Postprint: Applied Research on BIM-based Pipeline Digital Management System in the Yangsigang Yangtze River Bridge Project

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Abstract

With the continuous development of urban modernization, current underground pipeline information management in old urban districts faces issues such as complex pipeline ownership relationships and unclear underground pipeline layouts. To address these issues, this paper proposes the construction of a BIM-based digital management system for underground pipelines and analyzes its role throughout the entire pipeline project lifecycle. Finally, this digital management system for underground pipelines is applied to the Wuhan Yangsigang Yangtze River Bridge project, achieving functions such as information classification, information retrieval, information visualization, and collision detection for underground pipelines. The system effectively improves management efficiency and increases project benefits, providing a valuable reference for the integration of BIM technology with underground pipeline information management.

Full Text

Preamble

Title: Study on the Application of BIM-based Digital Management System of Pipelines in Yangsigang Yangtze River Bridge Project

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Abstract: With the continuous development of urban modernization, the current situation of underground pipeline information management in the old town has problems such as ownership of complex pipelines and unclear layout of underground pipelines. In order to solve these problems, a BIM-based digital management system for underground pipelines was proposed, and the role of the system in the whole process of the pipeline project was analyzed. Finally, the underground pipeline digital management system was applied to the Yangsigang Yangtze River Bridge project in Wuhan to achieve the functions of information classification, information retrieval, information visualization and collision detection for underground pipelines. The system effectively improve the management efficiency, increase the project revenue, and provide a useful reference for BIM technology combined with underground pipeline information management.

Keywords: Digital Management System; Complex Underground Pipeline; BIM; Whole Process

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Introduction

Underground pipelines are vital to urban economic development and constitute the lifeline of cities. These pipelines include water supply, stormwater, sewage, electricity, information, telecommunications, gas, and other types, which are constructed, managed, and maintained by various entities including water utilities, drainage companies, electric power companies, telecommunications firms, gas companies, heating companies, government agencies, and military units. Throughout the entire pipeline construction process, management of different stages falls under different government departments, resulting in complex ownership structures [1]. The multitude of integrated pipeline systems, further complicated by height-based zoning, leads to highly intricate pipeline layouts [2].

Currently, most urban utility tunnels in China are constructed along main roads in newly developed urban districts, where higher construction standards are required for urban road traffic, landscape, and environmental considerations [3]. In contrast, pipelines in old urban areas are characterized by aging infrastructure, predominantly direct-burial installation, complex underground arrangements, and incomplete documentation. How to strengthen construction management, renovation, and upgrading of underground pipelines in old districts while reducing maintenance costs and risks represents an urgent challenge.

1. Current Status of Underground Pipeline Management

The management of underground pipelines in old urban areas faces various problems across planning, construction, maintenance, and information management stages. Prominent issues include: pipeline archives that do not reflect actual conditions; absence of departments responsible for dynamic updating of integrated pipeline management information; imperfect management systems lacking effective channels for sharing data and information resources among departments; difficult inter-departmental coordination due to the lack of a unified coordinating body, resulting in implementation obstacles, significant financial waste, and low problem-solving efficiency, with situations of "multiple managers" or "no manager" [4]. Additionally, some as-built documents provided by ownership units fail to document local directional or depth changes made during construction to avoid other pipelines or structures, and short-distance pipeline modifications are often not drawn or explained [5].

During earthwork excavation and other construction activities, unclear understanding of underground pipeline layouts frequently leads to pipeline damage incidents, causing emergency repairs, rework, and project changes. This not only significantly impacts construction schedules and costs but also adversely affects surrounding buildings and infrastructure. To address these issues, BIM technology can be introduced to establish an integrated and shared information system platform, thereby enhancing pipeline management efficiency.

BIM is characterized by highly centralized and visualized information, permeating the entire project construction process to provide convenient communication platforms and resource sharing for construction projects. The unified and complete information data resolves defects across all engineering aspects, avoids information asymmetry, and provides a solid foundation for project construction and analysis [6]. Applying BIM technology to pipeline projects front-loads construction issues, reduces design and construction changes, ensures construction progress, lowers costs, and improves project risk control capabilities [7]. Therefore, to better manage underground pipelines, enhance project control efficiency, and reduce construction risks, we can leverage BIM 3D visualization information systems to establish 2D, 3D, and 4D information models during pipeline design, construction, maintenance, and relocation processes, thereby improving information collaboration and proposing better solutions for modern pipeline construction.

2. BIM-based Whole-Process Underground Pipeline Digital Management System

BIM represents the digital expression of a facility' s physical and functional characteristics, serving as a shared knowledge resource and a process for sharing facility-related information to provide reliable basis for all decisions throughout the facility' s lifecycle from concept to demolition. During different project stages, various stakeholders insert, extract, update, and modify information in BIM to support and reflect their collaborative work responsibilities [8].

2.1 System Development

(1) System Design

In the architecture of BIM-based underground pipeline digital management systems, information output can be divided into four planes with the BIM plane as the core of the information system process, based on information flow, status, and mapping relationships: the target plane, information plane, BIM plane, and user plane [9].

The target plane first decomposes pipeline requirements into specific project objectives based on needs, performing comprehensive decomposition according to pipeline locations, different ownership parties, and information collectors, until breaking down into controllable tasks that can be assigned to specific individuals, locations, and timeframes.

The information plane systematically codes various types of information collected for control objectives based on pipeline units and implementation stages, enabling unified organization of dispersed and voluminous information through a standardized system.

The BIM visualization plane constructs corresponding BIM models and master control platforms for pipeline information target control based on project objective decomposition, establishing unified BIM data naming rules and classification storage methods that link with uniformly coded information from the information plane. Compared with traditional reporting planes, the BIM plane can automatically analyze information and visualize data based on established rules, displaying planned progress and ongoing work status. BIM utilizes intuitive charts, data, and models to present otherwise cumbersome report information more clearly and concisely, addressing issues of delayed information transmission and slow information retrieval in traditional reporting. It generates real-time, dynamic, 3D visualized "reports" according to user needs, enhancing user comprehension of information.

(2) System Architecture

The primary purpose of the underground pipeline digital management system is to enable rapid and efficient querying and management of underground pipeline information, and to assist relevant departments in decision-making through analysis functions. The overall architecture of the management system proposed in this paper is shown in Figure 1 [Figure 1: see original paper], adopting a three-tier architecture model comprising, from bottom to top, the infrastructure layer, data layer, and application layer.

The infrastructure layer primarily consists of equipment and systems, providing fundamental physical hardware support and interfaces for operating various databases to achieve real-time data storage and comprehensive data collection. The data layer mainly includes basic topographic data, pipeline attribute and spatial data, and pipeline construction information. The application layer implements data management and analysis to fulfill user requirements for pipeline information querying and management functions.

(3) System Development

Establishing a BIM underground pipeline information management system requires comprehensive pipeline surveys of existing underground pipelines as the foundation for building a robust system. Pipeline detection methods include gyroscope detection, acoustic detection, direct method, induction method, and various other approaches, while simultaneously clarifying pipeline ownership information. After obtaining accurate pipeline attributes, locations, and ownership data, the statistical information is uploaded to a shared platform that enables information integration across organizations and departments, and visual 3D model information is established to more clearly and intuitively describe structural characteristics, benefiting the entire pipeline construction process. During the maintenance phase, real-time dynamic updates must also be implemented for subsequent project changes, new constructions, and demolitions, enabling traceability and resolving ownership ambiguities. The following subsections will describe the role of BIM in pipeline information management across different phases.

Figure 2 [Figure 2: see original paper] Construction Process of BIM-based Whole-Process Underground Pipeline Digital Management System

2.2 Survey Phase

In BIM-based underground pipeline digital management, possessing complete and comprehensive pipeline information forms the foundation for establishing a smoothly operating and highly efficient system. The prominent issues with underground pipelines in old urban areas are incomplete information and complex burial conditions. Therefore, during the survey phase, it is necessary to investigate the attributes and characteristics of existing pipelines and collect as accurate and complete information as possible.

The pipeline information that requires thorough investigation includes but is not limited to: (1) Pipeline name: Coding enables accurate and rapid retrieval of target pipelines and assists classification. (2) Start and end points: Helps construction units understand overall pipeline layout and facilitates complete pipeline maintenance and relocation. (3) Ownership unit: Identifying ownership units is crucial in pipeline projects, as it not only clarifies pipeline custodianship and enables provision of relevant pipeline data by ownership units, but also saves considerable coordination and management time during design and construction. (4) Installation method: Dynamic updates during design, construction, and maintenance phases to grasp actual pipeline installation methods can reduce various issues arising from unclear underground conditions. (5) Pipeline attributes: Including internal diameter, material, model, and other elements, which facilitate pipeline maintenance and replacement and enable detection of potential object collisions in Revit 3D modeling.

The collected information is processed, organized, transmitted, distributed, retrieved, and stored in the information management system to ensure that all project components, implementation phases, and participating parties can promptly and rapidly obtain required information.

2.3 Design Phase

The design phase typically determines approximately eighty percent of a project' s investment, making the development of a rational and optimized design scheme crucial for cost savings and project cost control. In old urban area pipeline projects, pipeline layouts are extremely complex, and both new construction and relocation involve numerous considerations. For instance, each earthwork excavation entails not only excavation costs but also estimates of impacts on surrounding buildings, traffic, environment, and other factors, with costs increasing accordingly. Through BIM pipeline digital mapping systems, visualization during the design phase can be achieved to simulate potential collision conflicts. Pipeline collision detection can identify possible design defects in advance, avoiding most unnecessary losses caused by design issues, improving design quality, and conserving resources.

During pipeline relocation projects, possessing accurate pipeline information enables project parties to coordinate with construction units and project management departments in a timely manner regarding relocation scheme development, and to design reasonable construction schedules based on pipeline relocation difficulty and duration. For pipelines with high relocation costs or coordination difficulties, economic feasibility comparisons can inform minor modifications to the construction design scheme at the pipeline location, or even avoidance of pipeline changes altogether.

2.4 Construction Phase

The pipeline construction process is a critical step in design implementation. Even with flawless pipeline project designs, various problems can still arise during actual construction.

Two particularly prominent issues exist. First, when undertaking pipeline relocation projects, coordination with pipeline ownership departments is required before specific construction begins. Under current conditions, since direct burial is common for pipelines in old urban areas, pipeline markings may be corroded or oxidized, making identification unclear. Pipeline information archives are often stored untimely, with significant information loss and incompleteness, making it difficult to identify accurate construction and management units. The second issue is that during earthwork excavation and other construction processes, unclear understanding of underground pipeline layouts frequently leads to pipeline damage incidents, causing emergency repairs, rework, and project changes. This not only significantly impacts construction schedules and costs but also adversely affects surrounding buildings and infrastructure.

To resolve these existing problems, introducing BIM technology to establish an integrated and shared information digital system platform has become an imperative solution. The system' s advantage lies in its ability to require all participating parties to input data information into an integrated and unified platform at the information generation stage, with continuous updates and maintenance throughout the project lifecycle, achieving timeliness and accuracy in information sharing. Simultaneously, necessary exploration is conducted for existing but unclear pipeline information to fill gaps and correct deficiencies. The 3D models built based on this information present a clear and complete picture of the underground world, significantly improving pipeline construction standards, reducing errors and rework, eliminating repeated road excavations, saving construction time, reducing costs, and playing a critical role in adding value to engineering projects.

2.5 Operation and Maintenance Phase

The underground pipeline digital management system serves not only the pipeline construction process but also continues to play a vital role after project completion. Based on the complete and clear pipeline data information integrated into the system during the design and construction phases, and through timely maintenance and tracking, we can intuitively observe the real-time status of pipelines. Through digital modeling, a three-dimensional pipeline network can be presented before us, forming a digital map.

Evidently, possessing an integrated and shared information system with complete information and convenient retrieval will effectively improve management efficiency in future pipeline projects and other construction projects involving pipeline changes or relocations. The substantial time spent on information collection and coordinating ownership units during project initiation will be eliminated, and the design phase can better avoid impacts of new pipelines on existing ones, such as collisions. During construction, with clear identification of pipeline locations, frequent damage to existing pipelines caused by unclear underground conditions can be significantly reduced.

This represents a system that serves the entire process of underground pipeline construction while also benefiting the entire processes of other projects closely related to underground pipelines.

3. Case Study: Yangsigang Yangtze River Bridge Project

3.1 Project Overview

The Yangsigang Yangtze River Bridge project has a total length of 4.134 km (K9+162.000-K13+296.377) and is the longest-span suspension bridge in China and the second longest in the world. The main bridge section is a single-span suspended steel truss girder suspension bridge with a total length of 1.7 km (distance between the two bridge towers). The Hanyang side approach begins at the Guobo Interchange, while the Wuchang side approach ends at the Batan Interchange, with the Hanyang side line measuring 0.973 km and the Wuchang side line measuring 1.461 km, making the total approach length 2.434 km. The

Yangsigang Yangtze River Bridge is located approximately 3.2 km downstream from the Yingwuzhou Bridge and 3.0 km upstream from the Baishazhou Bridge. The total project cost is approximately 8 billion RMB with a construction period of about 54 months.

Figure 3 [Figure 3: see original paper] Yangsigang Yangtze River Bridge

Due to relocation impacts causing significant schedule delays, and to ensure achievement of project construction management objectives according to plan, the project owner collaborated with the Institute of Engineering Management at Huazhong University of Science and Technology to develop a digital pipeline relocation system for the Wuhan Yangsigang Yangtze River Bridge using BIM technology, targeting pipeline relocation and new construction projects in the approach bridge areas on both banks.

Figure 4 [Figure 4: see original paper] Comprehensive Plan Layout of Pipelines on Wuchang Side of Yangsigang Yangtze River Bridge

3.2 Pipeline Relocation System

The digital pipeline relocation system was applied to the Wuhan Yangsigang Yangtze River Bridge project, where systematic information collection and organization were conducted for pipeline relocation and planning engineering throughout the construction process in the north and south approach bridge areas. Simultaneously, pipeline visualization was achieved based on BIM, enabling all construction participants, maintenance parties, and management entities to jointly update and control pipeline information through an integrated and unified platform.

3.2.1 Pipeline Information Classification First, based on construction organization design, the project was divided into two parts: the Hanyang side and Wuchang side, with separate construction by two project departments. The BIM pipeline relocation system similarly categorizes pipeline information into Hanyang and Wuchang sides, collecting information based on eight types of pipelines planned or relocated in 2D CAD drawings: water supply, stormwater, sewage, electrical, information, telecommunications, gas, and abandoned pipelines. Collected information includes name, location, characteristics, pipeline ownership unit, pipeline status (existing or planned), burial depth, and whether collision points exist, with this information presented concisely and intuitively in chart form on the user interface.

Figure 5 [Figure 5: see original paper] Comprehensive Interface of Pipeline Relocation System

3.2.2 Pipeline Information Retrieval The system features a retrieval function that can accurately and rapidly locate required pipeline information, with searchable criteria including basic information such as name, characteristics, pipeline ownership unit, pipeline status, and collision point existence. For more detailed information, users can click a detail button to access the pipeline detailed information interface, which includes pipeline BIM number, construction section, pipeline type, burial depth type, construction year, remarks, and additional information. Possessing a complete information database and a fully functional retrieval platform, along with maintenance and query users at different permission levels, can improve previous shortcomings of slow information collection, low efficiency, and lengthy coordination management time, significantly enhancing management efficiency during project design, construction, and maintenance.

3.2.3 Pipeline 3D Visualization A 3D visualization model of pipelines is established based on BIM, using 2D CAD drawings as the modeling foundation and upgrading planar pipeline drawings into intuitive, visual 3D parametric models through modeling tools such as Revit and 3Dmax. This reduces information loss and misinterpretation caused by traditional 2D drawings, enables early identification of potential design issues before construction, provides reasonable suggestions for design schemes, and improves project design and construction quality.

Figure 6 [Figure 6: see original paper] Underground Pipeline BIM Model

3.2.4 Pipeline Collision Detection When pipeline collisions are detected based on BIM, the system displays relevant information to users including problem ID, problem type, drawing name and number, relevant specialties, location, problem description, resolution status, registration date, and other related information. Simultaneously, the collision point detailed interface provides problem descriptions, recommended solutions, design responses, reviews, resolution status, and both 2D CAD drawings and 3D BIM modeling information. By analyzing collision conflict reports, design defects can be identified in advance, and improvement measures can be implemented to optimize 3D models. Similarly, during construction, it helps workers clearly identify key causes of delays, rework, and waste, effectively improving construction quality and the efficiency of labor, materials, and equipment utilization, thereby reducing unnecessary resource waste in the project.

Conclusion

Traditional underground pipeline information management in old urban areas faces numerous problems and challenges. This paper combines BIM methodology with information management, using the digital underground pipeline information management system of the Wuhan Yangsigang Yangtze River Bridge as a case study to explore solutions. This system can effectively address complex pipeline ownership units, unclear underground conditions, and proactively identify and resolve design issues during the design phase in pipeline relocation construction. Through the development of this system, traditional complex and cumbersome pipeline relocation management work can be conducted on a shared integrated platform with complete information data, rapid information transmission, and a simple, intuitive interface, effectively improving management efficiency.

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Figure 7 [Figure 7: see original paper] Comprehensive Pipeline Collision Report

Author Introduction

Lu Youyue (1966-), male, senior engineer, long engaged in construction management of municipal roads, bridges, and related supporting facilities projects.

Note: Figure translations are in progress. See original paper for figures.