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Application and Challenges of BIM Technology in China's Integrated Utility Tunnels

Feng Yang[1*], Wai Yie Leong[2]

[1]Fujian Forestry Vocational & Technical College, Nanping, Fujian 353000, China
[2]INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia

[*]**Email:** yfphd@outlook.com; waiyie@gmail.com

Abstract

In the context of rapid urbanization, integrated utility tunnels present an innovative solution by consolidating various pipelines into a unified underground system, improving construction efficiency and urban management. This paper explores the role of Building Information Modeling (BIM), a breakthrough technology that enhances project design, simulation, and construction efficiency through digital modeling. BIM technology is optimizing utility tunnel construction by enabling better planning, monitoring, and collaboration through 3D and 4D modeling. Using a PESTEL analysis framework, this study evaluates BIM's application in integrated utility tunnels in China and its potential for advancing the digital transformation of urban infrastructure. The research reveals how BIM can enhance the informatization and intelligence of utility tunnels and discusses the future opportunities and challenges for its expansion in China's urbanization efforts.

Keywords

BIM , Integrated Utility Tunnels, PESTEL, Municipal Engineering

Introduction

In recent years, China's urbanization process has been accelerating, the population density has been increasing, and the urban population has shown agglomeration, which puts forward higher requirements for the planning, construction, and management of cities.(Huang & Liu, 2021) However, the current urban space planning is not reasonable enough, especially since the utilization of underground space planning is more chaotic, resulting in the development and utilization of urban underground space being unreasonable. (Hao et al., 2024)

Building Information Modeling (BIM) has emerged as a powerful tool for managing complex infrastructure projects, including integrated utility tunnels. Yin et al. proposed a BIM-based framework for operation and maintenance of utility tunnels, demonstrating BIM's potential for lifecycle management. Yang et al. focused on generating topologically consistent BIM models for utility tunnels, addressing the challenge of creating accurate digital representations(L. Yang et al., 2023). Wang et al. developed an integrated underground utility management and decision support system, likely incorporating BIM technology(M. Wang et

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al., 2019). Lee et al. presented an integrated system framework using building information modeling for underground utilities, showcasing BIM's role in comprehensive infrastructure management(Lee et al., 2018). This paper addresses a critical gap in understanding the role of BIM technology in the construction and management of China's integrated utility tunnels. Specifically, it analyses how BIM can improve tunnel management, reduce inefficiencies and provide a roadmap for the future, as well as presenting challenges and opportunities for the future.

BIM technology is transforming the construction and management of integrated utility tunnels in China by improving planning, coordination, and monitoring through advanced 3D and 4D modeling. Supported by government policies and educational initiatives, BIM enhances efficiency, reduces costs, and promotes sustainable infrastructure development in urban areas. Using the PESTEL (Political, Economic, Socio-Cultural, Technological, Environmental and Legal) analytical framework, the article analyses the application of BIM in China's integrated tube tunnels and its challenges and development prospects, identifies barriers such as high initial investment, lack of skilled professionals and regulatory inconsistencies, and proposes recommendations for improvement accordingly.

Methodology

The research methodology employed in this study is designed to analyze the application and future prospects of Building Information Modeling (BIM) technology in China's integrated utility tunnels. This study utilizes the PESTEL analytical framework to explore the application and future prospects of BIM technology in China's integrated utility tunnels. The analysis focuses on six key external macro-environmental factors: political, economic, social, technological, environmental and legal: political, economic, social, technological, environmental and legal (Figure 1).

This approach allows us to assess how various external conditions affect the application of BIM in this particular infrastructure environment. This study also uses a number of government annual reports and related literature to provide a comprehensive overview of these factors.

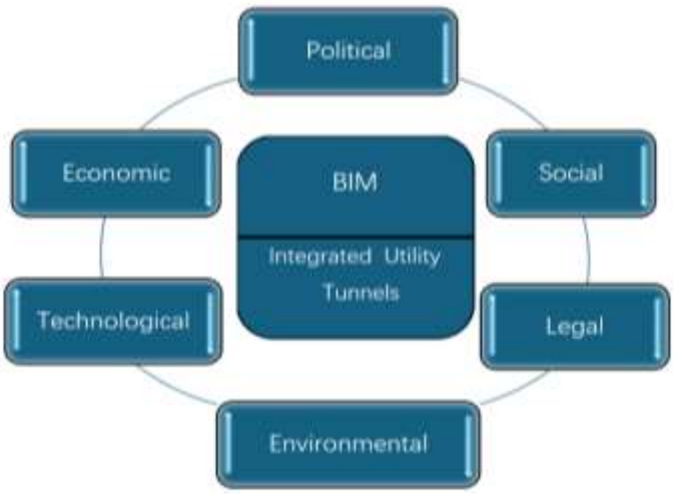

Figure 1. PESTEL Analysis Framework

Current Status of Integrated Utility Tunnel Construction

In recent years, Urban construction has accelerated, yet infrastructure, particularly underground, lags. Overhead lines mar cityscapes, and frequent excavations for pipeline maintenance disrupt residents. Integrated utility tunnels can integrate multiple pipelines, alleviate "zip roads," enhance city aesthetics, and safeguard key roads from obstruction. (T. Wang et al., 2018; Leong, 2024a). Therefore, more and more cities have begun to build integrated utility tunnels.

Integrated utility tunnels are urban underground corridors that accommodate water supply and drainage, heating, and telecommunication cables within a single tunnel and are managed centrally as a municipal infrastructure. Modern urban integrated utility tunnels are crucial for the normal operation of cities. (Luo et al., 2020)

In recent years, with rapid urban development and accelerated new urbanization, integrated utility tunnels have become essential for improving urbanization quality(Leong, 2024b; 2024c; 2024d). Integrated utility tunnels (IUTs) are vital for urban infrastructure, housing essential services like water, sewage, heating, gas, and telecom cables. They optimize underground space, easing infrastructure strain in densely populated cities. IUTs streamline operations and maintenance, enhancing efficiency and reducing infrastructure-related risks. In case of emergencies, these tunnels simplify maintenance, reduce costs, and promote economic development by attracting capital investment and stimulating economic growth(Sun et al., 2021).

Integrated utility tunnels (IUT) technology originated in France in 1833 and spread to the UK, Germany, Sweden, Spain, Russia, and Japan, with expanding scale and length. Japan enacted the "Special Measures Law on Joint Ducts" in 1963, completing over 300 km of IUTs by 1992(T. Wang et al., 2018; Choo, 2018).

Beijing initiated its first 1,000 m IUT in 1958, and Shanghai built an 11.125 km IUT in Pudong in 1994(Luo et al., 2020). China designated its first IUT pilot cities in 2015, including Baotou, Shenyang, Harbin, Suzhou, Xiamen, Shiyan, Changsha, Haikou, Liupanshui, and Baiyin, with a second batch announced in 2016. By June 2022, 279 cities and 104 counties had started 1,647 IUT projects, totaling 5,902 km. Despite a dip in investment from 2016, 2021 saw a resurgence with 53.89 billion yuan, an 18.8% rise (Yang & Peng, 2016).

The construction of these tunnels reduces the “zipper road” problem, improves urban resilience to sudden disasters, promotes employment, and drives urban infrastructure reform. The investment status of integrated utility tunnels from 2017 to 2022 is shown in Figure 2.

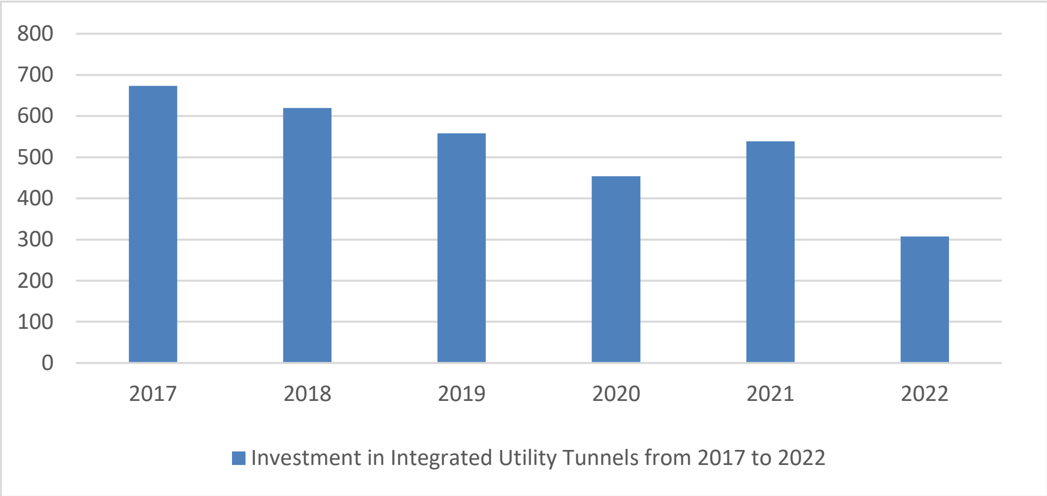

Figure 2. Investment in Integrated Utility Tunnels from 2017 to 2022

During China's 13th Five-Year Plan, urbanization advanced, and the push for integrated utility tunnels was notable. The "14th Five-Year Plan for National Urban Infrastructure Construction" aimed to expand tunnel systems, boost utility line capacities, and renew old networks. In H1 of 2022, 68 tunnel projects were underway, spanning 285 km at a cost of 29.4 billion yuan. The plan addresses issues like road excavation and pipeline accidents, enhancing city infrastructure and urbanization quality. It guides local planning for integrated utility tunnels, promoting their construction. Post-2023, China's utility tunnel construction is poised to stabilize, with government support as a key economic measure. High-demand areas like Nanjing's Jiangbei New Area and Chongqing have plans for extensive tunnel systems during the 14th Five-Year Plan period.

Application of BIM Technology in Integrated Utility Tunnels

During China's 13th Five-Year Plan, the construction sector advanced with over 100 informatization and BIM technology policies by September 2023. In July 2023, China streamlined construction approvals, promoting BIM for smart reviews. The 2023 Shanghai summit highlighted BIM's role in infrastructure. Universities focus on BIM talent, supporting its cross-sector integration. BIM's late start in utility tunnels is gaining traction through national initiatives, optimizing construction planning.

As shown in the Figure 3, BIM creates a model of the pipeline corridor, which allows the simulation of pipeline arrangement schemes and facilitates the selection of the optimal scheme. BIM technology can create 3D models combined with construction progress to achieve four-dimensional management of integrated utility tunnel construction. BIM combined with monitoring systems can effectively monitor the operational status of utility tunnels(Figure 4). By creating a BIM collaboration platform and organizing regular BIM-specific meetings, participants can discover and resolve issues, avoid rework, effectively control construction risks, and streamline coordination among parties.

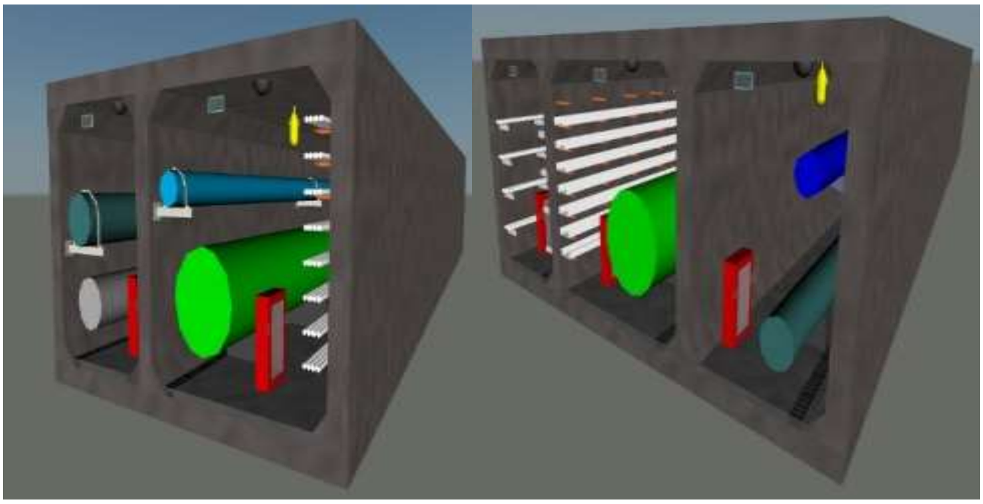

Figure 3. Comparison of BIM model scenarios

Figure 4. BIM combined with monitoring system

PESTEL Analysis of BIM Technology in China's Integrated Utility Tunnels

Political Factors: The Chinese government actively promotes BIM technology, especially in urban infrastructure and smart city projects. Key policies, such as the "2016-2020 Outline for Construction Industry Informatization," have facilitated the integration of BIM into urban planning and public projects. This ongoing support ensures the continued expansion of BIM in integrated utility tunnels as cities develop more advanced infrastructure.

Economic Factors: BIM technology significantly reduces construction errors and material waste, leading to cost savings. Although the initial investment in software and training is high, the long-term benefits, such as improved project management and reduced rework, contribute to increased economic returns by optimizing resource use and lowering operational costs.

Social Factors: As urbanization increases, the demand for efficient underground space management intensifies. BIM helps address these needs by improving coordination in underground pipeline construction and optimizing space utilization. Its growing role in smart city projects highlights its potential to enhance urban infrastructure management. Many colleges and vocational training institutions have begun to offer BIM-related courses to meet the market demand for BIM professionals, which has led to the increasing acceptance and recognition of the technology in various industries (Liu, 2009). This has laid the foundation for the future development of BIM.

Figure 5 shows the population and urbanization trends in China from 2013 to 2023. The population rises steadily from 1.37 billion in 2013 to a peak of 1.42 billion in 2021, and then declines slightly in 2022 and 2023. At the same time, the urbanization rate has risen from 54% to 66%. This growth intensifies the demand for urban infrastructure.

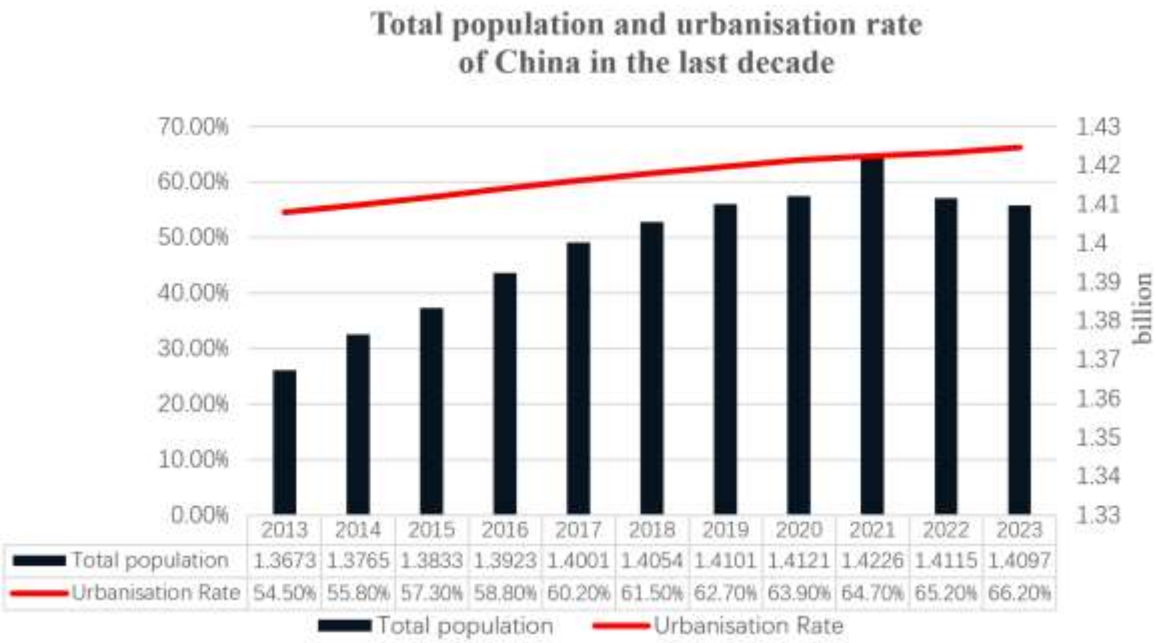

Figure 5 Total population and urbanisation rate of China in the last decade

Technological Factors: BIM technology integrates advanced tools like IoT, big data, and AI, offering comprehensive lifecycle management for integrated utility tunnels (Leong, 2024e). It allows real-time monitoring of operations, improving tunnel management . However, challenges such as inconsistent software use and the lack of standardized data sharing between departments remain. Additionally, BIM’s standardization across regions is still evolving, signaling the need for further improvements in its application.

Environmental Factors: BIM enhances the sustainability of tunnel projects by optimizing construction processes, reducing waste, and minimizing energy consumption. By consolidating various pipeline systems, utility tunnels reduce the environmental impact of frequent excavations. BIM also aids in designing environmentally friendly construction plans by simulating impacts and helping mitigate potential ecological damage during the planning and construction phases.

Legal Factors: China is gradually developing its legal framework for BIM technology, with regulations such as the "Building Information Modeling Technology Application Standards" providing guidelines for its use. However, issues like intellectual property protection and data security require more detailed legal specifications. Clear contractual agreements and role definitions are also needed to reduce disputes and enhance project efficiency in the application of BIM in utility tunnels.

Results and Discussion

Building Information Modeling (BIM) technology presents several significant opportunities for improving the design, construction, and operation of integrated utility tunnels in China.Table 1 provides an insightful comparison of how Building Information Modeling (BIM) technology has been adopted across several major Chinese cities in their respective utility tunnel projects. The table lists the five major Chinese cities—Shanghai, Beijing, Guangzhou, Shenzhen, and Chengdu—that have implemented BIM technology in their utility tunnel projects. These cities represent some of China's most significant urban areas, known for their rapid infrastructural development. Shanghai's early adoption reflects the city’s position as a leader in technological infrastructure development. Beijing and Guangzhou have also quickly followed suit as part of their urban development programs. Cities like Shenzhen and Chengdu, while progressive in other aspects, have been relatively slower in adopting BIM for utility tunnels. The scale and scope of these projects show that BIM has been instrumental in handling complex, multi-utility designs. Cities like Shanghai and Guangzhou are pushing the envelope by using BIM for smart city development, showcasing advanced applications of this technology. Revit’s dominance as the software of choice shows its popularity in handling large-scale utility projects, thanks to its robust design and analysis tools. ArchiCAD and Navisworks are also widely used, suggesting that different cities may prioritize different aspects of BIM functionality (e.g., coordination vs. design).Shanghai’s leadership is apparent, as it has reached the highest level of BIM adoption. Beijing and Guangzhou are close behind, while Shenzhen and Chengdu are still developing their BIM capabilities. This disparity reflects differences in investment, policy implementation, and available expertise in these cities. The table highlights some of the major hurdles faced by each city in adopting BIM technology: Shanghai: High initial costs are a significant barrier, despite its advanced adoption level. Beijing: Lack of skilled professionals is a major challenge, indicating a gap between technology availability and human resource capacity. Guangzhou: Integration with existing infrastructure is the key challenge, as the city has an extensive network of older, non-digital systems. Shenzhen: Regulatory barriers slow down the implementation of BIM, reflecting the need for more clear policies and standards. Chengdu: Cost overruns have been a significant issue, likely due to inadequate planning or management.

Table 1: Comparative Analysis of BIM Implementation in Major Chinese Cities

City	Year of First BIM Adoption	Major Projects Using BIM	BIM Software Used	Level of BIM Adoption (Scale: 1-5)	Key Challenges
Shanghai	2015	Urban Utility Corridor Project	Revit	5	High Initial Costs
Beijing	2016	Beijing Integrated Utility Tunnel	ArchiCAD	4	Lack of Skilled Professionals
Guangzhou	2017	Guangzhou Smart City Utility Tunnel	Revit	4	Integration with Existing Infrastructure
Shenzhen	2018	Shenzhen Urban Redevelopment Plan	Navisworks	3	Regulatory Barriers
Chengdu	2019	Chengdu Integrated Utility System	Revit	3	Cost Overruns

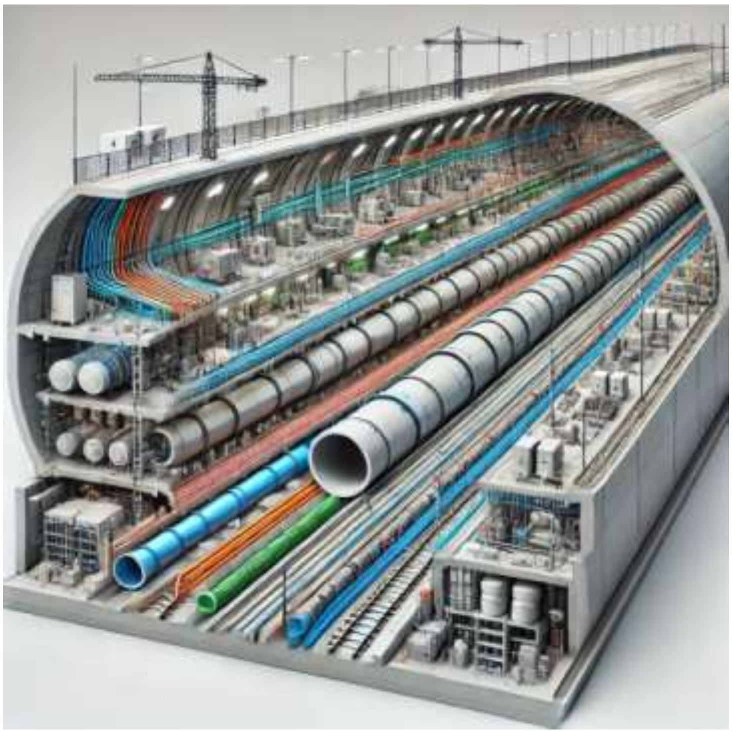

Figure 6. A 3D Model of an Integrated Utility Tunnel with Multiple Utilities (Electricity, Water, Gas, Telecommunications)

Each city faces unique challenges in its BIM journey, with common themes being cost and the availability of skilled personnel. More advanced cities like Shanghai are primarily concerned with financial factors, while cities that are still developing their BIM capabilities face challenges related to workforce readiness and integration with existing infrastructure.

The PESTEL analysis reveals that the application of BIM technology in integrated utility tunnels in China has a very broad outlook. Analyzing from political, economic, social, technological, environmental, and legal perspectives, BIM technology benefits from strong government policy support, delivers significant economic advantages, and is gradually gaining widespread social acceptance and recognition. Additionally, advancements in technology, improved standards, and positive environmental impacts provide favorable conditions for its application in integrated utility tunnels. While there are still some challenges in terms of technology and legal aspects, these issues are expected to be resolved with further technological advancements and policy support. Overall, BIM technology is poised to play an increasingly important role in China's urbanization process, especially in the construction of critical urban infrastructure such as integrated utility tunnels.

Challenges and Barriers of BIM Technology in China's Integrated Utility Tunnels

Building Information Modeling (BIM) technology offers many benefits in terms of efficiency, design accuracy, and operational insights. However, when applied to integrated utility tunnels in China, several challenges and barriers have emerged that must be addressed to maximize the potential of BIM.

High Initial Investment Costs: The high costs associated with adopting BIM technology include Software and Hardware. Advanced tools like Autodesk Revit or Navisworks, along with powerful computing systems. Extensive training is required for engineers, architects, and project managers, increasing both cost and implementation time. These initial investments deter small firms and local governments, especially in projects where cost control is paramount, such as public infrastructure like utility tunnels. Figure 7 showcasing cost distribution over different project phases: planning, design, and construction, comparing traditional methods to BIM-enabled methods.

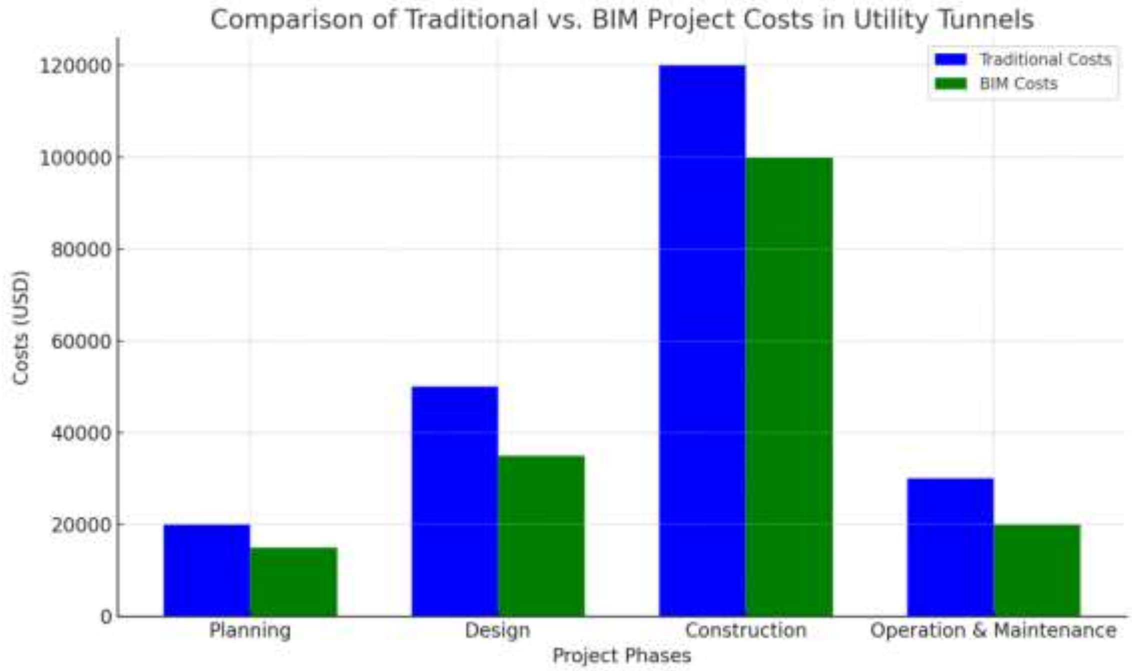

Figure 7: Comparison of Traditional vs. BIM Project Costs in Utility Tunnels

Lack of Skilled Professionals: BIM requires a specialized skill set that is not yet widely available in the construction workforce in China. Training professionals to fully understand BIM models, simulation, and integration with existing infrastructure is time-consuming. Few universities and professional bodies in China offer standardized training or certification programs for BIM, contributing to the skill gap. This shortage of skilled professionals slows down the adoption of BIM, with construction teams resorting to traditional methods when faced with tight deadlines or complex challenges.

Integration with Existing Infrastructure: Many existing utility tunnels were developed without digital documentation. Integrating these old systems with new BIM models is complex and often requires the creation of digital replicas of existing infrastructure. Data from legacy systems often isn't compatible with modern BIM platforms, creating delays and potential for errors.This presents an enormous challenge, as much of China's urban infrastructure is already in place. Recreating these existing systems digitally is both time-consuming and expensive.

Figure 8 shows a 3D BIM model with utilities like water, electricity, and gas pipes within a tunnel cross-section, demonstrating the complexity of infrastructure integration.

Figure 8: A BIM Model of an Integrated Utility Tunnel

Regulatory and Standardization Barriers: BIM adoption across China lacks standardized frameworks, making it difficult for cross-region collaborations. Different municipalities have their own regulations, which can slow project approval and implementation. While China's government supports BIM technology for larger infrastructure projects, local governments and smaller municipalities struggle to adapt to national-level BIM frameworks. Without unified regulations, BIM models must be customized to meet local standards, leading to delays, additional costs, and administrative burdens. Table 2 compares major regulatory hurdles in cities like Shanghai, Beijing, and Chengdu, focusing on inconsistencies in BIM-related standards.

Table 2: Regulatory Challenges in Different Regions of China

Region	Regulatory Body	Key BIM Regulatory Challenges	Impact on Projects
Shanghai	Shanghai Municipal Engineering Commission	Complex approval process for BIM models	Delays in project approvals
Beijing	Beijing Urban Planning Bureau	Inconsistent standards across projects	Difficulty in cross-project collaboration
Guangzhou	Guangzhou Infrastructure Development Authority	Integration with existing non-BIM projects	High cost of integrating new and old systems
Shenzhen	Shenzhen Urban Development Authority	Slow adoption of national BIM guidelines	Slower project execution timelines
Chengdu	Chengdu City Planning and Development Commission	Lack of clear local BIM implementation frameworks	Confusion among stakeholders regarding compliance

Data Security and Ownership Issues: Integrated utility tunnels house critical infrastructure such as telecommunications, water, and electricity. Centralizing this data in BIM models raises concerns about cybersecurity and access control. In large-scale projects, there are often multiple stakeholders, including government agencies, contractors, and service providers. Deciding who owns the data can be contentious. Data security concerns can cause delays in BIM implementation, particularly in utility tunnels that house critical infrastructure, which are considered vulnerable to cyber-attacks. Figure 8 showing the concerns of various stakeholders, such as government bodies, private contractors, and service providers, related to data security and model ownership.

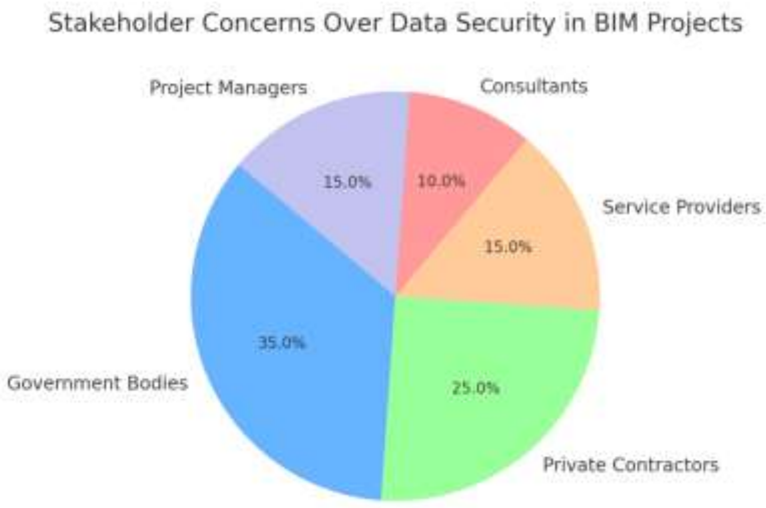

Figure 9: Stakeholder Concerns Over Data Security in BIM Projects

While the application of BIM technology in China's integrated utility tunnels holds immense promise, there are significant barriers to widespread adoption. High initial costs, lack of skilled professionals, difficulties integrating with legacy infrastructure, and regulatory hurdles are among the key challenges. Moreover, issues such as data security and ownership, budget overruns, and resistance to change must be tackled for BIM to become a core component of China's urban development strategy.

Conclusions

The application of Building Information Modeling (BIM) technology in China's integrated utility tunnels has marked a significant advancement in the planning, construction, and management of urban infrastructure. BIM's ability to create accurate 3D models, improve collaboration, and optimize both construction and maintenance processes has made it a critical tool for managing complex utility tunnels that house essential services like electricity, water, gas, and telecommunications. Despite the clear benefits, such as improved design accuracy, reduced rework, and enhanced project coordination, challenges remain. High initial costs, a shortage of skilled professionals, data security concerns, and inconsistent regulatory frameworks across different regions of China are significant barriers to widespread BIM adoption. Looking ahead, the prospects for BIM in China's utility tunnels are promising. Government initiatives, especially related to smart cities and infrastructure modernization, provide strong support for BIM implementation. As technological advancements such as AI integration and digital twin technology emerge, BIM’s role in real-time monitoring and predictive maintenance will grow, offering even greater efficiencies and sustainability. In conclusion, while challenges remain, the continued development and standardization of BIM technology, coupled with governmental backing, position BIM as an essential component for the future of integrated utility tunnel construction and management in China. Its potential to improve project outcomes, reduce costs, and contribute to more sustainable urban infrastructure makes BIM a key tool in China's evolving infrastructure landscape.

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