Research on the Implementation Path of Digital Transformation in Highway Survey and Design

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Abstract. The survey and design phase, as the source of highway engineering models and data, plays a crucial role in the digital transformation process throughout the entire lifecycle. Addressing the deficiencies in digital standards and construction, digital surveying and design, and BIM-based digital applications, emphasis has been placed on enhancing survey and design capabilities while focusing on data accumulation and utilization. Consequently, a comprehensive development strategy has been proposed, encompassing digital construction, BIM technology application at various stages, BIM-based information management, and intelligent control. Moreover, design and development have been undertaken in digital standard systems, digital design software, engineering data centers, and integrated platforms, offering practical solutions for the digital transformation and development of survey and design enterprises in the highway industry, thereby laying a solid foundation for subsequent smart highway construction.

Keywords: Digital Transformation, Digital Construction and Application, Highway Engineering, Top-level Design

1 Introduction

In 2023, the Ministry of Transport issued the "Opinions of the Ministry of Transport on Promoting the Accelerated Development of Smart Highway Construction through Advancing the Digital Transformation of Transportation" (Document No. Jiaogonglufa [2023] No. 131). It delineates the directions of development in smart construction, intelligent maintenance, smart travel, intelligent governance, standards, and support. The document's content spans the entire life cycle of highway survey, design, construction, maintenance, and operation, with data as a core element. Specific requirements were outlined for industry regulators, project owners, design units, construction units, and other participating parties.

The digital transformation in the development of highway survey and design is imminent, yet there is a lack of research on its overall development strategy, and there exist several problems as follows:

Although the BIM standards for the highway industry have been released, there's still a considerable gap between the standards and their practical application. The

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software on which the standards rely is not mature yet. Some enterprises have attempted to develop integrated platforms for digital standards. However, due to the incompleteness of the standards themselves, there are numerous obstacles encountered in cross-platform transmission and sharing of models and data.

The digital development level between highway survey and design is incongruent [1], primarily existing in the stage of upgrading survey and design modes and tools. The digital transformation imposes higher demands on survey and design, requiring not only high-quality and efficient output of traditional design drawings but also the digital representation of design outcomes. There still exists a bottleneck in the cross-disciplinary data integration at the data level.

The overall input-output ratio of the application of digital design outcomes needs optimization. Due to inadequate digital infrastructure construction, redundant development exists in BIM technology application, BIM-based information management, and intelligent control [2-3]. The highway digital industry led by survey and design lacks maturity, resulting in insufficient ecosystem integration.

By summarizing years of experience in highway digital design and application, focusing on the digital transformation of survey and design, an overall approach is proposed. This aims to provide insights and references for the digital development of the highway industry.

2 Construction Overall Approach

2.1 Top-Level Design

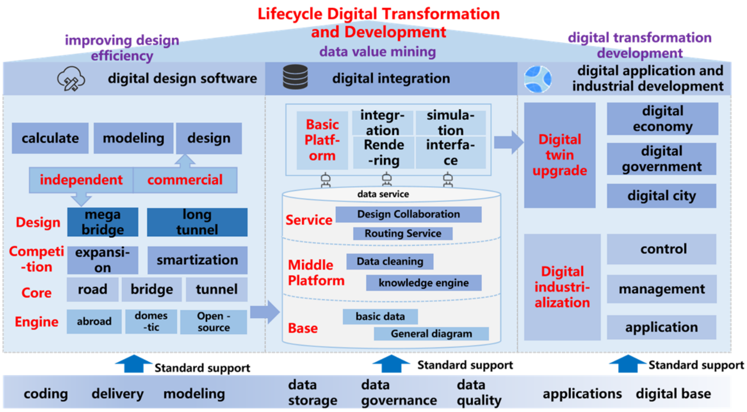

Fig. 1. Top-level architecture design diagram

The digitization and application in highway construction are at the core of transformative development, involving the entire project lifecycle and various stakeholders [4]. How to coordinate and achieve efficient data transmission and utilization is a key consideration in the top-level design phase. It requires a clear delineation, at a global level, of the stages and pathways for data transmission, the input and output requirements at each stage, and the interconnections needed to complete the business objectives. In the context of the digital transformation of highway survey and design, the top-level design architecture is depicted in Figure 1.

In terms of digital design software, a combination of independent research and commercial procurement is considered, focusing on key specialties such as roads, bridges, tunnels, aiming to cover the entire process, elements, and specialties of digital design in highway engineering surveys and designs.

For digital integration, the goal is to construct a digital foundation with a universal cloud platform as the front end and an engineering data center as the backend, facilitating data integration, simulation analysis, and efficient rendering. This structure, through standardized interfaces, aims to provide diverse services for a wide array of application scenarios.

Regarding digital application and industrial development, leveraging the leadership role of design data throughout the engineering lifecycle, and utilizing general platforms like the digital foundation, expansion is planned in the areas of digital application, information management, and intelligent control. There's also a focus on leveraging transportation infrastructure in digital cities, achieving platform interoperability through interfaces to build a digital twin for cities.

Digital standards form the basis for the aforementioned work. This involves the construction of a system that includes standards like classification codes serving digital construction, design delivery, and modeling guidelines. It also encompasses standards supporting data integration applications such as data storage, governance, and quality. Furthermore, there are standards for industrial applications like digital application and digital foundation construction. The aim is to coordinate the entire process of digital transformation through standardized construction.

2.2 Development of digital standards and standard digitalization

Digital transformation requires standards as a priority. Within the national, industry, and regional standard frameworks, it's essential to establish an enterprise-level digital standard system that can mutually map and connect based on specific business characteristics. As depicted in Table 1, this system focuses on three aspects: digital construction, digital integration, and digital application and industrialization, aiming to establish a comprehensive digital standard system covering the entire process of digital transformation and development.

Table 1. Digital standard system

Serial	Area	Category
1	Digitalization	Classification and Coding of Geographic Geological Models
2		Classification and Coding of Highway Engineering
3		Delivery of Geographic Geological Models

4		Highway Engineering Delivery
5		Geographic Geological Modelling
6		Highway Engineering Modelling
7	Digital Integration	Data Dictionary
8		IFC Extension
9		Data Exchange
10		Data Security
11		Classification Coding Application
12		Data Conversion and Formatting
13		Lifecycle Data Management
14		Data Quality Assessment Methods
15	Digital Applications and Industrialization	Application of Design, Construction, Operation and Maintenance Technology
16		Digital Platform Development
17		Digital Platform Interface Development
18		Creating Multidimensional Models for Digital Twins
19		Intelligent Application of Digital Twins
20		Development of Digital Twin Platform

Further integrating standards into the platform to realize standardized production, storage, management, transmission, and application of models and data according to standard requirements is crucial. By developing engineering data centers and integrated platform, as shown in Figure 2 and Figure 3, an open digital infrastructure is established, promoting the formation of a digital industrial ecosystem [5].

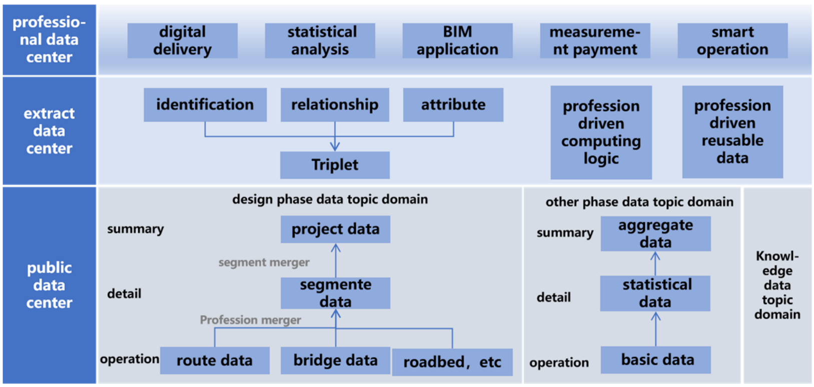

Fig. 2. Architecture diagram of engineering data center

The public data center aggregates design data from various specialties to form a comprehensive project data source, creating an operational data layer. After initial processing, it generates a detailed and aggregated data layer that remains consistent despite changes in business scenarios. To support efficient data application, the public data center establishes a knowledge data domain, storing design rules, delivery templates, etc., to facilitate the invocation of related data development tools.

Through scenario-based data application analysis, the curated data center constructs a digital representation data system centered around engineering objects. It computes data from the public data center, creating identifiable, attribute, relational, and behavioral information, forming reusable data resources driven by business requirements. This effort aims to link vertically fragmented data across specialties, stages, and platforms, supporting rapid invocation by frontend systems.

The professional data center provides encapsulated data interfaces to various application scenarios and systems, catering to relatively consistent data requirements throughout the entire engineering lifecycle.

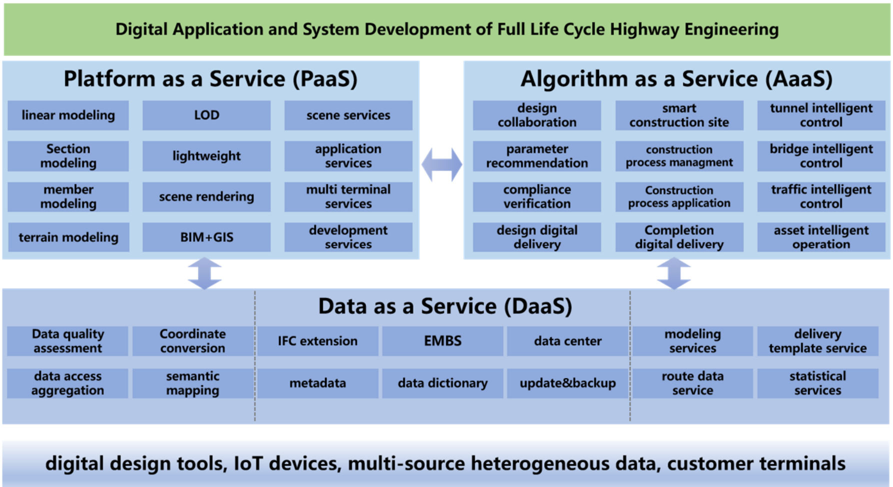

Fig. 3. Integrated solution for multi-service foundation cloud platform

The integrated platform establishes a Fusion Architecture that encompasses Platform as a Service (PaaS), Data as a Service (DaaS), and Algorithm as a Service (AaaS). Platform as a Service is built upon open-source graphic engine, encapsulating service interfaces in modeling capabilities, model rendering, and multi-scenario services. Data as a Service operates based on the Engineering Data Center, platformizing governance over data, including interface encapsulation in data preprocessing, storage, and delivery. Algorithm as a Service addresses the business needs of tunnels, bridges, traffic control, and asset operation and maintenance. It solidifies highly repetitive algorithms within the platform and encapsulates related interfaces for use in different products and rapid development.

2.3 Engineering Digitalization Construction and Application

The multiple disciplines involved in highway engineering exhibit significant differences in the development levels of their respective design methods and tools. By prioritizing design data, there's continuous updating and iteration of critical design tools, actively incorporating mature commercial software, and establishing data channels to support the digitization of highway engineering projects through a combination of "automatic, semi-automatic, and manual" approaches, as illustrated in Figure 4. There's an optimization of traditional computer-aided design (CAD) software by upgrading or replacing graphic engines. Additionally, the decoupling of business logic from modeling logic is implemented, utilizing route overall design data as the core to construct a cross-disciplinary data exchange framework aimed at enhancing the overall design quality and efficiency.

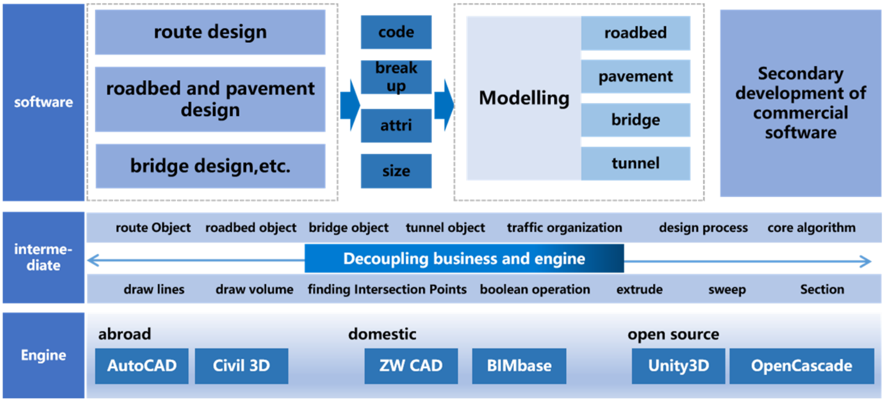

Fig. 4. Digital design software architecture diagram

2.4 The Digital Industrialization Development of Highway Engineering

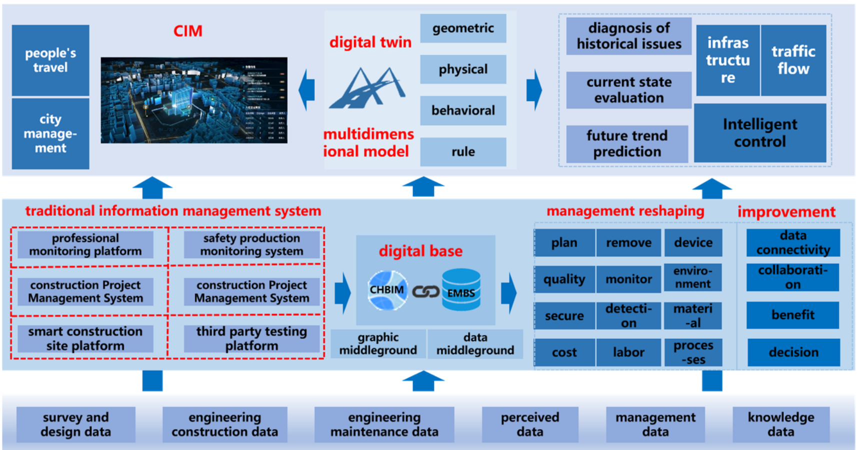

Fig. 5. Overall plan for digital industrialization development

The traditional information systems have led to the emergence of various "information silos." To address this issue, a core focus is on using BIM models and data to establish a data channel that converges information systems towards the model. This gradual separation of processes and data, coordinating and unifying data sources, aims to solve current challenges such as poor data transmission across platforms and low data utilization rates. Furthermore, there's an exploration of deep data application scenarios tailored for engineering project progress, quality, safety, site management, smart construction sites, and the health and safety monitoring of major bridge and tunnel projects. By integrating AI, big data, Beidou (BDS), and other modern digital technologies, the focus is on transportation infrastructure, smart transportation services, smart mobility, and aiding in the development of city information models, as shown in Figure 5.

3 Implementation Cases

3.1 Engineering Digitalization Construction

Upgrading the traditional "Jinsilu" highway design software series, deconstructing design data from various disciplines, and developing modeling systems to support rapid visualization of design outcomes, as shown in Figure 6; and for disciplines capable of conducting three-dimensional design, developing corresponding design tools to achieve three-dimensional design of traffic signs, tunnel engineering, etc., as shown in Figure 7.

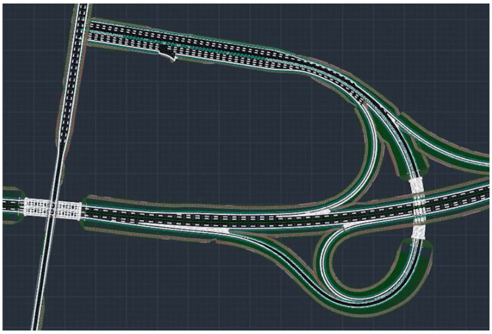

Fig. 6. Rapid modeling

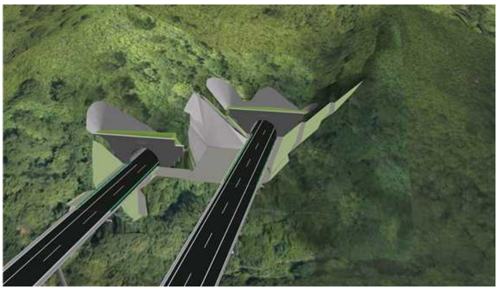

Fig. 7. Three-dimensional design

3.2 Application of Engineering Digitalization Results

Storing engineering digitalization results in the engineering data center, integrating or disaggregating data in the public data center, establishing multi-stage data subject domains based on engineering objects, and constructing material libraries, general drawing libraries, etc., in the knowledge data subject domain; in the data extraction center, establishing the Engineering Model Breakdown Structure (EMBS) to organize engineering ontology, attribute data, and business behaviors in a graph structure, supporting the business data center in accessing data, and enabling pile number queries, earthwork calculations, path calculations, etc., on the cloud platform.

3.3 Exploration of Digital Industrialization

In a mountainous expressway construction project, relying on the cloud platform and engineering data center, establishing a BIM information management platform, integrating data from multiple existing management systems, enabling rapid analysis and viewing of data in a three-dimensional scene, achieving data visualization through model integration, aggregating massive data resources on the platform, and developing business algorithms to assist in management decision-making.

In a project for constructing a particularly long tunnel, integrating data from intelligent construction sites, construction equipment, monitoring and control systems, etc., analyzing sensor data to address challenges such as traffic control difficulties in multi-working face muck-out areas in the long tunnel, implementing an intelligent control mode of setting traffic rules in the tunnel-interior, implementing control measures, and intelligently adjusting congestion, coordinating the construction progress of multiple working faces in the long tunnel.

4 Conclusion and Prospect

The digital transformation of the highway industry has clearly defined goals and directions at the policy level. Based on this, an engineering digitalization standard system covering the entire process and all elements has been established. A series of digital construction applications centered on data circulation has been developed to meet the needs of digital business innovation and industrial development. A digital infrastructure that meets the requirements of digital construction, digital applications, information management, and intelligent control has been constructed, along with an industrial development roadmap for digital construction, digital applications, information management, and intelligent control.

However, the highway industry still faces challenges such as lack of convergence in the digital industrial ecosystem and redundant technological development. Based on the aforementioned technological roadmap, proactive systematic technological applications are being carried out in typical projects with complex technical solutions and sufficient scale. This will help leverage the leading role of survey and design enterprises in the digital transformation of the highway industry, providing new impetus and opportunities for high-quality development of enterprises.

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