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BIM-Based Metro Station Pipeline Comprehensive Avoidance Optimization And Deepening Design Application Research

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***Abstract*— As one of the important components of the metro project, the pipeline synthesis is characterized by a wide variety of specialties and intricate arrangement, and multiple units and specialties are involved in the design and construction of each in the design process, which leads to the situation that various types of information data are difficult to interact with each other. To address this problem, the pipeline installation of a metro station in Qingdao is taken as the research object, and BIM technology is applied to the design and deepening of pipeline synthesis in metro engineering to establish the algorithm of automatic pipeline collision avoidance optimization. We combine the HiBIM plug-in to carry on the collision detection to the established full-professional pipeline comprehensive BIM model of subway station to solve the problems such as errors, omissions and deficiencies in the comprehensive design of subway station pipelines. The results show that the developed pipeline avoidance algorithm solves a total of 442 collision problems and saves a lot of time for pipeline avoidance optimization; after the specific deepening design and application of the integrated model of all professional pipelines in metro stations, it brings significant results in improving the design efficiency and quality, and provides positive thinking for the integrated design and deepening of pipelines in metro stations.**

***Index Terms*— BIM; metro station; pipeline synthesis; deepening design; pipeline avoidance algorithm**

I. INTRODUCTION

In the construction process of the subway, the prerequisite to ensure the construction efficiency and construction quality of the project is its complete design quality and design effectiveness [1]. Pipeline synthesis is an extremely informative, complex and tedious work in metro engineering, which can better reflect the quality of metro engineering [2]. A reasonable comprehensive design of pipelines can ensure the effective and adequate use of underground space, as well as reduce the cost of pipeline construction and installation, and also facilitate the maintenance and management of pipelines [3].

Restricted by the traditional two-dimensional design approach, designers of various disciplines often need to spend a lot of time and energy to understand and coordinate the design information of non-specialties, which makes it more difficult for designers to deal with comprehensive pipeline problems and leads to low design efficiency [4], and it is difficult to reasonably arrange the space arrangement of each pipeline, as a result, the space resources are underutilized and the space utilization rate is seriously reduced.

BIM technology can effectively solve the above problems. Due to its advantages in modeling and visualization, it allows the construction of the project clear, thus realizing the corresponding engineering construction simulation and further mastering the progress and details of the construction [5]. Li-Chuan and UnurjargalDolgorsuren both proposed a BIM detailed construction design and picking optimization system based on steel engineering for traditional steel engineering works [6]; YuChen used Revit to perform 3D modeling on the basis of CAD construction drawings of the cigarette factory, and it only took about 30 days to build the entire 3D model of the building, structure, equipment, and piping, saving more than 90% of the time cost and money cost caused by rework and material waste [7]. GeF et al. proposed to apply BIM technology to the planning, design, construction and operation management of underground integrated pipe corridors to overcome the shortcomings of traditional two-dimensional design in the design performance of underground integrated pipe corridors [8], but the study did not include detailed construction simulation with in-depth collision detection and no specific improvement measures; Yang Yuanfeng et al. established the electromechanical model by BIM, and then used BIM technology for deepening work such as collision detection, and used the collision detection function of RevitMEP software to find and eliminate collisions after the modeling was completed in the local area, which further verified the advantages of BIM technology in the comprehensive deepening design of pipelines compared with the traditional deepening method based on BIM [9].

Comprehensive research and application of BIM technology in the field of deepening design at home and abroad can be concluded that BIM technology is an important development trend and decisive factor in the field of future engineering construction, but the use of BIM technology in China at this stage is biased toward the integration and sharing of one-sided static information. For the comprehensive design and deepening design of pipelines and other aspects of the lack of a comprehensive and deeper application of research, no detailed, in-depth, integrated measures to improve the design program, the advantages of BIM technology still has not been used to the maximum extent.

To effectively combine BIM technology with the deepening design of metro station pipeline to reduce the engineering cycle and rework is the urgent problem to be solved in this

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paper. To address this problem, this paper takes BIM technology as the core, and firstly establishes building model, structural model, electrical model, HVAC model and water supply and drainage model with Revit, and integrates each sub-model to complete the construction of a comprehensive 3D model of all professional pipelines based on BIM. Secondly, the secondary development of collision pipeline auto-avoidance based on Revit, determine the development environment and development tools, develop the pipeline layout principle according to the design specification and actual engineering situation, develop the process algorithm of collision pipeline auto-avoidance based on the principle of pipeline layout and avoidance, and realize the pipeline auto-avoidance plug-in based on Revit secondary development. In the example verification, for the deficiencies in the integrated design of the pipeline, based on HiBIM plug-in, according to the requirements of the building information model construction application standards, the integrated three-dimensional model of the pipeline to deepen the design, the established metro station full professional pipeline integrated BIM model for collision detection, generate collision reports, analysis of collision results, the use of automatic pipeline avoidance plug-in for optimization and re-arrangement.

II. TO ESTABLISH A COMPREHENSIVE MODEL OF ALL-PROFESSIONAL PIPELINE

A. Project Overview

A subway station in Qingdao studied in this paper is a single island double-layer open-cut station, the underground floor is the station hall floor, and the negative second floor is the platform floor. The station is located in the green belt on the east side of the intersection of Shenzhen Road and Changsha Road. It is set up along Shenzhen Road south and north across Changsha Road. Residential areas are the main areas near the station. The starting and ending mileage is YSK43+786.182~YSK44+015.482, the effective platform center mileage is YSK43+941.982, the total length is 229.30 meters, the standard section width is 20.90 meters, the total construction area is 12808 square meters, the main construction area is 9676 square meters, and the ancillary area is 3132 square meters. This paper models the building structure and pipeline synthesis of the subway station based on BIM, and makes use of the advantages of BIM technology to solve the problem of comprehensive design and installation of subway station pipelines.

B. BIM model construction

According to the characteristics of the actual engineering project and combined with the specification, the BIM model construction standard is established, and the modeling principles, modeling software and specific modeling process are determined. The building sub-model, structure sub-model, warm-through sub-model, electrical sub-model and water supply and drainage sub-model are established by using Revit software, and integrated into a full-professional pipeline comprehensive model after audit. The details are as follows:

(1) Build a building model

The parametric function of BIM is used to edit and construct the building walls, structural columns and other components, combining 3D and plan view to determine the size and location of each component, not only to meet the architectural design specifications, but also to consider the specifications and needs of the structural and piping integrated system majors. The 3D building model section is shown in Figure 1.

(2) Build a structural model

The component information of the structure is generated into a component schedule, including the volume, elevation, numbering and positioning marks of the components and based on these data to draw a 3D model map The 3D model of the structure is shown in Figure 2.

(3)Build an HVAC model

Create air supply, return and exhaust air duct system to adjust and analyze the duct network in the metro station project, generate layout settings after creating the system type, with the HiBIM plug-in to connect the air ducts, air outlets and other functions to achieve rapid modeling of the HVAC model, significantly improving the efficiency of modeling. The HVAC 3D model is shown in Figure 3.

(4) Build a electrical model

In response to the disadvantages of traditional electrical design expressed in graphical symbols, the visualization and diagrammability of BIM technology can maintain a mutually supportive expression of 2D drawings and 3D models. The use of HiBIM plug-in in the public family library and personal family library, greatly improve the efficiency of the modeling, while ensuring the accuracy of the model. The electrical model is shown in Figure 4.

(5) Build a water supply and drainage model

By analyzing the professional properties of water supply and drainage, the drainage system is mostly pressure pipeline or gravity pipeline, and attention should be paid to its slope setting according to the standards and specifications in the modeling process to ensure the smooth discharge of sewage. According to the two-dimensional drawings to determine the location of each pipeline and drawing, layout equipment and accessories, and finally complete the BIM water supply and drainage model, as shown in Figure 5.

After the construction of each professional model is completed, the integration of each professional BIM model is needed. If the collision detection and net height analysis are carried out using the models linked by each profession will lead to the situation that some component information cannot be identified, which will lead to a mismatch result. Since the structural building model elements are simpler and less errors occur when combining the models, integrating the structural building model into the mechanical and electrical model can ensure the integrity and accuracy of the comprehensive model of all professional pipelines, as shown in Figure 6.

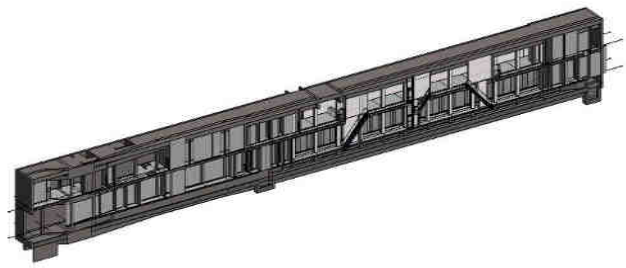


Figure 1. BIM building model section

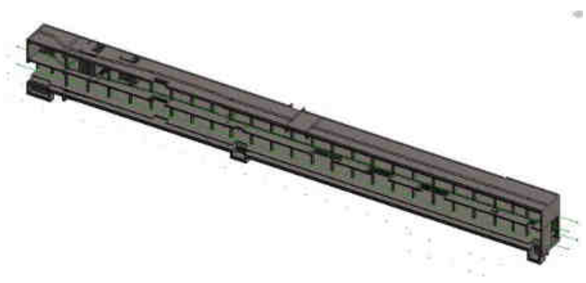


Figure 2. BIM structural model section

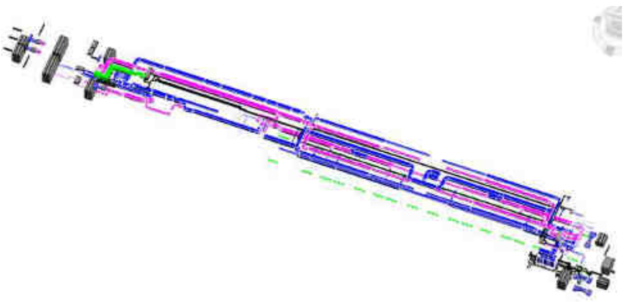


Figure 3. BIM HVAC model

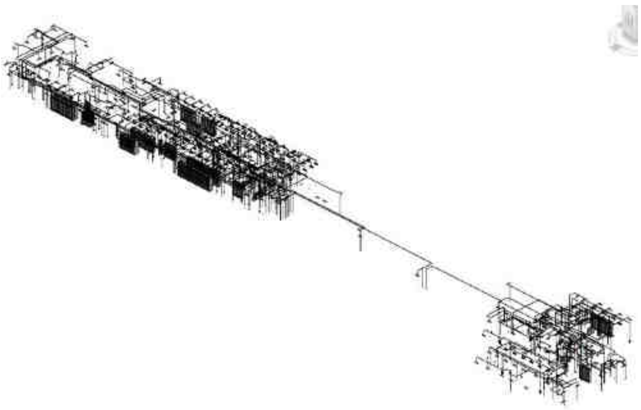


Figure 4. BIM electrical model

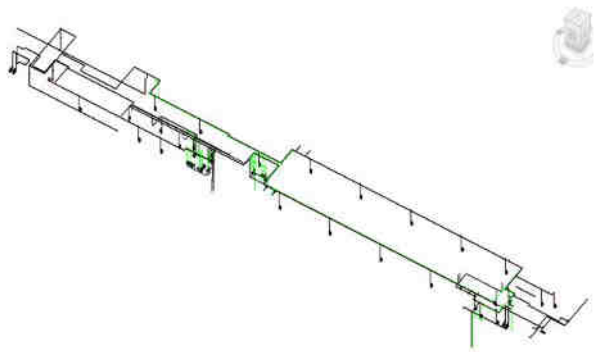


Figure 5. BIM water supply and drainage model

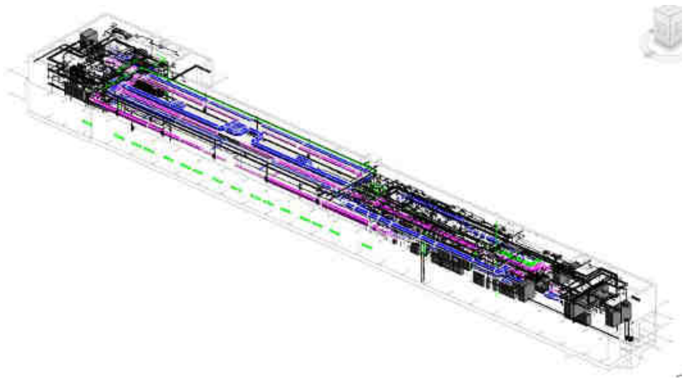


Figure 6. Comprehensive model of professional pipeline

III. BIM-BASED METRO STATION PIPELINE COMPREHENSIVE AVOIDANCE OPTIMIZATION METHOD

A Pipeline collision avoidance principle

According to "Metro Design Code GB50157-2013" [10] and the research analysis of engineering examples, this paper summarized the following principles for the comprehensive pipeline collision avoidance metro station pipelines:

(1) First big and then small principle. Large diameter pipe bends more difficult than small diameter pipe, and will use more materials, cost higher.

(2) Pressure makes no pressure principle. Part of the non-pressure pipeline belongs to the gravity flow pipeline, and the arrangement has a slope setting requirements, which does not allow upward turning bend, and can avoid the phenomenon of blockage of such pipelines.

(3) Cold water pipe so that the principle of hot water pipe. If the hot water pipe continuously adjusts the elevation, which will cause problems such as gas accumulation. And hot water pipe cost is higher.

(4) The principle of domestic water pipes to avoid fire water pipes. In the subway station project, fire protection facilities are very important. Fire pipe diameter is large, and water consumption is large, which should be given higher priority.
(5) The principle of gas tube letting liquid tube. The power cost of liquid flow is higher than that of gas flow, and the cost of liquid tube is also higher.

(6) the principle of less concessions and more concessions. Pipes with fewer accessories should avoid pipes with more accessories, which is conducive to construction operation and maintenance and replacement of pipe fittings. The reserved maintenance space should be greater than or equal to 500mm.

(7) the principle of transferring weak electricity to strong electricity. The size of the weak power pipeline is generally smaller, which is easier to install, and the cost is lower than that of the strong power pipeline.

(8) The principles that should be followed in the vertical arrangement of pipelines are shown in Table 1.

Table 1. Vertical pipeline layout principle

Vertical arrangement mode		Reason
Above	Below	
Air duct	Cable or slot rack	The size of the air duct is larger, and the air duct is convenient for the installation and maintenance of the cable or slot rack.
Cable or slot rack	Water pipe	The water pipe has the risk of dripping and leaking, and the cable or bridge will accelerate aging and damage when exposed to water for a long time, and in serious cases, it will cause short circuit and power outage, resulting in greater production losses.
Hot water pipe	Cold water pipe	The insulation layer of hot water pipe is easy to be aged and damaged in case of water. Avoid the water supply would risk contamination of the drainage.
Water supply pipe	Drain pipe	Avoid the risk that the water supply will be contaminated.
Non-corrosive dielectric tube	corrosive dielectric tube	The pipeline leakage is easy to cause corrosion to the lower pipeline, the corrosion medium pipeline should be arranged at the top.
High pressure tube	Low pressure tube	The pressure of the high-pressure pipeline is strong, and the bearing capacity of the support is high. For the sake of safety, the high-pressure pipeline should be arranged above the low-pressure pipeline.
Metal tube	Non-metallic pipe	The performance of the non-metallic pipe is relatively stable to avoid the corrosion of the metal pipe caused by the leakage of pipeline medium.
Pipeline maintenance is not frequent.	Check and repair pipelines frequently	It is convenient for later maintenance workers to overhaul it.

B principle of automatic collision avoidance algorithm for pipelines

(1) identify the pipelines to be adjusted
According to the collision test report after collation and summary, the collision pipeline information is obtained, including the professional category, system type, pipeline parameter information, grid location and pipeline ID. After obtaining the above attribute and data and other parameter information of the pipeline, the analysis is based on the pipeline avoidance principle, and the pipeline that needs to be automatically adjusted is determined by using the collision pipeline ID.

(2) determine the length and height of the adjustment
In order to determine the height and length to be adjusted for the colliding pipeline, mark the avoidance pipe as L1, the collision pipe as L2, and the horizontal pipe resulting from avoidance as L3. Each point of the position of the avoiding pipe L1 is marked, as shown in figure 6, H is the avoidance height to be adjusted by the avoiding pipe L1, L is the avoiding length to be adjusted by the avoiding pipe L1, and point An and D are the starting points of the avoiding pipe L1, respectively.

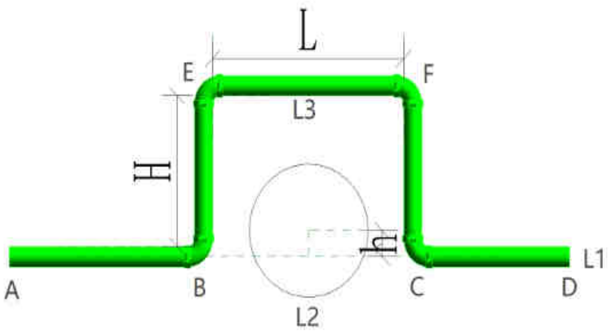


Figure 6. Schematic diagram of position marking of avoidance pipeline

The intersection area where the pipeline collides is affected by its own port diameter or width, so the height and length to be adjusted for avoidance need to be determined according to the diameter d1 of the avoidance pipe L1 and the diameter or width d2 of the collision pipe L2 (d1 < d2). Considering the follow-up maintenance requirements, this paper sets the reserved adjustment item D0. The length L and height H of the avoidance pipeline are as follows:

$$L = 3d_1 + d_2 + D_0 \quad (1)$$

$$H = h + \frac{1}{2}(d_1 + d_2) + D_0 \quad (2)$$

d1-diameter of dodging tube L1
d2-the diameter of the collision pipe L2 (take its width if L2 is not a pipe)
h-collision distance
D0-reserve maintenance space.
Through the manual collision avoidance optimization experiment, it is found that the diameter of the elbow automatically generated in the process of collision avoidance is the same as that of the pipe L1, and two elbows will be generated on the horizontal pipe L3, so L should at least add more than 2 times D1. Considering the cost control and the operation of the actual installation, the avoidance length L is set to add at least 3 times D1.
If there are special circumstances in the adjustment and optimization, L and H can also be adjusted freely according to the actual situation.

(3) determine the spatial coordinates of the adjustment position.

The center point of the intersection of the avoidance tube L1 and the collision pipe L2 is marked O, the spatial coordinates of the center point O and the coordinates of the B point and C point can be obtained by the combination formula (1), and the coordinates of the E point and F point can be calculated by the combination formula (2), as shown in figure 7..

(4) automatic generation of pipeline connection processing

Combined with figure 7, after determining the spatial coordinates of each point, the pipeline is created with BE, EF and FC respectively, and the connection elbow is created according to the actual position relationship of the pipeline to complete the optimization of pipeline automatic avoidance. The flow of the automatic collision avoidance algorithm for pipelines is shown in figure 8.

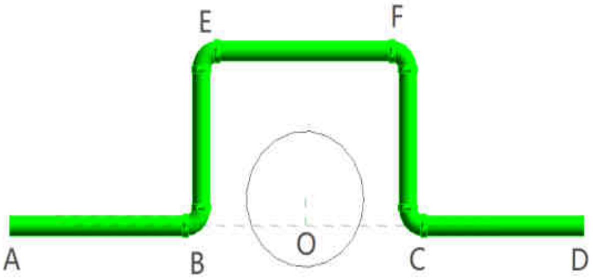


Figure 7. Schematic diagram of each point of avoidance pipeline

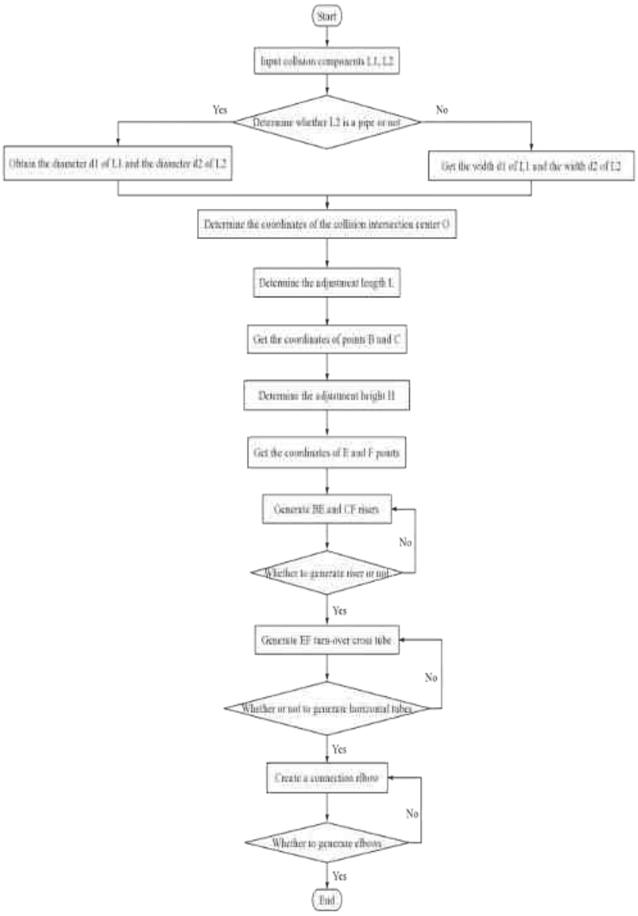


Figure 8. Automatic avoidance process of collision pipeline

C Development of pipeline collision automatic collision avoidance optimization plug-in

This paper uses C# with Visual2015 as the development platform to RevitAPI application interface development pipeline collision avoidance algorithm. It can be set in advance to reserve maintenance space value. The interface of the optimization plug-in as shown in Figure 9, gives the collision component category and ID, can be adjusted one by one or all and preview. And the adjustment results can be seen according to the adjustment state.

The pipeline example model is used to test the pipeline collision automatic collision avoidance optimization plug-in. Figure 10 shows the state of collision before collision optimization, and figure 11 shows the result of pipeline collision automatic collision avoidance optimization, as shown in the figure. The optimization results are in line with the principle of collision avoidance and the actual situation.

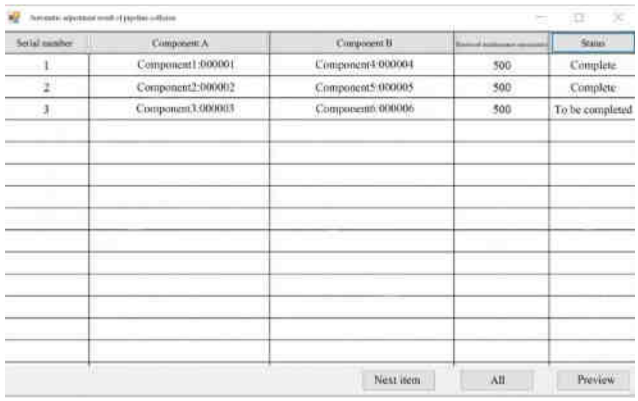


Figure. 9. Avoid optimizing the interface of plug-ins

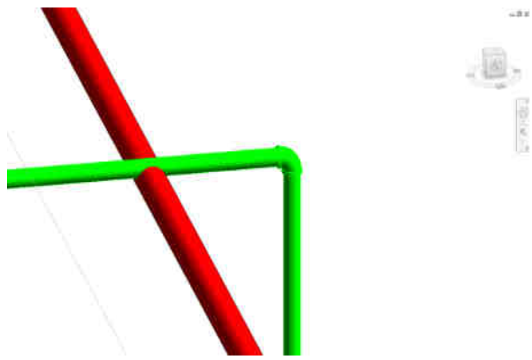


Figure 10. Examples before avoiding optimization

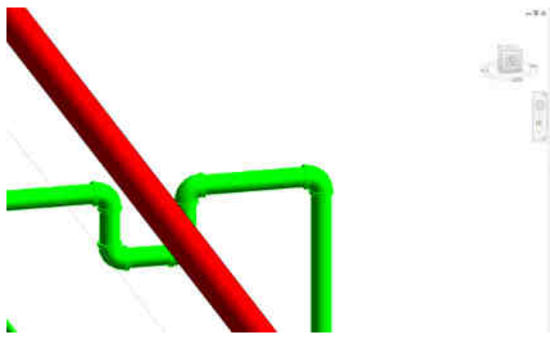


Figure 11. Avoid optimized instances

IV. CASE ANALYSIS

Deepening design is to refine and optimize the model on the basis of two-dimensional plane design drawings and according to the specific requirements of production and installation, so as to meet the design requirements and the technical standards of the owner and the design unit, and in line with the corresponding design specifications and construction and installation specifications, through examination to achieve graphic unity, which can directly guide on-site production and installation construction [11]. Taking a subway station as an example, this paper introduces the relevant contents and methods involved in the comprehensive deepening design of pipelines, which provides basic data for construction, installation, operation and maintenance.

A Collision detection

The HiBIM plug-in is used to detect the collision of the model, generate the collision detection report, analyze and verify the collision report, and pick out the invalid collision points in the collision report because the software regards the connection of the adjacent components as the collision.

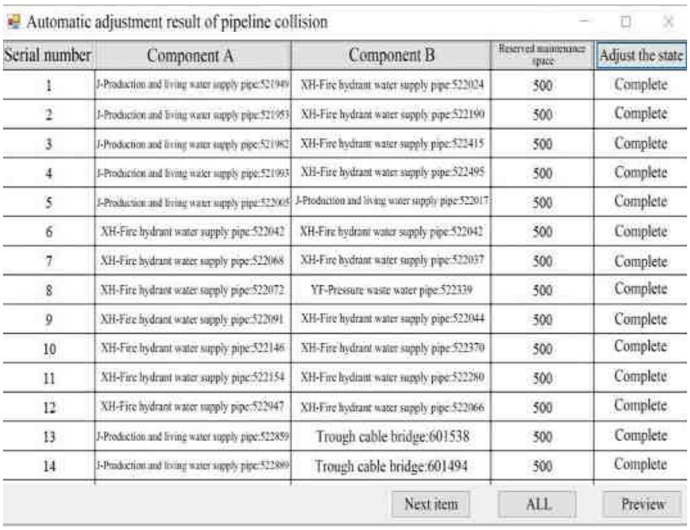
According to the classification and screening of collision reports, a total of 454 effective collisions were obtained, including 135 water supply and drainage and HVAC majors, 71 water supply and sewerage and electrical specialties, 21 HVAC and electrical specialties, 12 structure and MEP (HVAC, electrical, water supply and drainage), 148 water supply and drainage majors, 67 HVAC majors and 7 electrical majors.

B Collision avoidance optimization

According to the principle of comprehensive arrangement of pipelines, 454 collision problems are optimized. 12 collisions between structure and MEP are optimized by adjusting elevation. The pipeline automatic collision avoidance module is used to optimize the collisions of 442 professional pipelines, load the results of collision detection, obtain the ID and location information of collision components, and realize the function of automatic collision avoidance optimization of pipeline collision. According to the actual demand of the project, the reserved maintenance space is set to 500mm, and the result of automatic adjustment of pipeline collision is shown in figure 12.

This paper uses the pipeline collision automatic collision avoidance optimization plug-in to solve the collision problem, and combined with the actual needs of the project to solve the pipeline space layout problem, the following two examples of collision optimization results are selected:

(1) Example 1: in the area near axis A ~ C and axis 24 in the hall floor of the underground station, there is a collision between the professional production and domestic water supply pipe and the fire hydrant fire water supply pipe, as shown in figure 13, the coordinates of the collision location are: (6.90202.44.40). According to the principle of domestic water to avoid fire water, the production and domestic water supply pipes are adjusted downwards according to the algorithm, as shown in figure 14.


Automatic adjustment result of pipeline collision

Serial number	Component A	Component B	Reserved maintenance space	Adjust the state
1	J-Production and living water supply pipe:521949	XH-Fire hydrant water supply pipe:522024	500	Complete
2	J-Production and living water supply pipe:521953	XH-Fire hydrant water supply pipe:522190	500	Complete
3	J-Production and living water supply pipe:521962	XH-Fire hydrant water supply pipe:522415	500	Complete
4	J-Production and living water supply pipe:521993	XH-Fire hydrant water supply pipe:522495	500	Complete
5	J-Production and living water supply pipe:522005	J-Production and living water supply pipe:522017	500	Complete
6	XH-Fire hydrant water supply pipe:522042	XH-Fire hydrant water supply pipe:522042	500	Complete
7	XH-Fire hydrant water supply pipe:522068	XH-Fire hydrant water supply pipe:522037	500	Complete
8	XH-Fire hydrant water supply pipe:522072	YF-Pressure waste water pipe:522339	500	Complete
9	XH-Fire hydrant water supply pipe:522091	XH-Fire hydrant water supply pipe:522044	500	Complete
10	XH-Fire hydrant water supply pipe:522146	XH-Fire hydrant water supply pipe:522370	500	Complete
11	XH-Fire hydrant water supply pipe:522154	XH-Fire hydrant water supply pipe:522280	500	Complete
12	XH-Fire hydrant water supply pipe:522947	XH-Fire hydrant water supply pipe:522066	500	Complete
13	J-Production and living water supply pipe:522859	Trough cable bridge:601538	500	Complete
14	J-Production and living water supply pipe:522889	Trough cable bridge:601494	500	Complete

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Figure 12. Automatic adjustment result of pipeline collision

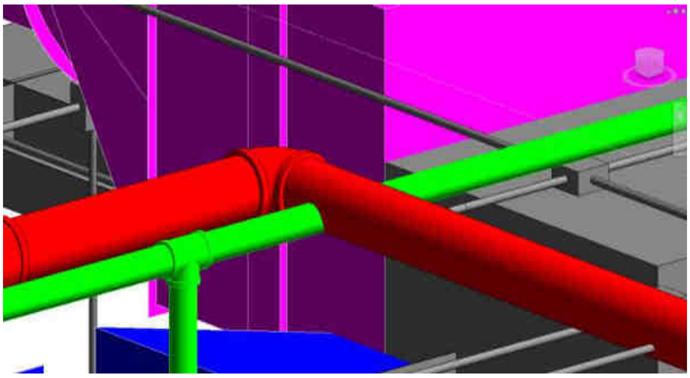
Figure 13. Example 1 Diagram of collision location

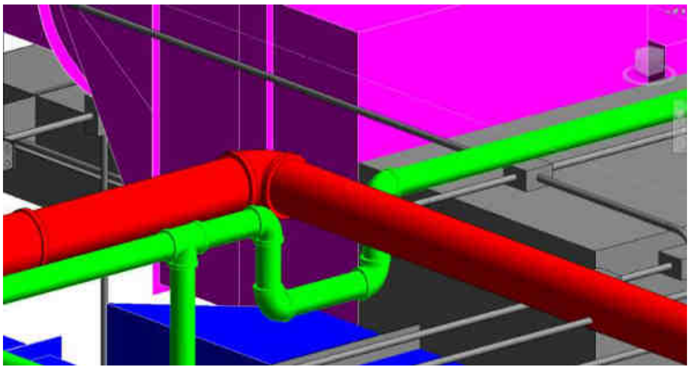
Figure 14. Example 1 Diagram after collision voidance optimization

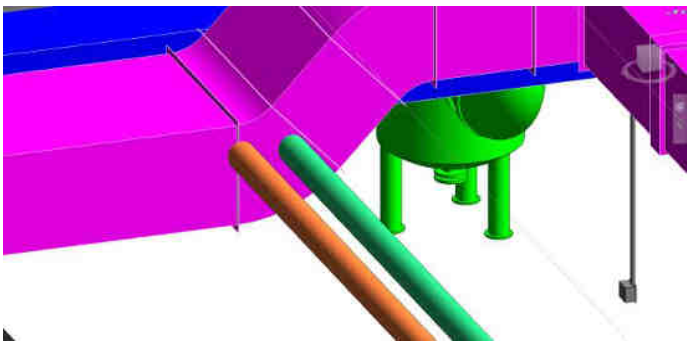
Figure 15. Example 2 Diagram of collision location

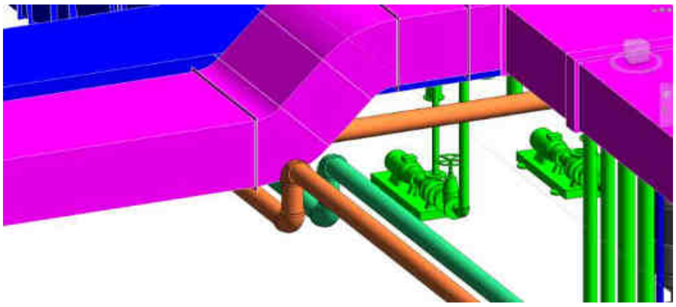

Figure 16. Example 2 Diagram after collision avoidanceptimization

Example 2: In the area of axes A ~C and 23 ~24 of the underground station hall floor, the HVAC return air pipe collides with the circulating return water pipe and the circulating supply water pipe, as shown in Figure 15. The coordinates of the collision position are (x,y,z) :(8.54,193.55,3.30). According to the principle that the air pipe is on top, in order to facilitate maintenance and make the pipeline layout beautiful, the circulating return pipe and circulating supply pipe turn down in parallel and in the same position according to the pipeline collision automatic collision avoidance algorithm. The optimization results are shown in Figure 16.

Through the analysis of an example, the optimization situation meets the actual needs, and the use of pipeline collision automatic collision avoidance plug-in can effectively optimize the collision problem, which greatly improves the work efficiency of pipeline collision avoidance deepening design and has high applicability. It reflects its practical application value in engineering projects.

CONCLUSION

(1) Establish architectural model, structural model, HVAC model, electrical model and water supply and drainage model. After the review and proofreading of each sub model, integrate each professional model into a comprehensive model of subway station pipeline, and improve the modeling efficiency and accuracy.

(2) The automatic collision avoidance algorithm of pipeline is designed. Through the analysis of the design code and the actual situation of the subway project, the collision avoidance principle of this project is summarized, and the feasibility is verified by the test of an example. It is concluded that this algorithm can be applied to the comprehensive collision avoidance optimization of pipelines.

(3) By comparing and analyzing the advantages of deepening the design of the subway station pipeline comprehensive model based on BIM technology, this paper proposes to deepen the design of the pipeline comprehensive model with HiBIM plug-in. Carry on the collision detection to the full professional pipeline comprehensive model, according to the results of the collision test report, optimize 454 collision problems, and use the pipeline automatic avoidance optimization plug-in to solve 442 collision problems.

REFERENCES

[1] Fajun Ma.Application of BIM Technology in the Construction of Metro Station [J]. Chinese architectural decoration and decoration, 2021(06):182-183.

[2] Huijuan Zhong.Comprehensive Pipeline Construction Technology in the installation of Mechanical and Electrical equipment in Metro Station [J]. Building materials and decoration, 2020(20):253+256.

[3] Shan He, Chen Li, Dajian Liang, Zhigang Wang.Application of BIM Technology in Pipeline Comprehensive Design of Tianjin Metro Hongqi South Road Station [J]. Power generation and air conditioning, 2013, 34(3):4.

[4] Lamine Mahdjoubi, Cletus Moobela, Richard Laing Providing real-estate services through the integration of 3D laser scanning and building information modelling,Computers in Industry, 2013, 64(9):1272-1281.

[5] Li Chuan Lien,Unurjargal Dolgorsuren,BIM-based steel reinforcing bar detail construction design and picking optimization,2023,49:520-536.

[6] Yu Chen,Design and optimization of construction equipment pipelines in cigarette factories based on BIM technology [J]. //Ain Shams Engineering Journal, 2022, https://doi.org/10.1016/j.asej.2022.102054.

[7] Ge F, Xu X. Research report on the Utility Tunnel Engineering based on BIM technology [C]. //Journal of Physics: Conference Series. IOP Publishing, 2019, 1176(4): 042028.

[8] Yuanfeng Yang, Xiaobao Cai.Practice and Technical discussion on Comprehensive Design of three-dimensional Pipeline [J]. Architectural skill, 2011(Z1):154-159.

[9] GB 50157-2013, Subway Design Code (with provision description) [S]

[10] Organized and compiled by the continuing Education Committee of China Construction Education Association, Technical management of c onstruction project [M]. China Construction Industry Press, 2016.

[11] Li Y F, Wang H C, Zhao X F, et al. Research on BIM technology application in the construction of a subway station [C]. //Applied Mechanics and Materials. Trans Tech Publications Ltd, 2013, 405: 3396-3400.