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Research on Building Process Optimization Framework Based on BIM-DT

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Abstract: Aiming at the problems of low integration of enterprises in various parts of the construction process, low productivity, serious waste of resources, and poor construction safety, this project constructs a framework for optimizing the construction process based on BIM-DT through an in-depth analysis of the characteristics and development status of the digital twin technology and BIM technology. The framework is a complete cycle system, including data management system, BIM modeling system, and digital twin model, which are integrated with each stage of survey and design, construction preparation, construction, and operation and maintenance, respectively. Finally, in the empirical study, the construction phase is taken as the object of study, and the data management system is constructed to comprehensively demonstrate the realization process of each system, and the BP neural network is utilized for fault diagnosis.

Keywords: building information modeling; digital twin; intelligent optimization; whole building process

1 INTRODUCTION

The Annual Development Report of China's Construction Industry 2023 shows that the growthvalue of the construction industry accounts for 6.24% of the GDP [1]. From this, it can be seen that the proportion of the construction industry in China's GDP is still large, so whether the key aspects of the construction industry can be successfully upgraded and transformed so as to achieve high-quality development is a very critical issue. Construction process optimization is essentially a component of process optimization, [2]. Hammer et al. proposed the theory related to engineering process optimization as early as in the last century. The construction process is a single, unrepeatable process, and it is more important to carry out overall organization and coordination of the interests and dynamic relationships of the participating enterprises, to promote the cooperation and coordination of enterprises in the whole process, and to improve the efficiency of the implementation of the overall process as well as the possibility of achieving the purpose perfectly, so that the multi-party satisfaction of the target system can be improved [3]. There are still some urgent problems that need to be improved in the construction process, first, the construction cycle of the construction project is relatively long, the mobility of personnel is more complex, which is not conducive to the improvement of the personnel management system to achieve the precise implementation of the personnel scheduling plan. Second, the construction process of the various stages of information is complex, and the information cannot be exchanged in a timely manner, the data is more disorganized, which is likely to lead to data loss, late access to the difficulties, and even no evidence. Third, the upstream and downstream enterprises in the construction process are not strongly correlated, and the stakeholders are not clear about the role of the transmission and acceptance of information when receiving and transmitting information, leading to the weakening of information transfer and formatting the "information islands". Forth, the management style that managers mastered is relatively old, and cannot be combined with the latest management technology. In view of the above problems, the paper builds the construction process optimization framework with the digital twin (digital twin), and BIM (Building Information Modeling) fusion way to build the construction process optimization framework. The real-time performance of the digital twin model and the professionalism of BIM technology are integrated to achieve the overall optimization of each stage in the construction process and effectively solve the problem of information island in the construction process.

2 BIM/DT/DEVELOPMENTS

Digital twin was introduced as a formal concept in 2003, [4]. Grieves formally introduced the concept called "digital twin" in a product lifecycle management course at the University of Michigan and introduced the digital twin conceptual model. After continuous application and iteration for many years, the digital twin model based on physical space, virtual space and the connection between the two was finally formed [5]. Tao Fei proposed a five-dimensional model of digital twin application, pointing out that digital twin should be composed of physical model, virtual model, connection, data and service, which plays a paving role for the development of digital twin in China. DigitalTwo-Twin is a tool applied to manufacturing production process optimization and smart manufacturing upgrade.... A combination of monitoring and diagnostic methods is used to identify the operating conditions of the instrument in order to realize the optimal control of the instrument, thus ensuring the stable and safe operation of the equipment in the event of a malfunction. He [6] integrates digital virtual modeling and process monitoring technologies into the automated process framework to effectively enhance the safety of the process system. A combination of monitoring and diagnostic methods is used to identify the operating conditions of the instrumentation in order to achieve optimal control of the instrumentation, thus ensuring stable and safe operation of the equipment in the event of a failure. Li [7] proposes a digital twin-based industrial safety control framework for human-computer interaction with respect to human-computer interaction in industrial safety management, and identifies and determines the key technologies involved in its implementation. BIM (Building Information Modeling) was first introduced by [8] Charles Eastman, who first proposed the concept of building information modeling. [9] Eastman later defined

BIM in his book as: "BIM is the integration of building component information into the building model through parametric modeling, and the transfer and exchange of project information through the model at all stages of the project life cycle." In China, Tsinghua University proposed a building information modeling standard (CBIMS) containing data exchange, information classification and process rules in 2010, forming the first relatively complete standard system framework in China. After several years of development, in 2016, the Ministry of Housing and Construction released the Unified Standard for Building Information Modeling Application, which innovatively put forward the P-BIM model application method suitable for China's engineering practice, pointing out the direction for promoting the application of BIM in China. The core concept of BIM is to build a "3D+" collaborative information management method based on the whole life cycle of the project, i.e., by inputting, modifying and outputting the project information in the 3D BIM model. It can thus provide a reliable information basis for the accurate management of each link of the construction project [10]. The concept of BLM is Building Lifecycle Management (BLM), which establishes a complete communication platform to unite all parties. And BIM technology is often combined with other technologies to solve some specific problems in the construction process. Schiavi [11] combines VR and AR with BIM technology focusing on risk prevention and field operations in the construction phase. Kashtim [12] established project information management through BIM technology to enable the team to effectively focus on risk management of the project. Chen [13] proposed an innovative technology integration framework for the risk of high-rise fires, which combines BIM, IoT, and AR/VR systems into a single system and is fully validated by actually combining fires. Huang [14] proposes a development model of building industrialization by combining the concept of smart manufacturing and describes in detail how BIM technology is integrated with the six stages of the building process. Zhong [15] combines the value flow chart with genetic algorithm to conduct a detailed study on the problems of low productivity, poor process stability, and serious waste of resources in the construction process. Huang [16] explores the problems of urban underground infrastructure through the combination of BIM technology, machine vision technology and machine learning. Zhu [17] developed a unified framework for all data processing tasks in BIM/GIS data integration by combining BIM technology with CIS technology based on the information flow perspective. To summarize, the function of BIM technology in the field of construction industry has been more mature, and there are also many researchers who combine BIM technology with more mature technologies in other fields for problem exploration. However, the problems concerned and solved are still mainly focused on the building process of design-transportation-construction-operation and maintenance, among which there are more problems or technical difficulties in a certain stage. Currently, based on the whole process perspective of the building process, there is a lack of research on the inefficiency, long duration and waste of resources in the whole building process. For this reason, this project proposes to establish a framework for optimizing the construction process based on BIM-DT, starting from the whole process of construction and combining BIM modeling and digital twin technology. Combine which with the every stage ofthe construction process to realize the overall optimization of the construction process. The research results of this project help to solve the problems of poor continuity, low productivity, serious waste of resources, and construction safety hazards in all parts of the construction process.

3 CONSTRUCTION OF BUILDING PROCESS OPTIMIZATION FRAMEWORK BASED ON BIM-DIGITAL TWIN

In this paper, we first consider the building process composed of each stage of "survey stage - design stage - construction preparation stage - construction stage - completion and acceptance stage - operation and maintenance stage" as a physical entity and construct a basic BIM model in each sub-stage, and then transfer the data in the process of constructing the BIM model, the data of the initially discovered problems, the data of the existing problems and the data of the problems to be solved to the data management system. The data in the process of constructing the BIM model, the data of the preliminary problems found, the data of the existing problems and the data of the problems to be solved are transferred to the data management system. The information obtained by the data management system can be stored in NoSql, Sybase, Oracle and other databases. Through the data management system, unnecessary data and redundant data are eliminated and existent problems and suspected problems are recorded and uploaded into the digital twin system. The digital twin system adopts Flexsim visual modeling technology. After receiving the import of the BIM model, it combines the collected information with the field information detected by the sensors, establishes a mathematical model with the minimization of the number of failures and the minimization of the cost as the objective function, and warns of the possible hidden problems by using the BP neural network. After obtaining the prediction results, false problems are eliminated and the real problems are improved and the detected problems are transmitted to the constructed BIM model. The BIM model is able to make all-around corrections to the received information in real time, thus realizing a complete operation process. At the same time, by providing real-time feedback to the BIM model, the problem that the BIM model itself cannot be updated in real time can be solved well. In order to make the digital twin model better access to the real scene information, it is necessary to fully configure the corresponding sensors in all aspects, and try to achieve two-way operation to ensure that the provided data and correction programs are real and correctable. Meanwhile, the operation and evolution of the BIM model and digital twin model in the framework are accompanied by a complete cycle of survey - design - construction preparation - construction - completion and acceptance - operation and maintenance and other phases, but the data management system is no longer combined with each phase separately. The data management system stores all the data of each stage of the construction process, which not only facilitates the timely reception of all the data and information of the previous stage in the next stage after the completion of a certain stage, but also effectively prevents the emergence of "information islands". On the other hand, it also helps to realize the integration of the various stages, so that the entire project becomes an organic whole, thereby greatly improving the progress and quality of the project. As shown in Fig. 1 and 2, comparing the BIM-DT-based construction process model with the traditional construction process model, the efficiency of the construction process has been significantly improved (see Tab. 1).

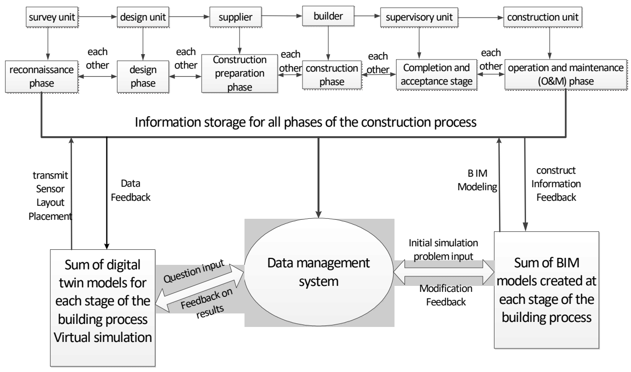

Figure 1 BIM-DT based building process model

Table1 Comparison of the effect of traditional building process and BIM-DT based building process

comparison	Traditional Building Processes	Building processes based on BIM-DT
Question	Need to seek out the party responsible for the previous stage for questioning and, when the issue is more complex, to move on to the next stage.	Issues are sent to the data management system, which performs direct issue detection based on incoming information from all phases
Problem solving	The parties meet and come up with a program to be implemented. If the program is not reliable, another meeting is needed to argue for a new program.	The data management system enters the solution into the BIM modeling system for modification and simultaneously checks the solution for compliance.
Data management	Professional data organizers are provided and the completeness of the data is ensured. If there is a need for inspection, the information needs to be checked manually, which is time-consuming, laborious and less accurate.	The information program is stored in the data management system and can be updated and reconciled with the BIM modeling system at any time in accordance with the digital twin system.
People management	High mobility of personnel makes it difficult to specify information on all personnel	All information on personnel is entered into the data management system and is kept up to date for both active and separated personnel
Security issue	After-the-fact remedies, the effectiveness of which is difficult to guarantee, cost large sums of money.	Adoption of algorithms for prediction and prevention of relevant problems beforehand
Cost control	Adoption of ongoing or ex post controls	Cost prediction is prioritized in the model, always comparing the initial cost and always updating it during the process.
Engineering Acceptance	Manual checking of information to organize acceptance is costly in terms of financial and material resources	The digital twin and the BIM model work in tandem to compare real-time and modeled information with high speed and accuracy.
Operation and maintenance (O&M) phase	Ex post facto remedies, which are costly in terms of human and financial resources	The digital twin model is always updated with information and the BIM model performs simulation exercises based on the information. Ensuring that problems are detected and dealt with early.

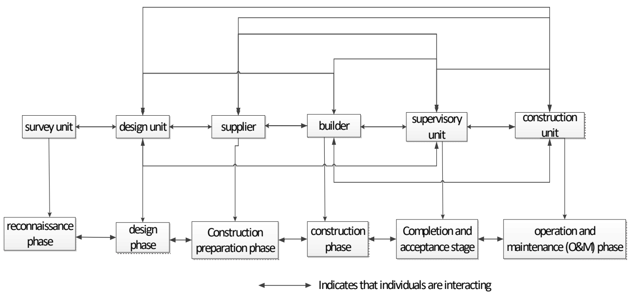

Figure 2 Traditional building process model

3.2 Digital Description of a BIM-DT-based Framework for Building Process Optimization

The Building Process Optimization Based on Building Information Model-Digital Twin Model (BIMDTM) framework (as shown in Fig. 1) is deeply integrated with the survey phase – design phase - construction preparation phase – construction phase - completion and acceptance phase - operation and maintenance phase. The Building Process Optimization Based on Building Information Model-Digital Twin Model (BIMDTM) framework mainly consists of a building information model (BIM, BM), and a data management system (DMS). Data management system (DMS), digital twin (DT) framework are digitally described as shown in Eq. (1), (2), (3) and (4):

$$\mathrm{BIMDIM} = \left\{\mathrm{BM, DMS, DT}\right\} \tag{1}$$

$$\mathrm{BM} = \begin{Bmatrix} \mathrm{BIM, IS + BIM, DS + BIM, CPS +} \\ \mathrm{+ BIM, CS + BIM, CAS + BIM, OMS} \end{Bmatrix} \tag{2}$$

Among them: BIM, IS: Building Information Modeling in Survey Phase; BIM, DS: Building Information Modeling in Design Phase; BIM, CPS: Building Information Modeling in Construction Preparation Phase; BIM, CS: Building Information Modeling in Construction Phase; BIM, CAS: Building Information Modeling in Completion and Acceptance Phase; BIM, OMS: Building Information Modeling in Operation and Maintenance Phase.

$$\mathrm{DMS} = \left\{\mathrm{BIM\ data + Digital\ twin\ data}\right\} \tag{3}$$

Where: DMS: data management system; BIM data: BIM model data; Digital twin date: digital twin data.

$$\mathrm{DT} = \begin{Bmatrix} \mathrm{DT, IS + DT, DS + DT, CPS +} \\ \mathrm{+ DT, CS + DT, CAS + DT, OMS} \end{Bmatrix} \tag{4}$$

Among them: DT, IS: survey phase digital twin model;

DT, DS: design phase digital twin model; DT, CPS: construction preparation phase digital twin model; DT, CS: construction phase digital twin model; DT, CAS: as-built acceptance phase digital twin model; DT, OMS: operation and maintenance phase digital twin model.

4 OPERATIONAL MECHANISMS FOR BUILDING PROCESS OPTIMIZATION BASED ON BIM-DIGITAL TWINS

The operation mechanism of the BIM-digital twin-based building process optimization model (shown in Fig. 4).

4.1 Application at the Survey and Design Stage

Generally speaking the survey and design stage belong to the pre-preparation stage of a construction project, and there is a close connection between the survey stage and the design stage. Therefore, the process of detailing the use of BIMDIM model is selected to combine the survey stage with the design stage in order to improve the efficiency of the work. First, the basic situation of the project, the content of the equipment and the scope of the main design parameters of the construction, the guaranteed value of the test, and the requirements of the construction time and quality are determined. Secondly, the work in the investigation stage focuses on determining the natural conditions of the construction site, such as climate, temperature, air pressure, humidity, etc. The digital twin concept is introduced into the engineering construction, and sensors and other monitoring equipment are set up at the relevant locations to monitor the site conditions and site changes in real time, and to construct a virtual model of the digital twin. All the basic information collected in the investigation stage is sent to the design stage together with the virtual model of digital twin built according to the real-time situation. After receiving the basic information provided in the survey phase, the design phase no longer uses 2D design and mapping software; although CAD is standardized and easy to operate, it lacks visualization and 3D expression and has a large workload. Therefore, the design unit firstly constructs the BIM model for the first time according to the data information of all parties related to the project sent by the survey unit and the information related to the completed digital twin model, and in the process of constructing the BIM model, the construction problems encountered are sent to the data management system, which processes the information and sends it to the digital twin system. By actually predicting, analyzing, and improving the received problems, they are fed back to the data management system. Through the feedback to the BIM model, the BIM model will be further improved.

4.2 Application during the preparatory phase of construction

The construction preparation stage, as the name suggests, is to make sufficient preparation for the work in the construction stage, and carry out the pre-construction preparation work in accordance with the BIM model and digital twin model established by the survey and design, and combined with the corresponding information. First, the staff of the project department is organized to have a preliminary understanding of the project according to the details in the design drawings, and to have a visual and three-dimensional understanding of the characteristics of the project through the building information model (BIM). Then, carry out quality planning for the project, formulate the project quality plan, and develop quality control measures for special processes, key processes, and critical processes. The construction process measures for sub-parts of the project will be prepared according to the construction organization design; in order to realize the intelligent production of building components, a component production workshop based on digital twins will be established. Second, based on the virtual construction information in the BIM model, the construction team will be organized, the construction team will be divided, the order of entry will be determined, and the material supply plan and use plan will be put into practice. Third, based on the information in the BIM model, determine the location of the project and the key points and difficulties in the construction of the project, and propose corresponding countermeasures. Fourth, through the BIM model, the basic information of the components is transferred to the data management system and sent to the digital twin system through the data management system through the arrangement of sensors, IoT, big data management and the deep integration of manufacturing technology. After the workshop receives the determined prefabricated component production parameters, it is uniformly transmitted to the production line to execute the production orders of related accessories and form the component production plan. In the production stage of the components, the sensors and other monitoring facilities arranged in the production workshop always feel the changes and feed back to the data control system, which regulates the actual demand and production progress and then scientifically adjusts the work progress of the production unit. At the same time, in order to ensure that the pre-stress, bearing capacity and other indicators of the components manufactured in the workshop can meet the needs of the design, each product has a special identification. Each product is labeled with an authentication code by the staff using radio frequency identification technology, and through scanning, the product number, production time and other information can be seen. And the parts leaving the factory are matched with the product positioning system. Through the whole process of identification, positioning, tracking and monitoring management of prefabricated components, it ensures that the overall quality of products in the workshop is fully controlled. In order to realize the integration and synergy of production and construction, a series of process information such as production scheduling, material procurement, production control, transportation and use in the digital twin parts production workshop can be recorded and fed back in real time in the data management system, so that all aspects of the construction process can grasp the real-time process of the production and transportation and use of the parts in a timely manner. On this basis, the progress information of each component can be obtained in real time through the BIM model and digital twin model, and the reasonable time for each component to enter the site can be judged.

4.3 Application During the Construction Phase

The application of BIM-DT-based construction process optimization technology to the construction phase of the construction process is at the heart of building construction sites, embracing new technologies to achieve smart manufacturing. During the implementation of the construction phase, the three main aspects of project management are implemented, i.e., pre-control, mid-control, and post-control. Prior to the start of the project, a variety of testing equipment, such as GPS, GPS, is deployed on the construction site and the actual information collected is entered into the data management system. When receiving new information about the construction site, the system will send new information to the BIM system and make corresponding adjustments and improvements to the new information. On this basis, a virtual construction site is established, and according to the situation of the virtual construction site, the following work is accomplished. I. Prepare the construction general control program to determine the overall goal; prepare the schedule, materials, equipment and other derivative plans. Second, through roaming, collision detection and other methods, to determine the key points and weak links of each project, and develop the corresponding construction organization design, construction program, technical delivery and so on. Implementation of specific plan solutions. Third, sensory visualization of the building information model and digital twin model according to the information collected on site, site layout, including the design of the site layout plan, the arrangement of large machinery at all stages, the arrangement of production processing and material yard at all stages. It ensured that the whole project was in order, and ensured that the project was carried out smoothly and reached the target of the scheduled construction period. The optimization of the construction phase includes: i.

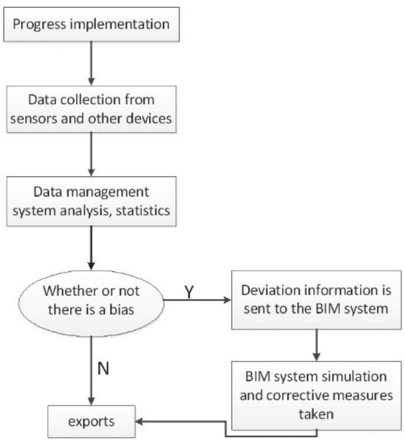

Figure 3 Corrective measures during the construction period

The assurance of the construction period (see Fig. 3) is to use monitoring equipment such as sensing devices to collect the actual progress, and then upload the collected progress information to the data management system. After receiving the data, it is compared with the construction schedule. The comparative differences are transmitted to the BIM modeling system, which then adjusts the changes and feeds the new improvements back into the data management system, enabling adjustments to the construction schedule.

Second, in the construction phase, the construction quality is optimally controlled. Managers can use sensors and other monitoring equipment on the construction site to track and monitor the project. If there are quality problems or human safety hazards, then pictures of the problems and descriptions of the problems are uploaded to the data management system, and after confirming the problems, the problems are transmitted to the BIM model. The BIM model receives it, locates it, corrects it, amends it, and feeds it back to the data model, thereby closing the loop. If it is man-made, a rectification notice is issued, the rectification is carried out according to the regulations and uploaded to the data management system. Third, the optimal allocation of resources during the construction phase is carried out, and the visualization model is used to sequence the construction plan and construction progress. Human resources are rationally arranged and executed to complete their work tasks and get the special tasks done. In this way, conflicts in the work can be minimized and work efficiency can be improved. Secondly, the pre-set construction sequence is closely integrated with the digital material workshop to realize the synergy between work processes according to the production and construction sequence of materials. Establish a reasonable material supply plan. According to the regulations, the administrator scans the information code on the materials and conducts random sampling test on the relevant material information. Based on the proposed construction plan and virtual construction site, formulate a plan for equipment entry and material stacking. The optimization of the completion stage is mainly reflected in the quality of the project for inspection and acceptance to reduce the project risk and ensure the quality of the project. The project department sets up a project acceptance working group, establishes a BIM acceptance model, and builds a corresponding virtual site. First of all, the acceptance group compares the relevant results of daily quality inspection, irregular inspection, engineering node inspection and acceptance, material and equipment field acceptance, engineering inspection lot acceptance, intermediate acceptance, and stage acceptance with the data in the data management system, in order to determine whether the corrective measures are put in place. For the BIM model and the corresponding virtual construction site, comprehensive testing and simulation of bearing capacity in the corresponding future state are carried out. After submitting the test results, the results are summarized in accordance with the relevant construction specifications, engineering contracts, technical agreements, design documents, opinions of the site supervision engineers, opinions reached at regular engineering meetings, and special requirements of the project construction. Through the BIM model, virtual site, and acceptance report, the acceptance information of the whole project can be obtained intuitively and three-dimensionally to prevent information islands.

4.4 Applications in the Operation and Maintenance Phase

Optimization of the O & M phase of the process is achieved through two methods: health management and failure prediction. Health management focuses on certain weaker parts of the project, as well as parts that become more dangerous as the service life increases. First, sensors and related monitoring equipment are used at relevant nodes and parts of the project to analyze the data transmitted to the data management system at random intervals and to diagnose faults, and if a component is detected to have a relevant health hazard, it is transmitted back to the data management system. After this data is recorded, it is fed back into the Building Information Model (BIM), where it is corrected by the BIM so that appropriate solutions can be proposed to reduce or eliminate the risk. When the plan is recorded in the data management system, the digital twin can predict the locations that are associated with this risk or subject to interactive stresses. If an error occurs, it is determined by the Building Information Modeling, and if not, it is returned to the normal mode of operational inspection. This real-time storage by the data management system for the record to facilitate the operation and maintenance personnel for a variety of emergencies, based on similar cases that have occurred in the development of emergency response plans to improve the safety of the building.

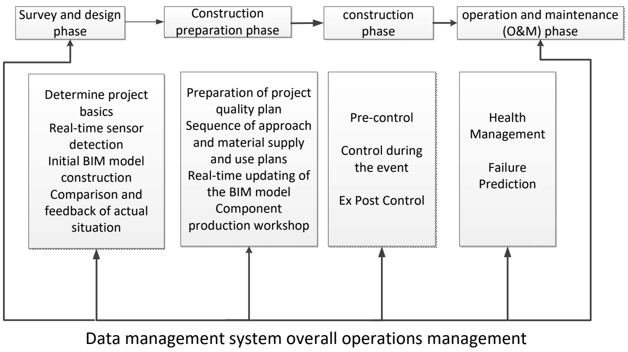

Figure 4 Operation mechanism of BIM-DT based building process optimization model

5 EMPIRICAL DESIGN AND ANALYSIS

Based on the BIM-DT based construction process optimization framework proposed in this paper, the paper focuses on describing how the corresponding functional modules of the framework are implemented based on a construction process.

5.1 Basic Information

The project has a structural height of 32.500m, 1 floor underground and 10 floors above ground; the structure is reinforced concrete shear wall structure; the foundation is raft slab foundation. The design reference period is 50 years; the seismic defense intensity is 6 degrees. The main types of steel bars used in this project are HPB300; HRB400; HRB400E.

5.2 Building BIM-DT Based Construction Process Optimization

The core of constructing the construction process optimization framework based on BIM-DT lies in the construction of the data management system. In this paper, the front-end technology of constructing data management system adopts jQuery vue front-end JavaScript framework to construct the interface of data management system, and constructs various functions in the system by means of code. After the completion of the basic framework of the data management system, springboot + vue + mysql + elementUI + redis + mybatis front and back separation mode is used to realize the dynamization of the data management systems so that the data management system can realize the real-time data update function.

5.2.1 Building Full-process Data Repository

The whole construction process data repository stores the data of each module in this construction process, such as project information, quality management, safety management, video monitoring, environmental monitoring, quality testing and other data. The interface of the system can update the problem list in real time, and the problem list is labeled with detailed information about the time of the problem and whether it is verified or not. At the same time, the system records the number of types of problems per day, the number of rectification, and by analyzing the responsibility of each unit to achieve a clear division of powers and responsibilities, which is conducive to the early rectification of the problem. (As shown in Fig. 5).

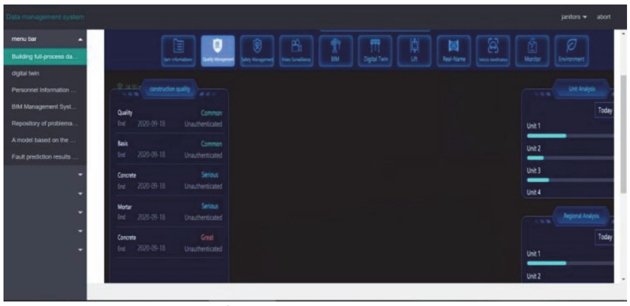

Figure 5 Construction-wide data repository

5.2.2 Digital Twin

The digital twin system builds a virtual model of the physical entity and arranges sensors and corresponding monitoring facilities on site. Through real-time monitoring of the site, real-time prediction of problems is achieved. The predicted problems and corresponding rectification solutions are transmitted to the BIM modeling system, which simulates the relevant rectification solutions and adjusts the model accordingly. After the completion of the problem and the relevant rectification program will be stored to the data management system. (As shown in Fig. 6).

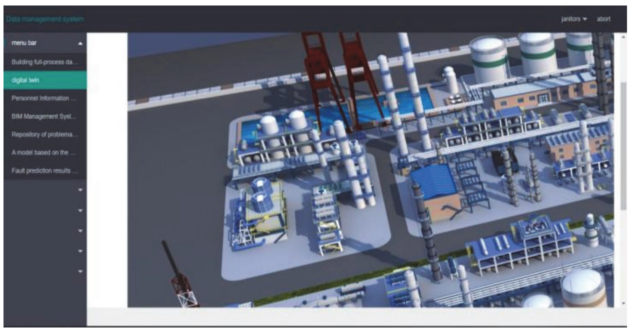

Figure 6 Digital twin

5.2.3 BIM Modeling System

The BIM modeling system stores all the information of the building and pre-constructs the construction project, which is beneficial for the potential problems and cost estimation of the project in the pre-construction stage. In the mid-construction phase, the feasibility of the construction program is determined through testing, and when problems are found, virtual simulation of the improvement program is conducted. When it is determined that the improvement program is feasible, then the improvement program will be implemented. The modeling system and related data are stored in the data management system and updated in real time, which is conducive to clarifying relevant information and reducing resource consumption at the acceptance stage. (As shown in Fig. 7).

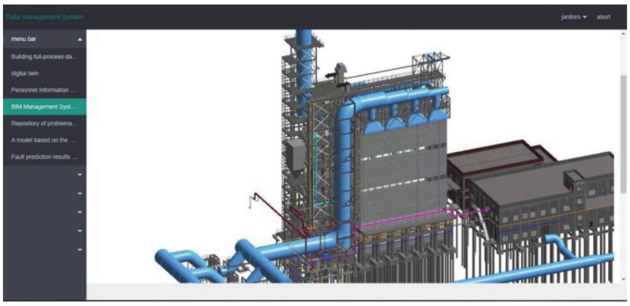

Figure 7 BIM management system

5.2.4 Personnel Information Management System

The personnel information management system can effectively clarify all the information of the personnel involved in the project, and realize a detailed understanding of the increase or decrease of personnel through personnel changes, which is conducive to the unfolding of the project management, as well as the division of related responsibilities. (As shown in Fig. 8).

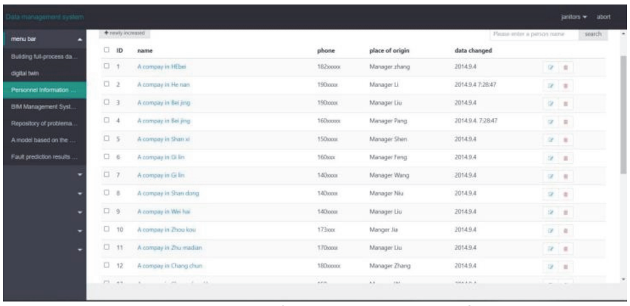

Figure 8 Personnel Information Management System

5.3 Model Construction

In this paper, drawing on the research of Wu Changqian (2021) [18], the construction process is optimized by minimizing the number of construction failures (5) and minimizing the construction cost (6) as the objective function, where the meaning of the symbols is explained as shown in Tab. 2. The number of construction failures is minimized as:

$$\min\left\{\max_{n\in(1,N)} F_n\right\} \tag{5}$$

Formula: $F_N = \sum_{j=1}^{n} X_{U_{ij} D_{pl}} t_{U_{ij} D_{pl}} + t_{U_{ij} D_{pl}} S_{U_{ij}}$,n is the total number of assignments. The construction cost is minimized as:

$$\text{Minq} = \min \sum_{i=1}^{n}\left[\beta_i + \sum_{i=1}^{n}\sum_{K=1}^{K}\left(a_{ijk}+g_{ijk}\right)X_{U_{ij} D_{pl}}\right] \tag{6}$$

where: K is the number of mechanical categories.

Table 2 Explanation of the meaning of the symbols in Eq. (5) and (6)

Grade	Hidden meaning
U_{ij}	The jth process of the ith construction operation
D_{pl}	Lth process for construction operation item p
$X_{U_{ij} D_{pl}}$	Construction operation U_{ij} selection of construction method D_{pl} construction, taking the value 0 or 1
$S_{U_{ij}}$	Number of failures of $U_{ij} > 0$
$t_{U_{ij} D_{pl}}$	Construction time for construction operation U_{ij} selecting construction method D_{pl}
β_i	Material costs for construction operation i
a_{ijk}	U_{ij} Utilization fee for construction apparatus K
g_{ijk}	U_{ij} Labor costs for the use of construction apparat

5.4 Fault Prediction Based on BP Neural Network

The prediction of faults in the digital twin system uses BP neural network. The BP neural network is mainly divided into two stages. The first stage involves the forward propagation of the signal, which starts from the input layer, passes through the hidden layers, and finally reaches the output layer. The second stage involves the backward propagation of the error, typically using the gradient descent method. This process starts from the output layer, moves through the hidden layers, and finally reaches the input layer. During this stage, adjustments are made to both weight and bias values: from the hidden layers to the output layer, as well as from the input layer to the hidden layers. These adjustments are necessary in order to optimize both weight and bias values within each respective layer of neurons in relation to one another. The weights and biases of the hidden layer are crucial parameters in a neural network architecture. In this paper, we take the construction of a three-layer neural network as an example (as shown in Fig. 9).

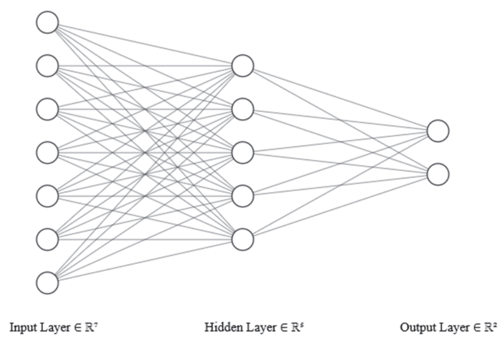

Figure 9 Structure of three-layer BP neural network

5.4.1 Network Initialization

Assume that the number of nodes in the input layer is 7, the number of nodes in the hidden layer is 5, and the number of nodes in the output layer is 2. The weight from the input layer to the hidden layer is w_{ij} and the weight from the hidden layer to the output layer is w_{jk}. The bias from the input layer to the hidden layer is set to b, and the bias from the hidden layer to the output layer is set to b_k. The learning rate is μ, and the excitation function is $g(x)$, taken as a Sigmoid function. The form is: $g(x)=\frac{1}{1+e^{-x}}$. The output of the implicit layer is notated as D_J: $D_J=g\left(\sum_{i=1}^{n} w_{ij}x_i+b\right)$. Output of the output layer $F_K=\sum_{i=1}^{5} w_{ij}x_i+b_k$. Calculation of errors $E=\frac{1}{2}\sum_{K=1}^{M}\left(T_K-P_K\right)^2$ where T_K is the desired output. Output the result if the error is small and enter the back propagation process of the error if the error is large.

5.4.2 Fault Diagnosis Based on BP Neural Network

Eight types of construction process fault data as samples, randomly selected fault types totaling 1 300 will be 400 samples as a training set for BP neural network training, and then use 900 samples as a test set to test the fault diagnosis method. (The fault types are shown in Tab. 3).

Table 3 Types of faults

grade	Fault type
A1	normalcy
A2	Wrong treatment of construction joints
A3	Poor bonding of grouting mortar
A4	Outside dimensions of the skeleton are not allowed
A5	Flat protective layer not allowed
A6	Misalignment of insertion bars in frame beams
A7	Excessive joints of the same section
A8	muscle cramp
A9	Wrong pouring sequence

5.4.3 Normal and Individual Fault Test Results

After diagnosis and classification by BP neural network, there are 9 groups of classification errors in 900 groups of test samples, and the correct rate is 99%, the results are shown in Tab. 4. It can be seen that: BP neural network as when there are faults in the construction process, BP neural network can accurately identify the faults based on the target settings, which is conducive to the complete implementation of the overall process optimization.

Table 4 Normal and fault test results

Grade	Fault type	Total number of test samples	Number of correctly diagnosed groups	Correct diagnosis / %
A1	normalcy	100	0	100
A2	Wrong treatment of construction joints	100	4	96
A3	Poor bonding of grouting mortar	100	0	100
A4	Outside dimensions of the skeleton are not allowed	100	1	99
A5	Flat protective layer not allowed	100	0	100
A6	Misalignment of insertion bars in frame beams	100	0	100
A7	Excessive joints of the same section	100	3	97
A8	Muscle cramp	100	1	90
A9	Wrong pouring sequence	100	0	100

5.4.4 Comparison of Different Algorithms

In order to further validate the diagnostic performance of the proposed method, the accuracy of fault diagnosis between the proposed method and three different fault diagnostic methods is tested by using the convolutional neural network method (Method 1) in literature [19], the SVM-based method (Method 2) in literature [20], and the particle swarm algorithm-based method (Method 3) in literature [21] as the comparative methods, and the results are shown in Tab. 5. The accuracy of fault diagnosis for construction process is high, with an average of 99%, while the accuracy of fault diagnosis for Method 1, Method 2, and Method 3 is 90.23%, 89.19%, and 89% respectively. The accuracy of this method is 99% on average for the construction process, while the accuracies of Method 1, Method 2 and Method 3 are 90.23%, 89.19% and 88.35% on average, respectively. It can be seen that this method can diagnose the faults in the construction process more accurately, and it maintains a more stable output of the fault determination results, which has good application reliability. (As shown in Tab. 5)

Table 5 Fault Detection Accuracy of Different Methods

Name	Troubleshooting accuracy
This method	99%
Method 1	90.23%
Method 2	89.19%
Method 3	88.35%

6 CONCLUSION

In view of the problems such as low integration degree, low production efficiency, serious waste of resources and hidden dangers in construction, new ideas and methods are put forward. This project intends to organically integrate the characteristics of BIM visualization and the real-time feedback technology of "digital twin" physical model into the construction process, and establish a BIM dt construction process optimization framework for the whole life cycle of buildings. In the empirical stage, the optimization process of the framework is described in detail. The method proposed in this paper is conducive to solving the information island effect in the current construction process and improving the efficiency in the construction process. However, there is still a shortcoming in this paper, that is, it does not describe in detail how the various stages of the construction process are integrated with the BIM-DT model and upgraded. The main work of future research will focus on how to apply the various stages of the framework's work in practice.

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