technology is used to conduct a three-dimensional simulation of its engineering project, thus simulating a three-dimensional model of the plan, which helps managers to better analyze the plan and achieve automated control and decision-making, so as to improve management level and efficiency. The following section provides a simulation experiment (Huang et al., 2021).

EXPERIMENTAL EVALUATION OF ENGINEERING PROJECT OPTIMIZATION CONTROL

For the experimental analysis phase of this study, the gymnasium building of a civil engineering project was selected as the data sample. The experiment first used BIM to design and plan the project and built the architectural model and structural model of the gymnasium. Next, professionals were used to build the sample architectural model of the gymnasium, as shown in Figure 3.

Figure 3 shows the BIM model designed and planned by professionals for the architectural model of the stadium. After building the model, it is uploaded to the software system, and the overall model is imported into the software system, which would display the three-dimensional information of the project architectural model, as well as the time schedule and cost information. After establishing a complete BIM model, the construction site of the project is surveyed to determine the actual cost. Convolutional neural network models are used to train data collected from construction sites.

Figure 3. Sample architectural model of civil engineering project



Combining with the BIM model platform, both actual and budgeted costs are input simultaneously for automated analysis.

The BIM database stores the labor, material, and machinery usage as well as cost information and data information of the completed works in each phase of the project, which provides input data and desired output for the prediction model of convolutional neural network, saving labor and time for data collection.

In this paper, the data in BIM is used as the sample of convolutional neural network to run the cost estimation model in MATLAB platform. Before inputting the indicator into the convolutional neural network, it must be normalized. After normalizing the data, the set of samples for the input sequence of the stadium counterfeiting estimation indicator is $X=(x_1,x_2,......x_n)$ and n samples are converted through the convolution and transformation operation in the lth layer as in formula (1):

$$x_j^l = f\left(\sum_{i\epsilon n} x_i^{l-1} * w_{ji} + B^l\right) \quad (1)$$

W_{jt} and B^l denote the convolution kernel and bias corresponding to the jth input for neuron i in layer l, respectively, and the expression is formula (2):

$$f\left(z\right) = \frac{1}{1+\epsilon^{-z}} \quad (2)$$

The convolution kernel mainly contains m features of n samples convolution pooling operation, let the convolution kernel size is h*w, pooling method 2 kinds, respectively, formula (3), formula (4):

$$g\left(x\right) = \frac{\sum_{k=1}^{h*w} x_k}{h*w} \quad (3)$$

$$g(x) = \max(x_k) \quad (4)$$

1«k«h*w

The pooling method of the choice equation, so that M=n/(h*w), samples X= $(x_1,x_2 \ldots\ldots x_n)$ after convolutional pooling is re-obtained as equation (5):

$$X=(x_1,x_2,\ldots\ldots x_n) \tag{5}$$

Then the conversion operation is performed according to the convolutional pooled samples in accordance with formula (1).

Let the predicted output of the kth node of the output layer be y_k, and the actual output is d_k, then the error term Δk is the formula (6):

$$\Delta k= (d_k-y_k)\ y_k\ (1-y_k) \tag{6}$$

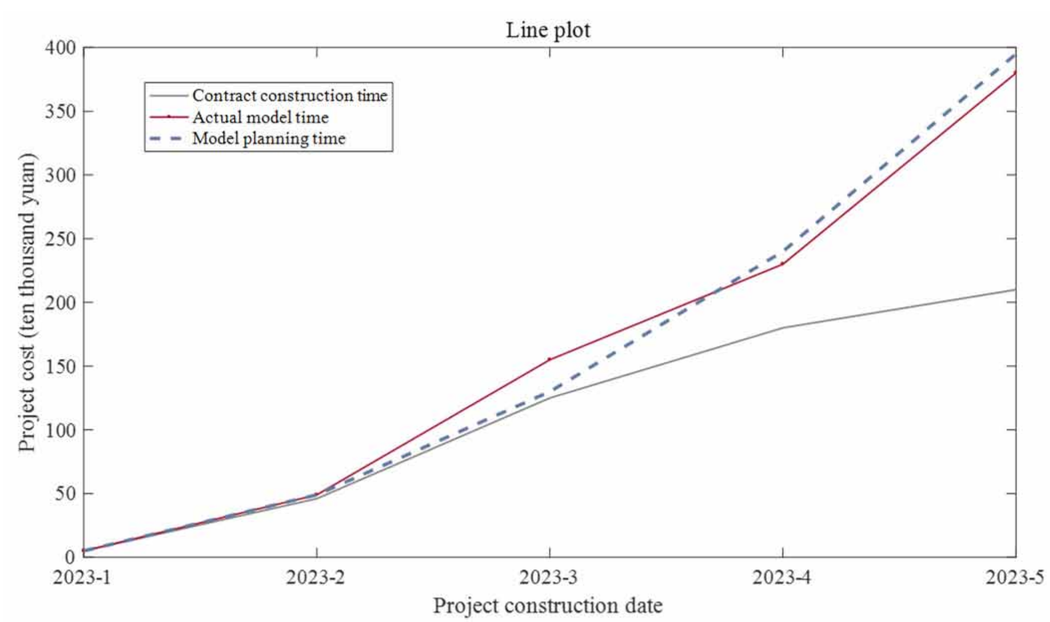
The error function for all nodes of the convolutional neural network training is formula (7):

$$E= \frac{1}{2}\sum_{K=1}^{M}\left(d_k - y_k\right)^2 \tag{7}$$

Figure 4 is a cost control curve simulated based on the progress of the civil engineering sports hall project.

The three curves in Figure 4 represented the cost of the engineering project contract, the actual cost of the BIM model, and the planned cost of the model. From the curve in the figure, the BIM model could predict the trend of cost changes with construction accuracy well. The cost of actual time and planned time was analyzed separately based on the construction progress of the engineering project. According to the data in the above figure, the BIM model of this engineering project predicted that the planned cost would exceed the actual cost as the project progresses (Vadyala et al., 2022). The planned cost of engineering cost followed the progress of the project. In the later stage, the planned

Figure 4. Cost planning and control of civil engineering projects



cost exceeded the actual cost by nearly 100,000 yuan, reducing the cost budget of the project. This could save engineering cost for enterprises and create greater economic benefits. The combination of BIM model and deep learning algorithm could effectively control the cost of civil engineering projects, plan costs for engineering projects, and create better economic benefits for enterprises. This was an analysis of the cost of the gymnasium engineering project during cost planning, and optimal control of the project materials was also an important step. Figure 5 shows the results of the BIM model for the allocation of engineering materials.

Figure 5 shows a curve chart of the resource optimization and control effect in the sports hall project. The figure shows the amount of steel bars (t) required for the engineering project and the progress of the project implementation. The material quantity curve of its steel reinforcement plan was always higher than or equal to the actual material quantity and the material quantity planned in the contract. Among them, only during the construction phase in March did the BIM model predict a material quantity higher than the actual material quantity of 20,000 tons. It could be seen that BIM models could predict the amount of materials required for engineering projects, and provide them to managers for decision-making. It could optimize resource allocation for engineering projects, and effectively control the materials required for engineering projects. During the construction phase, it was necessary to control the construction quality and safety of the project. At this point, the photos of the construction site could be transmitted back to the BIM model center, converted into a three-dimensional model, and positioned. After collecting all the images, the project security analysis report was generated. The positioning of three-dimensional model images required the use of convolutional neural network models to process and analyze variables in the target. Figure 6 shows the statistical analysis of the positioning error values of the construction point model for engineering projects using a convolutional network model.

Figure 6 shows the use of deep learning convolutional neural networks and traditional neural network algorithms to locate construction point models in civil engineering management projects, with error values changing with increasing testing time. Figures 6a and 6b represent the mean variance plots of positioning errors for convolutional neural networks and traditional neural networks, respectively. From the data in the figure, it could be observed that the mean positioning error of the convolutional neural network algorithm for engineering project models was below 2%, and its variance

Figure 5. Resource optimization control of civil engineering projects

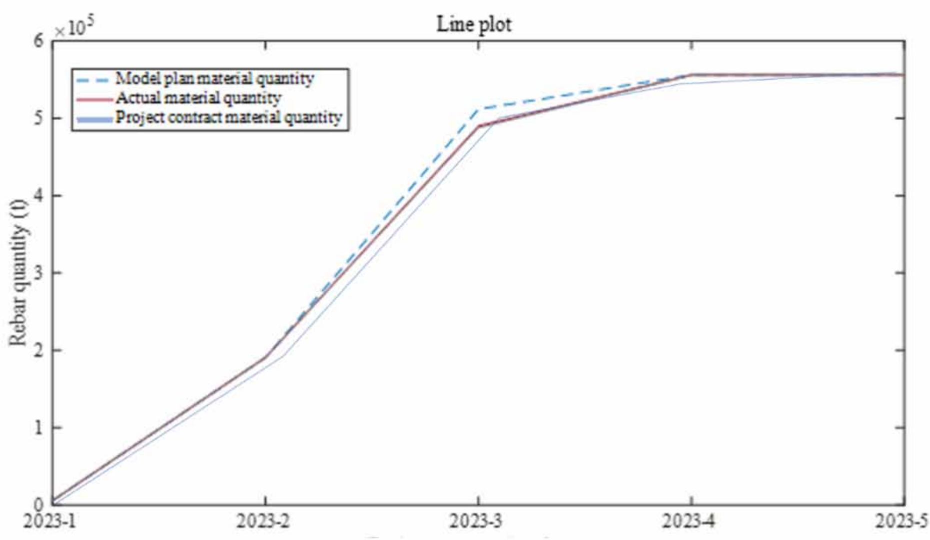
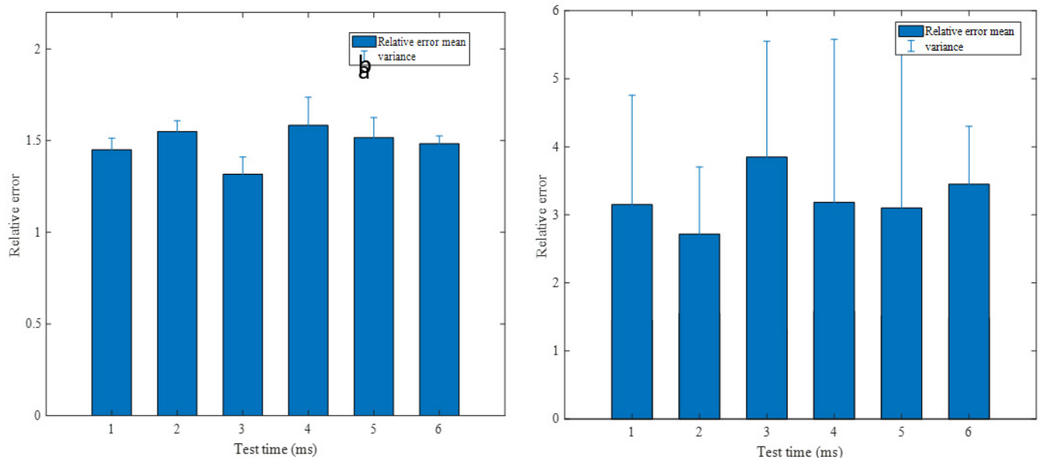


Figure 6. (a) Relative error mean variance graph of convolutional neural networks and (b) Traditional neural network algorithm relative error mean variance diagram



was also relatively stable. From this data, it could be concluded that the convolutional neural network algorithm could accurately locate the BIM model of civil engineering projects, and the error could be controlled within a certain range. The convolutional neural network algorithm significantly improved the positioning accuracy of the engineering project model. The management and control of civil engineering projects at all stages would generate a large amount of complex data, and effective data processing could greatly improve the construction progress of engineering projects. The following tests were conducted on the efficiency of convolutional neural network models and traditional neural network models in processing engineering project datasets. The test data is shown in Table 1.

The data in Table 1 show that, as the minimum support threshold of the engineering project dataset increased, the processing runtime of the algorithm system also decreased. Overall, convolutional neural network algorithms took less time to process datasets, indicating faster efficiency in processing data. Compared to traditional neural network algorithm models, convolutional neural networks had better adaptability to the processing of engineering project datasets and could process datasets faster, thereby improving the efficiency of civil engineering project management.

After experimental analysis, it is evident that the time of convolutional neural networks in processing civil engineering cost is much shorter than that of traditional neural networks. The BIM model combined with the deep learning algorithm effectively controls the production cost and conducts a reasonable cost analysis for the project.

Table 1. Dataset efficiency for processing civil engineering projects

Minimum support threshold (%)	Convolutional neural network processing time	Traditional neural network processing time
0.1	250s	390s
0.2	140s	240s
0.3	110s	190s
0.4	90s	145s
0.5	92s	150s

CONCLUSION

Intelligent automation technology can accurately analyze the data of various parts of engineering projects and provide a scientific basis for engineering project management, so as to ensure the best decisions and improve the level and efficiency of engineering project management. This article studied the optimization control of civil engineering project management and analyzed the application of BIM technology in civil engineering projects. The analysis results indicated that BIM optimization tools also required a combination of intelligent technology to provide the best optimization control effect. The deep learning convolutional neural network algorithm model was used to improve its technology. The experiment shows that the convolutional neural network has a good optimization control effect. Finally, the article selected a civil engineering sports project for simulation experiments to optimize the cost and materials of the project. The optimization control results showed that the cost budget and material budget of the project were reduced. The mean-variance diagram of relative positioning error for the construction point model of engineering projects using the convolutional neural network algorithm and the time test results of processing the dataset showed that the convolutional neural network model based on deep learning had a good error control effect and data processing efficiency. The combination with BIM technology could provide strong technical support for the optimal control of civil engineering project management and improve the level and efficiency of engineering project management.

This study provides new perspectives on and methods for cost management in the civil engineering field. The integration of BIM and convolutional neural networks brings a more accurate and efficient means for cost prediction. In the future, we can further explore more application scenarios of complex civil engineering projects and apply these methods to real projects, thus promoting digital transformation and innovation in the civil engineering field.

DATA AVAILABILITY

The figures and table used to support the findings of this study are included in the article.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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