

APPLICATION OF BIM DURING LEAN CONSTRUCTION OF HIGH-RISE BUILDINGS

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ABSTRACT

At present, the construction industry is in urgent need of a big transformation from the traditional extensive development model to achieve transformation and upgrading. The cooperative application mode of lean construction and BIM is the important driving method of this change. It effectively solved the information technology problems in the process of lean construction implementation. Meanwhile, the lean construction system also provides a better application environment for BIM and fully realizes the technical value. From the perspective of multiple applications, this paper introduces in detail how BIM uses its technical advantages to enhance the application value of lean construction in the construction industry.

KEYWORDS

BIM, Lean construction, Site layout, Pipeline arrangement

INTRODUCTION

More engineering changes are common phenomena in construction projects, which will lead to high rework rate and labor and resource waste in the construction process. With the continuous development of the construction industry, lean construction[1] as an advanced engineering construction concept has been widely concerned in theoretical research and practical application. The prerequisite for implementing lean construction in engineering projects is that all participants of the project can comprehensively, timely and accurately understand the relevant information of the project and cooperate closely. BIM has just arrived at this demand and provided technical support for the implementation of lean construction.

Through the integration of BIM and lean construction, the efficiency of lean construction has been improved, the design has been improved due to the elimination of waste and the creation of value, and the performance of BIM applications has been greatly improved[2]-[6]. Rafael Sacks[7] believe that lean construction based on BIM, using BIM's 4D, 5D and other multi-dimensional visual technologies to help project participants control and manage the design and construction of the project, which can promote the integration of design and construction at the lowest cost and the shortest construction period to achieve high-quality building products. Rafael Sacks[8][9] analyzed the relationship between lean construction and BIM, pointing out that there is no building information model, lean construction is still possible to achieve project integration delivery, but BIM is indispensable for efficient implementation of lean construction.

Research and application of BIM started relatively late[10][11], but with the booming development of China's construction industry[12][13], BIM technology has also risen rapidly. From the high-rise buildings, super high-rise buildings to the construction of special-shaped structures, there is no shortage of BIM. BIM in the construction process integrates various professional information, which can effectively reduce the changes and waste of resources during the construction process. This paper aims to provide a solid foundation for the future research

and development of the construction industry based on the application of BIM technology and better service to lean construction based on existing theories and practices.

MECHANISM OF LEAN CONSTRUCTION AND BIM COLLABORATIVE APPLICATION

Application Value of Lean Construction and BIM Collaboration

The collaborative application value of lean construction and BIM can be divided into overall application value and partial application value. The overall application value refers to the full use of the value of lean construction and BIM in all stages and specialties of construction projects, so as to reduce social costs and improve work quality and efficiency. The realization of the overall application value is a huge system of engineering. The key condition is that it needs not only BIM application software for each stage and link, but also the necessary support of BIM application standards. At present, countries including developed countries do not have such conditions.

The local application value refers to the value brought by the lean construction and BIM in local construction projects, for example, in a certain stage of construction engineering or a certain construction process. For local applications, researchers have summarized a large number of BIM application points, and some researchers have summarized the application value of BIM technology according to the construction project participants. For example, for the construction phase, the main BIM application points include status model, cost forecasting, stage planning, construction coordination based on 3D model, site utilization plan, deepening design, digital assembly, 3D model-based control and planning. BIM application points and application values are not static and will evolve with the development of BIM application software and application standards.

Mechanism of Lean Construction and BIM Cooperative Application in Design and Construction Integration

As an information integrated management technology, BIM is essential information and its core is model. The realization of BIM application value is supported by the technology and management mechanism of collaborative application. As far as technical support is concerned, BIM collaborative application can support the realization of multi-specialty design and construction integration technology. First of all, BIM can realize the highly integrated design process of architecture, structure, decoration, electromechanical and so on, so that professional engineers can simultaneously carry out design work on the same platform and eliminate model conflicts. Through site analysis, scheme demonstration, visual control and dynamic optimization to avoid duplicate design, reduce design changes and a lot of rework. Secondly, BIM's virtual design and construction technology and matching software can realize the visual analysis of lean construction, such as building performance, collision detection, specification verification, system coordination, and simulate site construction on the design model with complete information. Finally, the BIM visual virtual animation can be used to arrange the construction site layout in advance and demonstrate the specific construction operation, so as to realize the optimization and improvement of the construction process and key processes in the design stage and reduce the waste in the construction stage.

A PROJECT INSTANCE

A project has a total construction area of 60,322.74 square meters, 4 underground floors, 25 floors above ground, and a building height of 96.85 meters. The design is for office buildings. The structural form is a frame core tube structure and a raft foundation. The project started on May 2015 and was completed on March 1, 2018. The construction site of the project is located in a small area, so the layout of the site is difficult. The materials entering and stacking are strictly controlled according to the construction schedule. There are many professional categories in the

basement division engineering, and the pipelines are densely arranged, and there are many cross-operations; the input of personnel, materials, and equipment is large, the process connection is large, the construction team is numerous, and the management is difficult.

In order to overcome the above unfavorable factors in the construction process, BIM technology is used to provide a multi-disciplinary collaborative work platform, which can strengthen process control and improve the overall quality and safety management level of the project; Using BIM to simulate the site layout plan and construction plan, make the construction plan more comprehensive and more reasonable, find problems in advance, solve the construction difficulties, reduce the phenomenon of rework, and shorten the construction period; Using BIM technology to simulate construction, realize visualization technological explanation, and make detailed material plans at various stages of construction to avoid material waste and improve the fine management level of the project.

Three-dimensional site layout

Use BIM software to simulate the construction site of A project and output a more intuitive and beautiful three-dimensional effect, and can perform 3D roaming. The modeling software can carry out a plausibility check according to relevant Chinese standards and norms. During the roaming process, multiple parties can participate in the visual experience of the site layout, which guides the implementation of the site layout. The layout of the site is dynamically adjusted according to the schedule, which advantageously overcomes the problem of the narrow construction site and difficult layout of the site. The BIM software automatically generates engineering quantities as a basis for material planning reporting and material usage control, saving money.



Fig.1 – 3D site layout

The arrangement of the tower cranes should be focused on when placing the 3D site. Based on the three-dimensional visualization characteristics of the building model, under the premise of fully considering the intermediate support distance of the tower crane, the position of the vertical transport mechanism such as the tower crane is reasonably determined to avoid collision with the beam, column, and foundation of the main structure. In the simulation demonstration of the tower crane position, the self-programming program is used to realize the change of the lifting weight within the tower crane range. The weight of the component within the lifting range is automatically calculated, and the lifting display can be displayed in green, and the lifting cannot be displayed in red so that the safety during the use of the tower crane is guaranteed.

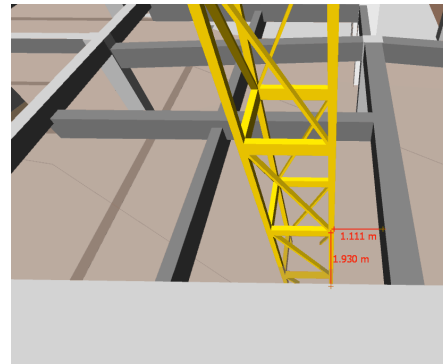
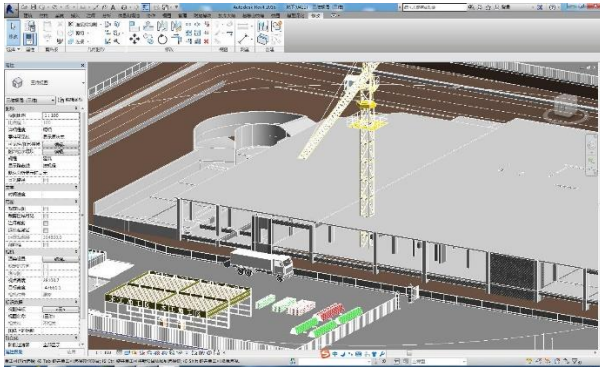


Fig.2 – Tower crane position layout

Scaffolding scheme simulation and calculation

The CAD drawings are used to build the structural model. The scaffolding BIM software is used to arrange the external scaffolding and supporting scaffolding based on the structural model according to the Chinese standard requirements. At the same time, it can issue a safety calculation book and generate detailed nodes. The scaffolding BIM software can output the scaffold material table, and the scaffolding and fasteners of different parts and specifications can be classified. The procurement and leasing plan can be arranged according to the schedule and site conditions, and the cost can be saved under the premise of ensuring the construction needs.

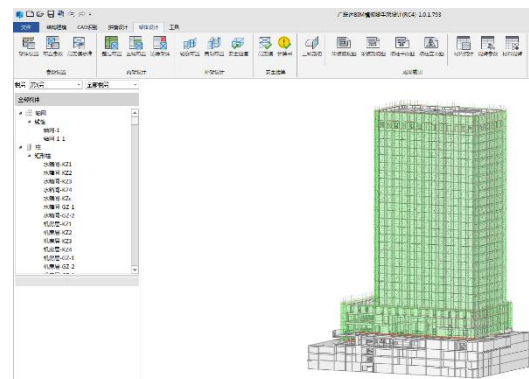
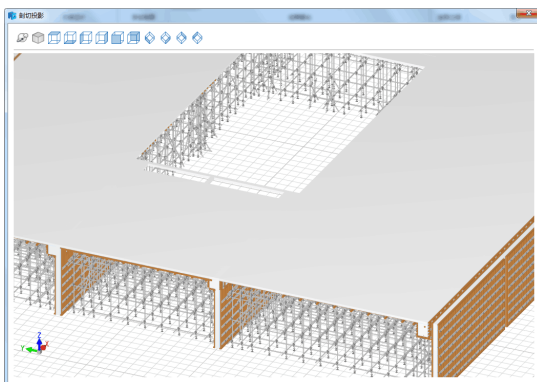


Fig.3 – Scaffolding details

According to the BIM software, the template support is designed, and the axial force is monitored on the parts with large stress. The project has set up the axial force monitoring and warning system to ensure the safety of the formwork. The forced state of the formwork support is monitored in real time through wireless transmission of the axial force meter and real-time safety warning is carried out.

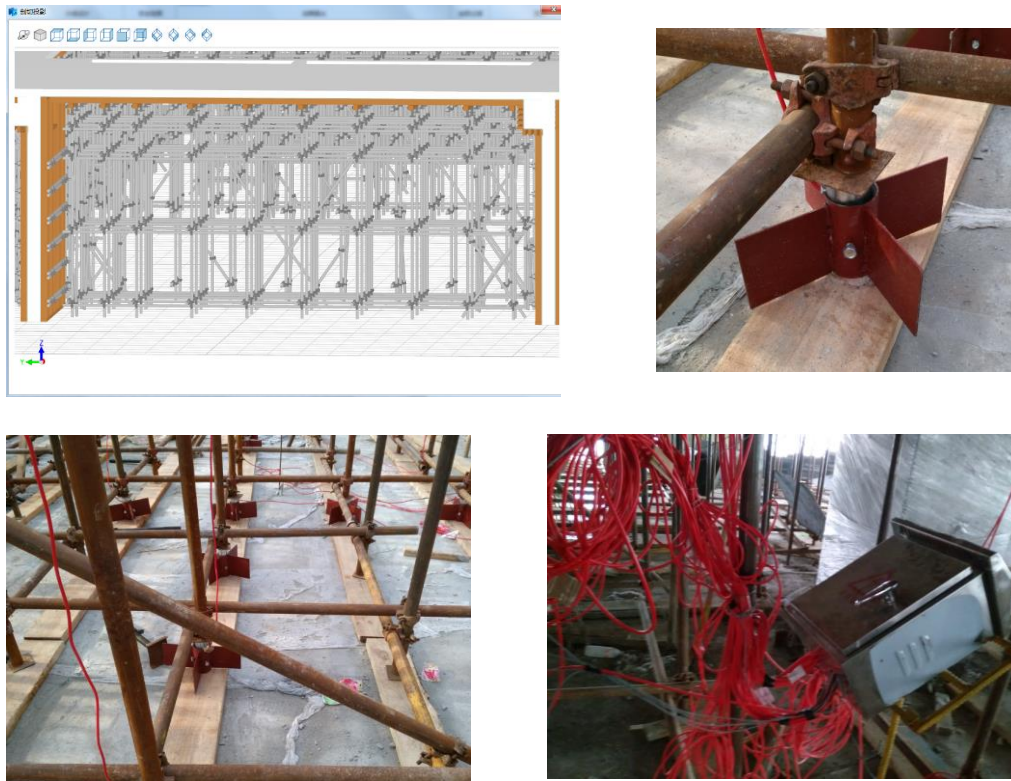


Fig.4 – Scaffolding axial force monitoring system

Integrated pipeline arrangement

Before the construction of each installation project, the A project uses Revit software to perform BIM modeling and deepen the comprehensive layout of the design pipeline. Then, the Revit pipeline model is imported into Navisworks software for collision detection, roaming inspection, and missing traps. After the Navisworks software imports the model, it performs collision detection and generates a test report. Based on the photos and ID information in the test report, it returns to the Revit software to find the corresponding collision point and adjust it.

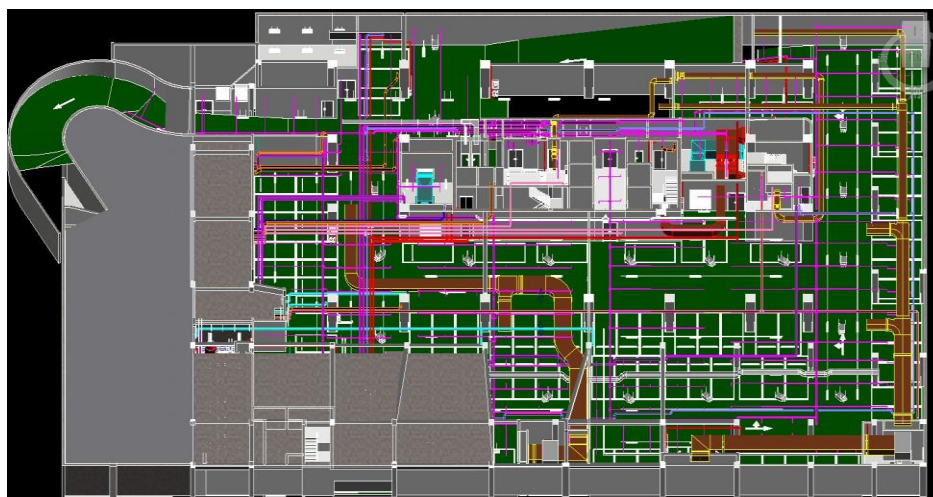


Fig.5 – Basement integrated pipeline arrangement

Using Navisworks software for third-person roaming inspections, you can find problems that collision detection cannot find. Select the component with the problem and mark it. After the overall inspection is completed, you can return to Revit to adjust the problem component by ID information.

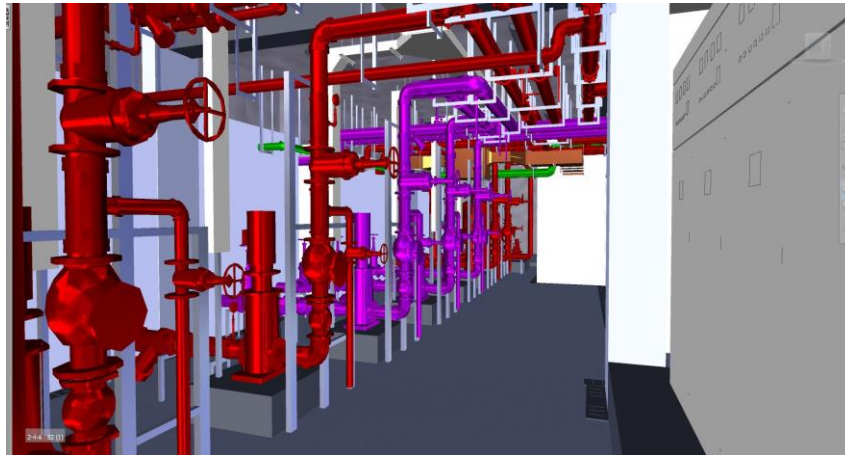


Fig.6 – Pump room integrated pipeline arrangement

For pipeline-intensive areas such as fire pump rooms, BIM modeling is a comprehensive arrangement of pipelines, which is conducive to the construction technology, improve the success rate, avoid rework, and improve the overall quality of the inspection, which is convenient for project completion and acceptance.

Optimization design of complex steel bars

Using BIM software to model the structurally complex node steel bars, a three-dimensional intuitive node map can be formed, reflecting the binding sequence and position requirements of the steel bars. Three-dimensional technical delivery of workers is carried out to avoid the inability of concrete to be poured due to the stacking of steel bars, and structural quality hazards arise.

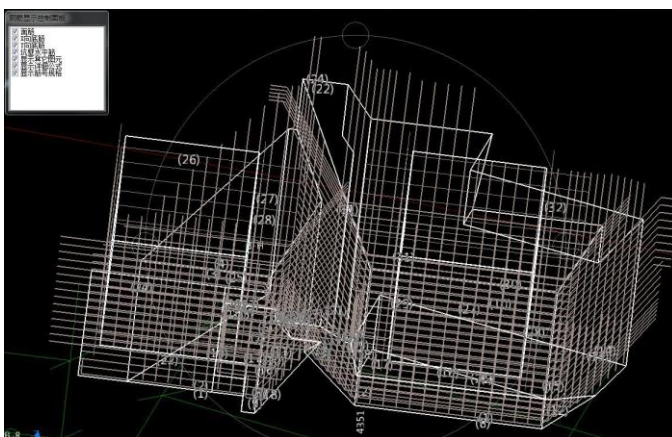


Fig.7 – Arrangement of testing points

The BIM software provides the rebar details for each component, including the specifications, pattern, length, quantity, weight, and placement of each rebar. And it can realize the automatic combination cutting according to the length of the on-site steel bar to minimize the generation of steel scrap. Software instead of manual sampling, greatly improving work efficiency.

Positioning robot application

The traditional electromechanical pipeline construction, using CAD drawings and tape measure tools, is purely manual on-site positioning, which has large errors and low work efficiency. A project uses a fully automatic positioning robot combined with BIM technology.

The electromechanical integrated pipeline model is optimized according to the arrangement principle, the clearance requirements, the deepening standards, etc., and the professional pipeline engineers jointly review and determine the integrated pipeline drawing. Combined with the main structural entity, a point on the structural axis that is easy to mark measurement is selected as the reference point, the pipeline support hanger points are arranged in advance, the key complex area points are refined, and finally the data points are generated. The main structure surveyor calibrates the building's one-meter line at the specified axis and then lays the reference point at the designated location. By focusing on the reference point, the position of the instrument in space and the distance from the staked point are calculated, and the infrared rays and the area are positioned one by one. The operation is extremely convenient, and one person completes the positioning work of hundreds of points in one day, and the efficiency is greatly improved. Figure 8 shows the model positioning and construction of the model into the positioning robot to ensure the accuracy of pipeline laying, installation of hangers and hangers, and improve the efficiency of field operations.



Fig.8 – Positioning robot application

3D laser scanning application

After the structural construction is completed, the spatial point cloud data quickly acquired by the 3D laser scanner is used to establish a 3D visualization model, and the scanning model and the physical space size of the BIM model are reviewed. In particular, the concrete structure and the masonry structure are subjected to a review operation, and if the deviation is large, the review portion is displayed in red. After reviewing the structural quality in Figure 4, the point cloud model is in good agreement with the original BIM structural model.

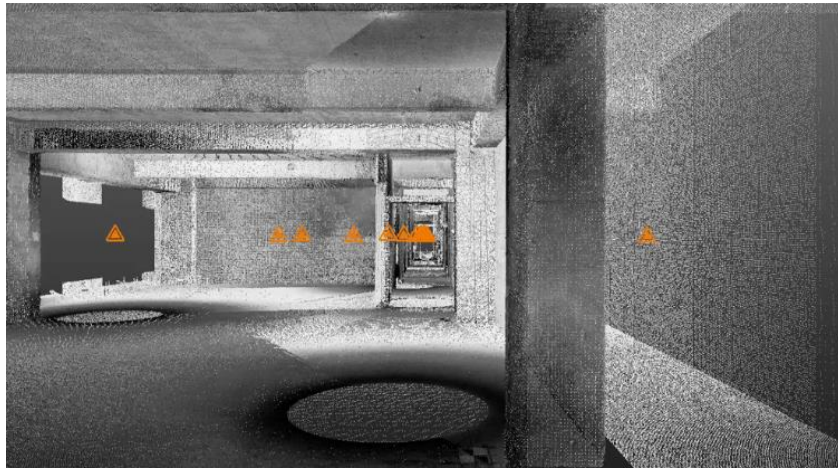


Fig.9 – 3D scanning effect



Fig.10 – Deviation comparison cloud

Mobile terminal application

During the construction process, a mobile client such as a tablet or a smartphone is used to download a dedicated APP and then import a BIM three-dimensional model for guiding construction and reviewing. The application of mobile terminals in project A has greatly improved the application scope of BIM and realized the application of the model in the construction site. Through the use of guidance, inspection, review and other aspects, BIM technology has become a powerful tool to ensure the quality and safety of construction.



Fig.11 – Mobile terminal application

Model simulation

In order to reduce the rework caused by the temporary change of the owner and ensure that the construction layout scheme is reasonable, we set up a Revit refinement model and import 3DMAX for rendering, output the effect picture and roam video, and then perform the construction after the owner has selected the effect picture. As the model size is consistent with the actual size on site, the space layout is realized to guide the construction.



Fig.12 – Virtual rendering

Template optimization design

Due to the large-scale use of wood formwork in Chinese construction projects, the combination of formwork plays a key role in cost control. The BIM formwork software is used to realize the intelligent template combination scheme and the accurate template processing diagram and provides the template support three-dimensional framing diagram, which can provide any part of the construction details, minimize waste generation, and save the amount of scaffold and formwork. The yellow part in Figure 13 is the uncut whole template, and the green part is the template that needs to be cut. The specific parameters can be used to query the template list.

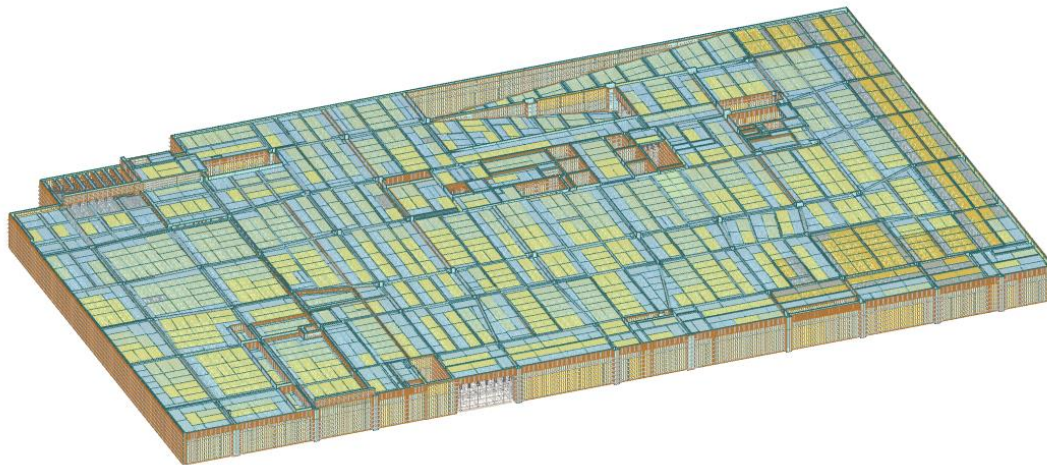


Fig.13 – Template combination diagram

ECONOMIC BENEFIT ANALYSIS OF LEAN CONSTRUCTION AND BIM COLLABORATIVE APPLICATION

Economic benefits of comprehensive pipeline layout

Traditional pipeline integrated design is based on two-dimensional drawings, and each system is superimposed by CAD software. Designers use their own design and construction experience to arrange and adjust pipelines in the plan, and express them in the form of traditional flat, vertical and cross-section, and finally form a comprehensive pipeline design. This two-dimensional drawing expression cannot solve the invisible problems of errors, leaks and collisions in the design process, affecting the success rate of installation. At the same time, in the general process of deepening design, only the section is drawn in more complex places, but the height and operation space of the local ceiling cannot be fully guaranteed in some places where the section is not drawn.

Tab. 1 - Basement Collision Check Statistics Table

	Architecture/number	structure/number	Water supply and drainage/number	HVAC/number	electrical/number
Architecture	—	—	29	8	9
structure	—	—	18	17	22
Water supply and drainage	29	18	16	100	156
HVAC	8	17	100	14	41
electrical	9	22	156	41	14

Tab. 2 - Benefit Analysis of Comprehensive Pipeline Arrangement

No.	Construction stage	Existing problems	Quantity/number	Material saving/USD	Manpower saving/working day
1	Structural Construction Stage	The collision between Electrical and Mechanical Pipelines on Underground Floor 1	40	8570	3
2	Structural Construction Stage	The collision between Electrical and Mechanical Pipelines on Underground Floor 2	10	2140	1.5
3	Structural Construction Stage	Reserved holes in basement brick wall	14	580	1.5
4	Decoration Construction stage	The collision between HVAC and water supply and drainage pipelines	100	2500	5.5
...
		Total	444	54400	25

As can be seen from Table 1, there are many collisions among various professional pipelines. The BIM technology pipeline comprehensive application of A project has a very high rate of return on investment. In Table 2 simple calculation shows that after 444 three-dimensional integrated pipeline layout, compared with the traditional method, the economic benefits achieved are 54400 USD and more than 25 working days ahead of schedule.

Economic benefits of formwork scaffolding

After completing the optimization design of the template, BIM software automatically generates statistics of the number of templates of various specifications and submits the corresponding results to the operators. The operators process the templates centrally according to the number of submissions, thus greatly improving the utilization rate of the template. According to the construction schedule and the total amount of formwork, steel pipe and fastener in a specific work area, the quantity of materials entering the site is controlled. This method ensures that the quantity of materials entering the site meets the construction requirements and reduces the backlog of materials on the site, and improves the turnover efficiency of turnover frame materials and funds. Using a perfect three-dimensional model to explain to the operator can improve the operator's intuitive and comprehensive understanding of the work content and reduce the time limit and cost pressure caused by on-site rework. Material calculation and actual storage in an area are analyzed as shown in Table 3.

Tab. 3 - Analysis of Material Calculated Quantity and Actual Entry Quantity in an area

Name of material	Software statistics	Statistical quantities in traditional methods	Actual Quantity	Deviation Ratio between Software Statistics and Actual Quantity /%	Material backlog reduction rate /%
Template	2826	3292	2959	-4.50	15.76
Steel pipe	49742	53555	48686	2.17	7.83
Right angle fastener	30139	32550	30778	-2.08	7.83
swivel fastener	9425	10461	9592	-1.74	10.80
sleeve fastener	3416	3989	3322	2.81	17.25
Adjustable support	3324	3762	3256	2.09	13.45

RESULTS AND DISCUSSION

Traditional construction methods cannot meet the growing demand for construction. The collaborative application of lean construction and BIM further improves the level of project fine management and brings good economic benefits. The collaborative application of lean construction and BIM has great application value for complex buildings. The collaborative application makes it possible for different professional engineers to work together on a unified platform. It provides a comprehensive simulation and multi-dimensional analysis for lean construction system. At present, three-dimensional site layout, simulation calculation of formwork scaffolding, pipeline comprehensive layout and so on are all local applications. With the development of BIM technology, BIM technology will be applied to lean construction system more comprehensively, which will make the design, procurement, construction, and operation process efficient and stable. The TFV (Transformation-Flow-Value) management system of lean construction has more advantages, and ultimately realize the collaborative application of BIM and lean construction in the whole life cycle of the project.

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