BIM-Based Integrated Design-Construction Collaborative Mechanism for Utility Tunnels: Postprint

Authors: Chen Yungang, Ding Jixiang

Date: 2018-10-26T00:00:00+00:00

Abstract

To enhance the efficiency of design-construction integration in urban underground utility tunnel construction, this study analyzes the reasons for insufficient coordination in design-construction integration under traditional modes from three dimensions: information flow, professional coordination, and process management. The entire design and construction process of utility tunnels is optimized based on BIM technology, and three optimization models are proposed: a BIM-based collaborative design mechanism for utility tunnels, a collaborative construction mechanism, and a design-construction integration interface mechanism. The feasibility of this design-construction integration coordination mechanism is validated through case study analysis, and practical implementation demonstrates that the optimization model provides valuable reference for achieving deep integration across design and construction phases.

Full Text

Preamble

Research on the Collaboration Mechanism of Integrated Design and Construction for Utility Tunnels Based on BIM Technology

CHEN Yungang[1], **DING Jixiang**[2]
(1. Anhui University of Technology, Ma' anshan 243000, Anhui, China; E-mail: mascyg@163.com)
(2. Anhui University of Technology, Ma' anshan 243000, Anhui, China)

Abstract: To improve the efficiency of design-construction integration in urban underground utility tunnel projects, this paper analyzes the root causes of inadequate collaboration in traditional utility tunnel projects from three perspectives: information flow, multidisciplinary coordination, and process management. By applying Building Information Modeling (BIM) technology to optimize the entire design and construction process, three enhanced models are proposed: a BIM-based design collaboration mechanism, a construction collaboration mechanism, and a design-construction integration interface mechanism. A case study demonstrates the feasibility of this integrated collaboration mechanism, showing that the optimization models offer valuable insights for achieving deep integration across design and construction phases.

Keywords: utility tunnel; BIM technology; design-construction integration; collaboration mechanism research
Classification Codes: TU28; TU71
Document Code: A
Funding: Anhui University of Technology 2017 Graduate Student Innovation Research Fund (No. 2017048)
Author Biography: CHEN Yungang (1975-), male, Ph.D., associate professor, master' s supervisor. Research interests: civil construction and management.

1.1 Analysis of Multi-disciplinary Coordination Issues in Utility Tunnel Design

Utility tunnels, also known as municipal utility corridors, refer to underground structures that accommodate municipal pipelines for power, water supply, drainage, communication, gas, heating, and other services, forming a scientific, standardized, and intensive urban underground infrastructure. Due to their large scale, unique structural configurations, involvement of multiple disciplines, long construction periods, and high technical complexity, utility tunnel projects inevitably face numerous challenges, particularly during the design and construction phases. Analyzing information flow and professional coordination issues in these phases holds significant practical value.

The design of utility tunnels primarily includes standard cross-section selection, cross-sectional dimension design, selection of pipeline types and sizes, and pipeline design at intersection nodes. These tasks can be categorized into two main components: tunnel structure design and pipeline integration design. Based on professional disciplines, utility tunnel design is divided into three categories: architecture, structure, and MEP (mechanical, electrical, and plumbing).

Through detailed analysis of the traditional utility tunnel design process, the three major design phases—schematic design, preliminary design, and construction drawing design—can be decomposed as shown in [Figure 1: see original paper]. This figure illustrates the complete process from schematic design to final drawing archiving. In this traditional model, the architecture, structure, and MEP disciplines only converge at specific design milestones for information extraction, with minimal horizontal data transmission between disciplines. Moreover, information is primarily conveyed through 2D CAD drawings and text documents, which cannot comprehensively reflect the design data status, leading to information loss during transfer.

Three fundamental problems characterize the traditional design model:

(1) Information Flow: Information exchange between design disciplines occurs only at phased milestones, with virtually no horizontal data transmission. The reliance on 2D CAD drawings and documents as information carriers fails to fully represent design data status, resulting in information loss.

(2) Professional Coordination: Clear task divisions and rigid, stage-based design patterns create severe fragmentation among architecture, structure, and MEP disciplines. Coordination requires formal consolidation meetings, which are time-consuming and labor-intensive.

(3) Design Process Management: The severe fragmentation across disciplines and design phases forces design managers to extract progress information from milestone nodes based on experience. The need for repeated, large-scale information extraction makes real-time sharing impossible, introducing significant information delays that limit collaborative work and cause multiple rework cycles, ultimately impacting overall design progress.

1.2 Coordination Issues Among Construction Participants

Construction information for utility tunnels encompasses all data generated throughout the construction process, while information flow represents the communication channels established among participants to overcome information asymmetry. Utility tunnel construction involves pre-construction preparation (design site handover), implementation (quality, schedule, and safety management), and completion acceptance, engaging multiple parties including the client, designer, supervisor, and contractor, along with massive amounts of construction information. Based on this context, [Figure 2: see original paper] presents the traditional construction workflow for utility tunnel projects.

As shown in [Figure 2: see original paper], the traditional construction process unfolds in distinct stages with near-linear information transmission. Design handover requires the design unit to lead the client and contractor in evaluating design outcomes and developing construction plans within a limited timeframe using 2D CAD drawings. During implementation, site management must coordinate trade sequencing, control quality, schedule, and safety, and manage material supply logistics.

Analysis of this traditional model reveals three key deficiencies:

(1) Information Carrier Limitations: The entire construction process relies on 2D CAD drawings for communication, creating difficulties for clients and contractors and making design issues difficult to detect, thereby increasing construction risks.

(2) Stage-wise Transmission: The linear progression from preparation through implementation to acceptance lacks feedback mechanisms, causing issues overlooked during design handover to propagate into construction, resulting in delayed problem identification and resolution.

(3) Participant Coordination: As [Figure 2: see original paper] illustrates, design, supervision, and client units have insufficient involvement during implementation, with no effective communication channels established among them. Additionally, internal trades within the contractor operate in mechanical series without mutual collaboration.

1.3 Interface Issues Between Design and Construction Units

Traditional construction projects suffer from long-term separation between design and construction due to professional specialization, with design work completed independently by design institutes. This organizational disconnect reduces design-construction integration. The interface between utility tunnel design and construction represents the transformation from design concept to physical infrastructure. Based on the work content of both phases, [Figure 3: see original paper] illustrates the interface between construction and design phases, showing that construction drawing delivery serves as the sole information carrier, with design information flowing unidirectionally from designer to contractor via 2D CAD drawings.

This designer-led model creates unidirectional information flow from design to construction, causing design defects to accumulate during construction. Such defects not only impact project progress but also increase construction costs. The traditional design-construction interface suffers from:

(1) Constructability Issues: The one-way information flow means designers lack practical construction experience, reducing design constructability. Problems are only discovered during construction, causing significant time delays.

(2) Design-Construction Separation: The two parties rely solely on 2D drawings for information transfer, which cannot effectively communicate complete design information, maintaining their relative isolation.

(3) Contractor Lag: Since construction drawings are completed entirely by the design unit before delivery, contractors must start from scratch in understanding design intent, wasting time and potentially leading to the issues described above.

2 Research on BIM-Based Integrated Design-Construction Optimization Models

2.1 BIM-Based Design Collaboration Optimization Model

Collaborative design in engineering refers to a multi-disciplinary cooperative work model where all design disciplines and managers operate on a unified platform (central file) to achieve real-time information sharing and design efficiency, aiming to resolve design conflicts caused by insufficient inter-disciplinary correlation. Addressing the coordination issues identified in Section 1.1, this study proposes a BIM-based optimization approach. The BIM central file synchronizes design progress information across disciplines, which can also extract reference data from each other. This breaks the traditional stage-based design pattern and rigid milestone consolidation, establishing the BIM-based collaborative design model shown in [Figure 4: see original paper].

As illustrated in [Figure 4: see original paper], the three major design disciplines (architecture, structure, and MEP) establish bidirectional data transfer channels with the utility tunnel BIM central file through synchronization and sharing. Disciplines are also interlinked to form an inter-professional collaboration mechanism, while design managers review design outcomes by accessing the central file. As design progresses, the utility tunnel BIM model gradually matures. Upon approval from the design review department, the BIM drawing issuance command is issued, completing the BIM-based design task.

Compared with traditional models, the BIM-based collaborative design approach allows disciplines to start essentially simultaneously, with structure and MEP disciplines beginning earlier relative to architecture. Through central files and mutual linking mechanisms, horizontal information flow between disciplines is achieved, while design managers ensure vertical information transfer by directly reviewing the BIM central file. This combined horizontal-vertical information flow reduces design cycles, minimizes information transfer instances, and enables inter-disciplinary collaboration throughout the entire process. Design defects can be detected at any time, enabling immediate feedback and resolution, significantly improving collaborative design efficiency.

2.2 BIM-Based Construction Collaboration Optimization Model

Coordinated construction refers to the real-time collection and processing of construction information and data by management teams throughout the project lifecycle, establishing communication channels among all participants and trades to break down “information silos” and improve construction management collaboration efficiency. The construction phase is the longest, most complex, and most personnel-intensive stage of a utility tunnel’ s lifecycle, directly impacting project efficiency, schedule, cost, and quality. Addressing the traditional construction issues identified in Section 1.2, this study uses BIM technology to connect all participants through the building information model, establishing the information flow paths and collaborative work model shown in [Figure 5:

see original paper].

As shown in [Figure 5: see original paper], the BIM-based construction collaboration model begins with the design unit delivering the completed utility tunnel BIM model to the contractor, who organizes all participants in design handover using the model. Identified issues are fed back into the BIM model for revision and improvement. The contractor then develops a BIM-based construction tracking model for real-time supervision of the implementation process, which design, supervision, and client units can access to understand construction status. During final acceptance, this model serves as a reference data model.

Compared with traditional construction, the BIM model permeates the entire process from design handover through implementation to acceptance, with all participants conducting deep information exchange and collaborative work based on the BIM information model. This approach weakens and blurs stage boundaries, achieving organic integration of design delivery, construction implementation, and acceptance through the utility tunnel BIM model. Construction managers can use BIM technology to track progress in real-time, predict and proactively address coordination issues among participants, and utilize the information-sharing capabilities of BIM to effectively connect internal divisions within client, design, and contractor organizations, enabling better project understanding and collaborative work.

2.3 BIM-Based Design-Construction Integration Optimization Model

Addressing the problems caused by traditional design-construction separation, this study introduces BIM technology into the design-construction interface process, using the BIM utility tunnel information model as a bridging mechanism. [Figure 6: see original paper] illustrates the BIM-based design-construction interface model. Compared with traditional interfaces, the BIM model strengthens bidirectional information transfer between construction and design, enabling contractors to communicate with designers through the model. Using the 3D visualization capabilities of BIM, contractors can better understand design intent, achieving seamless integration.

As shown in [Figure 6: see original paper], the design unit delivers its design outcomes to the construction phase as a BIM utility tunnel model. During construction, all participants review the design model through design handover, feeding back non-compliant elements to design management via the model to achieve data synchronization and information sharing with the design-phase BIM central file. During implementation, contractors can reflect constructability issues back to designers through the construction tracking model.

The BIM-based design-construction interface model uses the design unit' s BIM central file as a medium, achieving seamless integration from design to construction. Design outcomes no longer flow unidirectionally and irreversibly to construction; instead, the BIM model enables deep design-construction integration, blurring the boundaries between phases and allowing contractors and other participants to engage during the design stage. This not only accelerates understanding of design intent but also improves design constructability and reduces rework.

---

3 Case Study

The utility tunnel project in Bowang District, Ma' anshan City, was planned to support the development of the new Bowang area and enhance regional comprehensive strength. The project includes 24 kilometers of tunnels along Liaohe Road, Haihe Road, and other routes, with a total investment of approximately 2 billion RMB. Its extensive layout, massive engineering information, and numerous participating units distinguish it from typical construction projects. The project adopted the EPC general contracting model, which institutionally guarantees design-construction integration, and applied BIM technology throughout to facilitate design-construction collaboration.

During implementation, the design institute used BIM technology to develop architectural, structural, and MEP models for the utility tunnel. From the initial design stage, intra-disciplinary information was shared through file linking, enabling cross-referencing of plans, elevations, and sections. Furthermore, interdisciplinary coordination through central file extraction identified and resolved 714 issues early, including professional clashes (pipelines conflicting with architecture), unreasonable architectural design (chamber corners too small), and incorrect pipeline arrangements (unreasonable pipeline 避让 methods). As design progressed, the utility tunnel BIM central file matured (as shown in [Figure 7: see original paper]), enabling the design review department to monitor and approve the model in real-time. This reduced design rework cycles from over 10 to just 1, shortened the design 周期 from 7 days to 3 days, and significantly reduced design costs.

During construction, the contractor developed a digital construction tracking model based on the design institute' s BIM model. Using Navisworks construction simulation technology (as shown in [Figure 9: see original paper]), the contractor optimized sequencing among excavation, concrete, rebar, formwork, hoisting, transportation, and procurement departments to develop rational construction plans and methodologies. The digital construction model tracked the entire construction process, collecting site information and summarizing it digitally within the model. Through the BIM-based construction collaboration model, this information was shared with client, design, and supervision units, increasing participation, reducing engineering changes, shortening construction duration, and lowering project costs.

Although the project still used the traditional design-construction separation model (DBB), preventing contractors from participating in the detailed design process through the BIM central file under EPC leadership and from providing constructability feedback as per the model in [Figure 6: see original paper], the

EPC general contractor integrated the design institute' s BIM central file with the contractor' s construction tracking model. While the three models were not fully merged, this established a preliminary BIM-based design-construction integration collaboration mechanism, creating a new structure for external reporting, internal efficient coordination, and centralized information management.

However, because contractors could not engage in the detailed design process through the BIM central file, constructability issues persisted. As shown in [Figure 8: see original paper], during construction model 深化, contractors discovered excessively low door and window heights in utility tunnel node stairwells, exposing ongoing constructability problems. Additionally, contractors required extra time to understand the design intent within the tunnel model, potentially causing incomplete information transfer and erroneous construction planning—issues partly attributable to insufficient design involvement in the construction process.

Conclusion

To address the long-standing separation between design and construction in utility tunnel projects and improve design-construction integration efficiency, this study analyzed problems in traditional design workflows and construction management models. By applying BIM technology to the design-construction integration process, three optimization models were established: (1) a design collaboration optimization model that transforms rigid traditional workflows and enables information sharing and coordination among architecture, structure, and MEP disciplines; (2) a construction collaboration optimization model that blurs stage boundaries to facilitate integration across construction phases and improve participant coordination; and (3) a design-construction interface model that breaks down separation by advancing contractor engagement into the design phase, increasing mutual participation, improving design constructability, and reducing rework.

The integration of these three BIM-based optimization models into a unified collaboration mechanism was applied to a real project case. Practice demonstrates that these models and mechanisms are operable and provide valuable reference for utility tunnel project construction, improving management efficiency, accelerating information exchange, and reducing construction costs.

References

[1] ZHOU Hong, JIANG Qingxin. Preliminary interpretation of "Guidelines for Promoting Urban Underground Utility Tunnel Construction" [J]. Environment and Sustainable Development, 2015, (05): 58-59.
[2] BAI Hailong. Research on development trends of urban utility tunnels[J].

China Municipal Engineering, 2015(06): 78-81.
[3] ZHOU Wenlian. Promoting sustainable and healthy development of construction industry through design-construction integration[J]. China Survey and Design, 2017(04): 46-51.
[4] ZHENG Peixin. Application of BIM technology in design-construction integration[J]. Highway and Automobile, 2016(01): 234-237.
[5] YANG Dangfeng, LIU Xiaodong, SU Feng, et al. Research and application of intelligent operation and maintenance management for urban underground utility tunnels[J]. Journal of Information Technology in Civil Engineering and Architecture, 2017(06): 28-33.
[6] BAI Shu, CAI Mengna, et al. Analysis of BIM technology application value in urban underground utility tunnels[J]. Journal of Engineering Management, 2018(02): 74-78.
[7] CHEN Lin, SU Zhenmin. Research on integration of engineering project design and construction[J]. Commercial Economic Research, 2007(25): 66-67.
[8] RAO Pingping, LIANG Xiaodong, XU Ming, et al. Application of BIM-based construction information management platform[J]. Journal of Information Technology in Civil Engineering and Architecture, 2017, 9(03): 96-102.
[9] CHEN Jie, WU Diankun, REN Jianbo, et al. Research on collaborative design of construction projects based on Cloud-BIM[J]. Journal of Engineering Management, 2014, (05): 27-31.
[10] MAN Qingpeng, LI Xiaodong. Research on collaborative construction method based on pervasive computing and BIM[J]. China Civil Engineering Journal, 2012(s2): 311-315.
[11] LI Yong, QIE Entian, GUO Yang. Discussion on application of BIM technology in four major controls during construction phase[J]. Building Materials World, 2014(02): 103-107.
[12] ZHOU Bo, REN Yaping. BIM-based collaborative management model for construction process and its application[J]. Construction Technology, 2017(12): 78-81.

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