

Research on Collaborative Avoidance Design Technology for Road Horizontal Alignment and Underground Pipelines Based on BIM

Xiang Zhang

China Merchants Chongqing Communications Technology Research & Design Institute Co., LTD., Chongqing 400067, China

Copyright: © 2026 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), permitting distribution and reproduction in any medium, provided the original work is cited.

Abstract: Traditional road horizontal alignment design faces bottlenecks such as limited terrain representation, inefficient information updates, and inadequate multi-factor collaboration. Underground pipeline design also encounters issues of professional fragmentation and frequent conflicts. The lack of coordination between the two leads to construction rework and increased costs. Based on this, this paper first constructs a BIM-based technical system for road horizontal alignment and then explores collaborative avoidance techniques for underground pipelines. Using engineering examples, it investigates the BIM-integrated application of collaborative avoidance between road horizontal alignment and underground pipelines. Through analysis, the paper aims to address the challenges of coordination in road and underground pipeline design, break down professional information barriers, proactively avoid conflicts, and provide technical support and practical references for enhancing the quality and efficiency of municipal engineering design.

Keywords: BIM; Road; Horizontal alignment; Underground pipeline; Collaborative avoidance design technology

Online publication: March 11, 2026

1. Introduction

With the acceleration of urbanization in China, the scale of municipal infrastructure construction continues to expand. Roads and underground pipelines, as the core carriers of urban operations, directly impact project quality, duration, and cost through their design coordination. Under traditional design models, road horizontal alignment and underground pipeline design belong to different specialties and rely on two-dimensional drawings for information transfer, which easily leads to information gaps and comprehension biases. Road alignment often overlooks the distribution of underground pipelines, resulting in frequent relocations during later construction stages. Underground pipeline design fails to dynamically link with road alignment, causing conflicts between pipelines and road structures, as well as interference among pipelines. BIM technology, with its characteristics

of digital modeling, multi-specialty collaboration, and visual analysis, offers a new approach to addressing this challenge. BIM can construct three-dimensional visual models, integrate information from all disciplines, enable real-time design collaboration and dynamic adjustments, and proactively avoid conflicts^[1]. Therefore, conducting research on BIM-based technologies for road horizontal alignment selection and coordinated avoidance design of underground pipelines holds significant theoretical and practical importance.

2. Construction of BIM-based road horizontal alignment selection technology

2.1. Technical bottlenecks in traditional road horizontal alignment selection

2.1.1. Limitations in terrain representation

Traditional road horizontal alignment selection relies on two-dimensional representations such as contour lines and cross-sectional diagrams to depict terrain, which fails to intuitively reflect three-dimensional spatial characteristics. It inadequately captures details of complex terrains like mountains and river valleys, making it difficult for designers to accurately grasp terrain undulations. This often leads to issues such as excessive longitudinal grades and excessive slope excavation volumes. This two-dimensional information transfer can also result in misunderstandings between designers and construction personnel regarding terrain interpretation, frequently causing discrepancies between the actual terrain and the drawings during the construction phase, necessitating adjustments to the alignment selection plan. Furthermore, traditional alignment selection methods cannot integrate terrain with surrounding buildings, underground pipelines, and other elements, resulting in a lack of holistic consideration in the plan and potentially triggering conflicts between the project and the environment.

2.1.2. Inefficient information updates

Traditional alignment design information is stored in fragmented paper drawings or scattered electronic files, leading to fragmented management. When there are changes in the route's starting and ending points, updates to terrain data, or adjustments to specifications, designers must manually modify drawings and files, resulting in a significant workload and a high risk of information omission or errors. For instance, after terrain data updates, contour lines must be redrawn, cross-sections adjusted, and design description parameters updated, a process that is time-consuming and labor-intensive and difficult to ensure information consistency. Simultaneously, information transfer relies on manual communication, making it impossible to synchronize change information promptly to surveying, pipeline design, construction, and other units, leading to poor coordination among various stages and increasing the risk of rework.

2.1.3. Insufficient multi-factor coordination

The selection of road horizontal alignment requires a comprehensive consideration of factors such as terrain, traffic demand, environmental protection, underground pipelines, and land use. In traditional design, the analysis of each factor belongs to different professional modules, lacking an effective collaborative mechanism. Communication among different disciplines is conducted through meetings and emails, resulting in low efficiency in information transmission, which is prone to delays and distortions^[2]. Scheme optimization only focuses on a single factor without considering the interactions among multiple factors. Additionally, traditional alignment selection lacks quantitative analysis tools, relying on empirical judgment for scheme optimization, which results in insufficient scientificity and rationality.

2.2. Key technical aspects of BIM-based road horizontal alignment selection

2.2.1. Basic data collection and preprocessing

The quality of basic data directly affects the accuracy of alignment selection, necessitating the integration of multiple data collection technologies. Terrain and topographic data are obtained through a combination of unmanned aerial vehicle (UAV) aerial surveys and three-dimensional (3D) laser scanning (to supplement point clouds in complex terrain); geological survey data are collected through drilling exploration and ground-penetrating radar detection to construct a 3D geological model containing geological stratification and geotechnical parameters; surrounding environmental data are collected through field surveys and GIS technology to gather information on buildings, pipelines, and vegetation and associate it with the terrain; traffic demand data are collected through traffic flow surveys and questionnaires to support the design of the number of lanes and intersections.

Preprocessing involves three steps: cleaning redundant and erroneous data and filling in missing values; converting DOM, point clouds, etc., into BIM-compatible formats such as IFC and RVT; establishing data associations and integrating them into a unified database to lay the foundation for modeling.

2.2.2. Construction of a parametric alignment selection model

The model serves as the core of BIM-based alignment selection and is developed in a “top-down” approach in three steps as follows:

- (1) Define control elements, specifying the starting and ending points of the route, control points, and technical constraints such as design speed and horizontal curve radius in Autodesk Civil 3D;
- (2) Parametric modeling, where a horizontal alignment is first generated based on control points, the vertical profile is adjusted according to terrain and geology, and then a subgrade and pavement model is generated based on the number of lanes and subgrade width and integrated with the terrain. The model automatically updates when parameters are changed ^[3];
- (3) Associated information: Integrate geological, pipeline, traffic data, and design specifications into the model. Click on a component to view geological stratification, and receive automatic alarms when parameters exceed limits;

2.2.3. Multi-scheme comparison and optimization

Scientific decision-making was achieved through the following four steps:

- (1) Adjust control element parameters to generate multiple alternative schemes;
- (2) Conduct quantitative analysis by constructing a technical, economic, environmental, and social evaluation system, leveraging BIM for data extraction, interfacing with VISSIM simulation, and employing the Analytic Hierarchy Process (AHP) to calculate scores;
- (3) Perform visual assessment by examining the route’s compatibility with terrain through the model, simulating driving perspectives through walkthroughs, and overlaying GIS to check compliance with planning;
- (4) Optimize the scheme by adjusting the alignment or parameters in response to technical, cost, and environmental issues, with the model updating in real-time to achieve the optimal solution.

3. BIM-based collaborative avoidance design technology for underground pipelines

3.1. Current status and conflict types in underground pipeline design

Numerous issues plague current underground pipeline design, leading to frequent conflicts. Severe professional fragmentation exists, with disciplines such as water supply and drainage, gas, and electricity utilizing independent software and standards, lacking a unified information platform for real-time collaborative design. Design bases are outdated, with incomplete pipeline archives in some cities and on-site detection hindered by terrain and building obstructions, compromising data accuracy and causing discrepancies between the scheme and actual pipelines. Insufficient coordination with road design is also prevalent, as pipeline design often commences after road alignment is determined, necessitating redesign upon alignment adjustments, increasing workload, and fostering conflicts.

Underground pipeline conflicts mainly fall into three categories:

- (1) Conflicts between pipelines and road structures: Spatial interference between pipelines and roadbeds, pavements, and inspection wells, such as pipelines buried too shallowly below roadbed elevation or positioned coincidentally with inspection wells, impeding construction^[4]. When roads adopt tunnel or bridge structures, pipelines not designed collaboratively may penetrate the structure or conflict with foundations;
- (2) Conflicts between pipelines: Positional overlap and insufficient safety distances, with dense pipeline arrangements complicating later maintenance;
- (3) Conflicts between pipelines and the surrounding environment. There are conflicts between pipelines and buildings, structures, as well as the ecological environment. For instance, drainage pipes placed too close to building foundations can lead to foundation settlement; gas pipelines traversing ecological zones can damage vegetation and habitats; and conflicts with underground cultural relics or ancient trees can halt construction projects.

3.2. Technical framework for collaborative avoidance of pipelines using BIM

3.2.1. Three-dimensional parametric modeling of pipelines

Three-dimensional parametric modeling of pipelines serves as the foundation for collaborative avoidance. It necessitates the integration of multi-disciplinary data to construct a model encompassing both geometric and attribute information, which can be carried out in three steps as outlined:

- (1) Data collection and integration: This involves gathering data from existing pipeline detection reports, design drawings, and on-site investigations to verify the positions and burial depths of existing pipelines. For new pipelines, parameters are set in conjunction with road alignment and planning, with communication with road specialists. Subsequently, data is integrated into a database using a BIM platform, and association rules are established;
- (2) Establishing modeling standards: This step clarifies pipeline classifications (such as water supply and drainage), core parameters (such as pipe diameter and wall thickness), millimeter-level modeling accuracy, and the use of a city-independent coordinate system. It also specifies modeling software for each discipline and the IFC output format to ensure compatibility;
- (3) Constructing three-dimensional models: Each discipline models according to the standards. For example, in water supply pipe modeling, the road and environmental models are first imported to define the start and end points. Then, the main model is generated based on parameters, and accessories are added.

Finally, the models are integrated to examine spatial relationships, and attribute information is associated for easy viewing upon clicking.

3.2.2. Multi-disciplinary collaborative clash detection

Multi-disciplinary collaborative clash detection is a core component that integrates models to automatically identify conflicts. Initially, designers import pipeline models from various disciplines into the Autodesk BIM 360 collaborative platform and integrate them with road and environmental models. A model simplification algorithm is employed to retain core features and attributes while deleting redundant components and simplifying complex surfaces. The models are then converted into lightweight formats such as Navisworks NWD to enhance detection efficiency. Following that, parameters are set in accordance with the “Code for Comprehensive Planning of Urban Engineering Pipelines” (GB50289-2016), including collision types, safety distance thresholds, and detection ranges. Finally, the platform’s detection function is activated, and the software automatically records the locations of collision points, component types, and conflict distances, generating a visual report. Hard collisions are marked in red, and soft collisions are marked in yellow. Clicking on the markers allows users to view component properties. Conflicts are categorized and statistically analyzed to determine the proportions of hard and soft collisions, as well as the concentrated areas and causes of conflicts, providing direction for avoidance design.

3.2.3. Generation and validation of pipeline avoidance solutions

The generation and validation of pipeline avoidance solutions are crucial for conflict resolution and must be advanced by integrating specifications with practical considerations. Principles are first established based on specifications and experience: pressure pipelines should yield to gravity flow pipelines (due to adjustment difficulties), small-diameter pipelines should yield to large-diameter pipelines (due to high relocation costs), flexible pipelines should yield to rigid pipelines (due to greater flexibility), newly constructed pipelines should yield to existing pipelines (to minimize urban impact), and temporary pipelines should yield to permanent pipelines (due to longer cycles). Additionally, road structural layers should be avoided, taking into account both construction and operation and maintenance. Next, design is carried out. Based on the detection results and principles, solutions are formulated through methods such as plan offset and buried depth adjustment (e.g., if a drainage pipe’s shallow buried depth causes a conflict with the roadbed, it can be deepened to 1.0m below the roadbed). Dynamic parameter adjustments in the model are used to prevent new conflicts, and opinions from road and construction parties are solicited. Finally, multiple validations are conducted to check compliance with specifications (platform verification of parameters), construction feasibility (simulation and evaluation based on associated plans), and economic rationality (cost comparison with the original plan). Based on the results, the final solution is optimized and determined.

4. BIM integrated application for collaborative avoidance in road plan alignment and underground pipelines

4.1. Organizational structure and process for collaborative design

4.1.1. Organizational structure

The “project master control + professional collaboration” model is adopted to establish a collaborative team across three levels: The project master control level comprises the construction entity and the BIM consulting entity. The construction entity sets project objectives, approves plans, and coordinates resources, while the BIM

consulting entity establishes a collaborative platform, formulates modeling and data exchange standards, provides technical training, and resolves issues such as model compatibility. The professional design level encompasses road, pipeline, and geological survey disciplines. The road discipline constructs a route selection model and synchronizes change information; the pipeline discipline constructs a pipeline model, adjusts routes based on route selection, and provides feedback on requirements; the geological survey discipline provides a 3D geological model and highlights areas with unfavorable geological conditions. The construction consultation level comprises construction and supervision entities. The construction entity assesses the feasibility of construction plans, while the supervision entity oversees the design process and reviews the compliance of plans. All levels share information, communicate, and provide feedback through the BIM platform, forming a closed-loop management system.

4.1.2. Collaborative process

Following the main sequence of “data preparation–collaborative modeling–conflict detection–plan optimization–result delivery,” the master control level organizes the collection of terrain, geological, existing pipeline, and planning data, which is then integrated and standardized to form a basic database. The road and pipeline disciplines jointly review the accuracy of the data. The road discipline first constructs a route selection model and uploads it to the platform; the pipeline discipline then models based on the route selection model, referencing road information in real-time. Any issues encountered during modeling are resolved through platform communication. The BIM consulting entity integrates the models and uses Navisworks to detect conflicts, generating reports that are pushed to the relevant disciplines ^[5]. Based on these reports and avoidance principles, the road and pipeline disciplines formulate plans, dynamically adjust the models, and have the construction consultation level review feasibility. After optimization, another round of conflict detection is conducted to confirm the absence of conflicts. Each discipline completes the final model and drawings, submits them through the platform, and after the master control level organizes acceptance, they are archived in the BIM database to support construction and operation and maintenance.

4.2. Engineering case verification

4.2.1. Project overview

The newly constructed main road project in a certain city is located in the central urban area, with a total length of 3.5 km. It is classified as an urban main road, designed for a speed of 60 km/h, with a red line width of 40 m and six bidirectional lanes. It includes supporting construction of water supply and drainage, gas, electricity, and communication pipelines. The project area features flat terrain and runs through two residential communities and one city park. Underground, there are existing water supply pipes (with a diameter of 500 mm and a buried depth of 2.0 m), gas pipes (with a diameter of 300 mm and a buried depth of 1.8 m), and 10 kV power cables (with a buried depth of 1.5 m). Traditional designs for such projects often result in frequent pipeline relocations due to insufficient coordination. Therefore, BIM technology is employed to carry out collaborative avoidance design.

4.2.2. Implementation process of BIM collaborative design

The process are as follows:

- (1) Basic data collection and processing: UAV aerial surveying is used to obtain DOM and DEM with a resolution of 0.1 m. Three-dimensional laser scanning is employed in areas with dense pipelines to obtain

point cloud data, and existing pipeline parameters are determined in conjunction with detection reports. GIS integrates planning and community distribution data, and the BIM consulting unit cleans and converts the data before uploading it to the Autodesk BIM 360 platform;

- (2) Collaborative modeling and conflict detection: The road discipline uses Autodesk Civil 3D for modeling, with the starting and ending points determined as the intersections of Roads A and B, and two right-turn intersections are set up. The subgrade elevation ranges from 28.5 to 29.0 m. The pipeline discipline uses Revit and Bentley software for modeling (e.g., the water supply pipe is laid along the east sidewalk with a diameter of 400 mm and a buried depth of 2.2 m). After integrating the models, 12 conflicts are detected, including 3 conflicts between the subgrade and existing gas pipes, 5 conflicts between water supply pipes and power cables, and 4 conflicts between drainage pipes and existing water supply pipes (with a distance of 0.8 m);
- (3) Scheme optimization and verification: Collaborative meetings are organized to formulate solutions. For the conflicts between the subgrade and gas pipes, the route is shifted 2.0 m westward and the elevation is lowered by 0.3 m. For the conflicts between water supply pipes and power cables, the water supply pipe is deepened to 2.5 m.

4.2.3. Analysis of application effects

The newly constructed arterial road project in this city achieved remarkable results in design quality, construction efficiency, and cost control by applying BIM-based road alignment and underground pipeline collaborative avoidance design technology. The specific application effects can be analyzed from the following three dimensions:

- (1) Design quality enhancement: In traditional arterial road projects, an average of 10–15 conflicts between roads and pipelines were identified during the construction phase. In this project, all 12 conflicts were resolved during the design phase through BIM collaborative design, with no additional conflicts arising during construction, achieving a 100% avoidance rate. The three-dimensional visualization capabilities of BIM enable direct measurement of pipeline spacing (e.g., between water supply pipes and power cables), eliminating coordinate calculation errors inherent in two-dimensional drawings. Multi-disciplinary clash detection and code compliance checks (aligned with GB50289-2016) ensure regulatory adherence, while parametric linking ensures synchronized design updates, improving drawing accuracy by over 30% compared to traditional methods;
- (2) Construction efficiency improvement: The project duration was shortened by 15 days compared to traditional methods. In conventional approaches, resolving a single conflict typically required a 3–5-day work stoppage. By leveraging BIM to clarify pipeline locations and burial depths before construction, precise excavation plans were developed. Visual walkthroughs simplified blueprint comprehension, reducing excavation errors by 40% in densely piped areas through model-guided depth control. BIM integration with scheduling enabled dynamic progress management, ensuring timely completion;
- (3) Cost control optimization: Total savings of RMB 2.03 million (3.8% of total investment) were achieved, including: RMB 1.2 million saved by eliminating rework (which typically accounts for 2–3% of total investment in traditional projects), RMB 650,000 saved by reducing pipeline relocation length by 800 m, and RMB 180,000 saved through precise BIM-based material calculations that reduced roadbed filler usage by 5%. Additional savings came from avoiding supplemental labor and equipment costs,

demonstrating significant economic benefits.

5. Conclusion

This study focuses on BIM-based road alignment and underground pipeline collaborative avoidance design technology. By analyzing the limitations of traditional design methods, it establishes a technical framework for BIM applications in road alignment and pipeline avoidance, with engineering case studies verifying the technology's effectiveness. In the future, further research should be conducted on model data interaction technology based on the IFC standard to enhance collaborative efficiency. Additionally, in terms of the integrated application of BIM technology with artificial intelligence and big data, exploration can be made into utilizing AI algorithms to automatically generate route selection and avoidance plans, thereby elevating the level of design intelligence. Subsequent research can be centered around the aforementioned directions to further refine the BIM-based collaborative design technology system for municipal engineering, providing higher-quality technical services for urban infrastructure construction.

Disclosure statement

The author declares no conflict of interest.

References

- [1] Yan S, Lin Y, Sun M, 2025, Optimization Analysis of Comprehensive Pipeline Layout in Underground Garages Based on BIM Technology. *Electrical Technology in Intelligent Buildings*, 19(3): 124–127.
- [2] Ou K, 2022, Analysis of Road Route Selection for the Southern Extension Section of Huangge Road in Longgang District, Shenzhen. *Engineering and Technological Research*, 7(17): 9–11.
- [3] Zhang X, 2021, Research on the Design and Application of a Road Route Selection System Based on BIM+GIS Technology. *Communications Science and Technology Heilongjiang*, 44(9): 67–68.
- [4] Liao C, 2024, Collision Analysis and Technical Treatment of Water Supply and Drainage Pipelines in Urban Underground Spaces. *China Construction*, 2024(11): 169–171.
- [5] Wu B, Wang W, 2020, Research on the Application of BIM Technology in the Comprehensive Pipeline Layout of Municipal Road Reconstruction Projects. *Urban Roads & Bridges and Flood Control*, 2020(10): 191–193.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.