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BIM-based Construction Collision Detection and Pipeline Comprehensive Optimization

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Abstract: This paper explores the application of Building Information Modeling (BIM) technology in pipeline collision detection and optimization for a station and operation section project of Line 2 in a specific city. By leveraging BIM for 3D modeling, the study facilitates the identification of pipeline conflicts, enabling comprehensive optimization of the pipeline layout. Navisworks software is used for visualizing the model, providing an intuitive platform for detecting clashes and refining the pipeline design. The proposed BIM-based approach not only enhances construction efficiency by reducing rework and conflicts but also improves project quality through more accurate, coordinated designs. While the focus is on the construction industry, the methods discussed are applicable to various fields, offering broader potential for improving integration and efficiency in other types of construction projects.

Keywords: BIM; Collision detection; Pipeline optimization

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1. Introduction

1.1. Background

With the advent of the information age, BIM technology has gradually gained widespread attention. BIM is actually an information system that integrates various information such as buildings, city planning, environment, and human behavior based on a three-dimensional digital model. In the construction phase, the amount of field data is huge. How to effectively utilize it and achieve efficient collaboration among multiple professions has become one of the challenges faced by the current engineering industry.

Currently, scholars at home and abroad have conducted a lot of research work on BIM technology. Starting from the concept and definition of BIM, domestic scholars mainly focus on BIM application methods, BIM technical standards, BIM model optimization design, BIM technology application in construction simulation, and construction management and project delivery control based on BIM technology. Studies mainly focus on the value of BIM, modeling steps, collision detection algorithms, application effect evaluation, and the understanding and adoption of BIM technology by construction industry enterprises. At the same time, based on the above theoretical research results, many excellent cases have emerged in engineering practice. Among them, previous study analyzed the collision problems in the building information model and verified the effectiveness of the technology in solving pipeline conflicts through specific examples [1]. Fu Zi'an proposed a BIM pipeline comprehensive visualization design platform based on mobile terminals, which solves the problems of easy errors and inability to accurately reflect the actual spatial layout in the traditional pipeline drawing process [2]. Li Peng et al. developed a software for rapidly generating internal pipelines of buildings based on the building information model platform [3]. Li Minghao adopted computer vision technology to obtain three-dimensional contour data of objects through depth cameras, thereby detecting whether the pipeline layout in the building is reasonable [4], realizing the digitization of the construction process and improving construction efficiency.

1.2. Project overview

The project is located at a station and operating section of Line 2 in a certain city, with a building area of 208,000 square meters. It includes an underground station for the transfer between Line 1 and Line 2, post-station line sections, and a parking lot. The total length is 1,647 m, including two double-track tunnels (Type A), one single-track tunnel (Type B), and an underground station. This project requires the use of BIM software Navisworks for pipeline management and optimization. In traditional construction, untimely and inaccurate information communication between various professionals often leads to pipeline collisions. Taking this project as an example, there are 93 types of pipeline drawings completed during the design phase, including 50 tunnel segment pipeline layout drawings, 33 water supply and drainage pipeline network drawings, 24 integrated drawings, 18 structural construction drawings, and 21 steel component and curtain wall construction drawings. In addition, there are other auxiliary drawings. Since designers from various professions use CAD drawings, the information on the drawings is not effectively utilized, and real-time data updates cannot be achieved.

Therefore, when the project enters the implementation phase, many problems are found on the construction site, such as incorrect construction sequence, missing pipelines, repeated installation, and inconsistent pipeline sizes, which affect the on-site construction progress and cause unnecessary economic losses. According to the owner's requirements, all pipeline positioning and installation work must be completed within one month. Therefore, the effective use of BIM technology during project implementation can greatly improve efficiency. However, due to the lack of unified design standards among various professions and the use of different construction specifications by various units, the result is that the pipeline location, direction, quantity, and other information expressed in the design drawings would be chaotic, which brings great difficulties to later construction.

2. Materials and methods

2.1. BIM-based construction collision detection and integrated pipeline optimization

2.1.1. Construction requirements

Firstly, a unified pipeline database was established to enable data from various professions to be correlated, facilitating easy access and maintenance. Before construction, the design department uploaded the design drawings of each profession to the project collaboration platform and distributed them to all participants, allowing relevant personnel to view the project overview in a timely manner and understand the overall situation of the project. The construction party then organized relevant personnel to review these drawings, checking for omissions, errors, or unreasonable areas, and made timely corrections. Additionally, regular training was provided to designers from various professions to familiarize them with various standards and specifications, and to help them master advanced construction techniques, thereby improving construction quality and efficiency.

Secondly, conduct sufficient research on the construction site to clarify information such as the construction scope, length, elevation, and depth of burial for various pipelines, and develop a detailed "Integrated Pipeline Layout Plan". This plan has listed various pipeline types, specifications, lengths, materials, diameters, elevations, and other information. This could greatly reduce potential errors made by on-site construction workers during operations. Additionally, before actual construction begins, all of the starting and ending points pipelines was determined to avoid pipeline collision.

The pipeline laying stage is a critical and challenging part of the entire construction process. To avoid rework due to improper pipeline laying, aside from preparing well in the early stages, it would be necessary to take measures to ensure the accuracy of pipeline layout. For instance, during on-site construction, the construction leader should strictly follow the "Integrated Pipeline Layout Table" to ensure that each pipeline is laid in the specified position. If any issues are found, construction should be immediately stopped, and the position should be readjusted.

Lastly, to better achieve integrated pipeline optimization, BIM software was utilized for modeling and simulating the construction process. Through analyzing the model, one can intuitively understand the on-site construction situation, promptly identify potential problems, and make corresponding adjustments. Simultaneously, 3D animation was employed to showcase the entire construction process to the owners, providing them with a comprehensive understanding of the project's progress and enhancing their trust in the construction plan.

2.2. Basic process of integrated pipeline optimization

The pipeline design stage is a crucial phase of construction design. Based on different engineering characteristics and equipment features, comprehensive pipeline analysis and optimization across various specialties are required to achieve the best overall layout for the project. Currently, commonly used methods in domestic engineering practice include manual coordination, mechanical assistance, and software assistance. However, these methods often suffer from issues such as low efficiency, inaccurate results, and high costs [5].

This article analyzes the technical route of integrated pipeline optimization based on BIM: Firstly, Revit software was used to establish a construction BIM model and a site layout diagram was created based on it. Then, professional models such as architecture, structure, water supply and drainage, and firefighting was integrated into a unified platform to generate a general site plan [6]. Afterwards, integrated pipeline optimization plans were developed for various professional areas based on the site plan and integrated pipeline diagram. BIMsight software was utilized to establish a collision detection database and detect collision points. Finally, through secondary optimization and adjustment of the plan, the pipeline layout was completed.

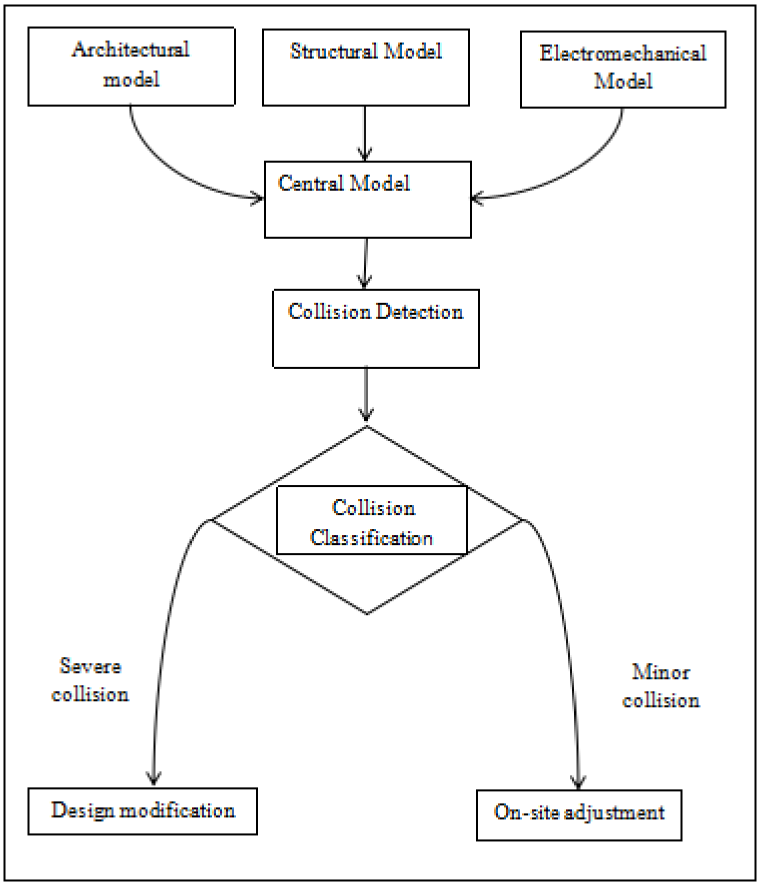

Figure 1. Basic Process of Integrated Pipeline Optimization.

The specific process was shown in **Figure 1**. This process has the following advantages: Firstly, it fully considers the architectural space layout and achieves collaborative work among various professions [7]; secondly, collision detection analysis can quickly locate collision areas, reducing unnecessary rework and modifications; thirdly, utilizing the optimized pipeline scheme can greatly reduce the difficulty of on-site implementation.

2.3. 3D model establishment

Before project implementation, a three-dimensional space coordinate system of the model was determined based on the actual situation of the project, providing precise reference coordinates for later pipeline optimization work.

When establishing a 3D model in Revit 2020 software, the following aspects was noted: (1) The model size should be consistent with the design drawings. For example, if the cable pipe specifications are marked on the design drawings, corresponding changes should be made in the model; (2) The material information in the model should be consistent with the design drawings to avoid problems such as material specification mismatches or inability to make changes; (3) For local components within the building plane, it is recommended to group them according to certain rules for easier viewing later; (4) Temporary facilities, tower cranes, etc., during construction should be modeled according to design requirements and numbered for easier drawing updates later [8]; (5) All independent pipelines, air ducts, hoods, and other components should be modeled separately for later merging; (6) For small-sized pipeline supports, bridges, and other components that do not affect the overall design, they can be directly inserted into the model without separate modeling. Additionally, during the modeling process, it should be ensured that the created model complies with national norms and acceptance standards.

2.4. Construction scheme design and optimization

According to the design drawings, the integrated pipelines of the project include sewage, water supply, firefighting, strong electricity, and weak electricity. Among them, sewage includes reclaimed water, rainwater, and sewage; water supply includes domestic water supply, production water, fire water supply, air conditioning chilled water, process water. For instance, firefighting includes fire hydrants, sprinkler systems, automatic fire alarm and automatic fire extinguishing systems, and more [9]; strong electricity includes power cables, lighting power sources, signal power sources, track circuits and others; weak electricity includes video monitoring systems, broadcasting systems, access control systems, computer network systems, telephone systems and more. During the construction process, due to lack of communication among various professions and unfamiliarity with the drawing content, on-site construction workers only follow their experience, resulting in many pipeline collisions or conflicts.

Therefore, before construction, BIM modeling of the construction project should be carried out, relevant information should be imported into the model, and a BIM model database should be established. Utilizing BIM technology can effectively improve design efficiency and the accuracy of pipeline collision detection, while also saving a lot of time.

2.4.1. Pipeline layout

After the completion of the architectural construction drawings, the pipeline layout drawings were reviewed. Due to the abundance of pipeline information, calculating and reviewing using traditional two-dimensional drawings were time-consuming, laborious, and prone to omissions or errors. Therefore, it is necessary to input the pipeline data into a BIM model and use Revit software for modeling and visualization.

Firstly, based on the pipeline layout principles, the direction and location of each layer of pipelines are determined. Secondly, according to regulatory requirements, appropriate pipeline types and materials are selected, and the pipelines are numbered [10]. Finally, parameters such as the elevation and slope of the pipelines are adjusted according to the needs of different professions. For some special pipelines, such as fire sprinkler pipes, smoke exhaust pipes, and supply and exhaust pipes, separate models need to be established. Additionally, for rainwater pipelines in underground spaces, due to limited site conditions, open excavation cannot be used for construction, and only underground excavation can be adopted. In this process, the positional relationship between pipelines must be considered to ensure that they do not affect subsequent construction processes.

2.4.2. Pipeline connection

In this study, the main equipment such as central air conditioning units, fan coil units, chilled water units, water pumps, and cooling towers was installed. Due to the numerous equipment pipelines and the fact that some equipment cannot share pipelines with other equipment, pipeline connections need to be made during construction. Before deepening the BIM model design on site, the connection scheme was the first step is to optimize to ensure that there are no duplications or omissions during construction, making the overall pipeline layout reasonable and aesthetically pleasing. By establishing a three-dimensional model of the entire building using BIM software, the layout of various equipment pipelines was combined with drawing requirements, which would be better adhere and control the positional relationship between the pipelines of various professions, achieve visual pipeline management, and discover and address crossing pipelines and collision points in a timely manner, improving construction efficiency. Meanwhile, pipeline layout at various stages was also optimized by using BIM software to avoid pipeline conflicts, improve construction efficiency, shorten the construction period, and provide support for later operation and maintenance [11].

During the construction process of this project, BIM technology was adopted to solve pipeline layout issues before construction design. Then, the Revit MEP function was used to perform precise modeling and spatial relationship analysis on the corresponding pipelines to determine the best construction plan. Based on the direction and placement of the pipelines, some obstacle areas can be effectively avoided, reducing construction difficulty, speeding up construction progress, and improving project quality.

3. Results

3.1. Collision analysis

Based on the BIM model established above, the architectural and structural components were integrated through Revit, and collision detection was performed on the integrated piping model using Navisworks.

For projects with a building height below 40 m, no underground structure, regular floor plans, and a small number and variety of pipelines, the use of Revit software combined with CAD software has already achieve relatively precise pipeline layout. However, when the building height exceeds 45 m and there is an underground structure, due to the complexity of the architectural plan and the dense piping, especially when construction workers use 2D drawings to coordinate with site conditions, it often leads to significant discrepancies between the actual piping layout and the drawings, resulting in rework.

3.2. Navisworks

To address this issue, the 3D piping model was imported into Navisworks for collision analysis. Both hard and soft collision rules could be applied to meet different construction requirements in Navisworks. Secondly, through Navisworks' visual collision report analysis table, quick queries of collision relationships between pipelines were achieved. Thirdly, by analyzing the collision results, reasonable optimization locations for the pipelines were determined. Finally, the comprehensive optimization layout of the pipelines was completed through adjusting the optimization locations, and 2D construction drawings which contain spatial information of the pipelines were suitable for the usage habits of site construction workers, was the output.

4. Conclusion

In this paper, BIM technology was adopted for collision detection of pipelines. By establishing a BIM model and combining it with Navisworks software, the 3D piping diagram is converted into a 2D detailed construction drawing. Firstly, piping space planning is carried out, and then components are created using 3D modeling software and imported into the BIM model to enable collision analysis and optimized layout of the pipelines. This method overcomes the disadvantages of long duration and low efficiency of manual measurement in traditional methods. It not only improves the accuracy of pipeline layout but also significantly reduces the rework costs caused by non-standard construction in the later stages. It enables site construction workers to visually understand the pipeline layout, avoiding issues such as errors, omissions, and collisions, thereby improving construction quality. Simultaneously, by sharing BIM model information with other construction units and design institutes, communication efficiency can be effectively improved, and project progress can be accelerated. The results can be applied to other construction fields, providing a reference for future promotion and application in more engineering projects.

Disclosure statement

The author declares no conflict of interest.

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