Preliminary Research and Practical Application of BIM Standard System Framework for Underground Engineering

JunTang Yang[a], XingTao Ren, JianBo Ren, Ke Lu, LinXing Qiu and JianTao Pei

Northwest Nuclear Technology Research Institute, No.28 Pingyu Road, Lintong District, Xi'an, China

Abstract: The intelligent transformation has put forward new requirements for the digitization and informatization of underground engineering. BIM can effectively support real feature perception, high-fidelity modelling, virtual mapping, and multi-physical simulation of underground engineering. However, the research on BIM in underground engineering is still in the preliminary exploration stage, and the standard system framework, key theories and technical directions are still not clear enough. Based on literature research, the current status of BIM standard system was analysed, and the preliminary framework for the BIM standard system combined with the characteristics of underground engineering and the needs of intelligent transformation has been established. According to the compilation principles, the standard system framework was divided into three parts: data standards, application standards, and management standards, and the composition of each part has been studied. The applicability of this framework has been demonstrated through an underground engineering example. The aim is to provide reference for the development of BIM theory and technology in underground engineering, and promote the full lifecycle digital information application of underground engineering.

1. Introduction

Underground engineering is accelerating the development of high quality, efficiency, and intelligence. Higher requirements have been put forward for efficient perception, dynamic response, rapid analysis, and optimized decision-making of information models in the stages of engineering geological survey, planning and site selection, professional design, construction, and operation and maintenance [1]. However, there are many problems in the current development of underground engineering, such as insufficient information under limited perception and hidden geological conditions, which makes it difficult to ensure the quality of engineering design and construction [2]. The delayed response limits the safety level of the project [3]. Existing analysis methods often select typical sections for idealized analysis [4], but their authenticity needs to be improved. The common bottleneck of the above situation lies in the low level of interaction and integration between underground engineering entities and virtual models, and the lack of standard systems and technical means to support the full lifecycle application and management research of underground engineering. This makes it easy to form an "information silo" between different stages, participants and professional designers.

BIM can circulate effective information and corresponding models throughout all stages of the full lifecycle, providing convenient and effective assistance to all project participants to complete the organization, management, and effective control of work content by all parties. Zhu et al. [5] developed a unified framework that includes all data processing tasks for BIM/GIS data integration, solving most of the problems of BIM to GIS data conversion. Louis [6] conducted further research on the feasibility of using BIM to measure various building health indicators. Pereira et al. [7] explored the impact of using BIM to improve building energy efficiency. Xiao et al. [8] established a conceptual model for PCP design using parametric design tools Dynamo and Revit. Mohammad et al. [9] developed an automated modeling system to facilitate integrated structural design and wind engineering analysis using BIM. The premise of BIM technology implementation requires a baseline integrating information integration, sharing and collaboration, namely BIM technology application standard system, to guide the application of BIM technology in practical projects. At present, the research on BIM standard system for underground engineering is relatively scattered and has not yet formed a system. In order to solve the problems, strengthen the applicability of BIM, and promote the development towards informatization, visualization, collaboration, standardization. This paper conducts preliminary exploration and application on the BIM standard system framework for underground engineering.

[a]yjt_12605@aliyun.com

2. Current Status of BIM Standard Systems

2.1. Current status of BIM standard systems Abroad

Table 1. The Development Status of BIM Standards Abroad.

Country	Time	Publishing agency	Name of Standard
USA	2015	NIBS	NBIMS-US V3
UK	2012	BIM Standards Committee for the Construction Industry	AEC(UK) BIM Standard for Revit
Finland	2012	Building SMART Finland Branch	Common BIM Requirements 2012
Norway	2013	Statsbygg	Statsbyggs BIM-manual V1.2.1
Japan	2012	JIA	JIA BIM Guideline
Singapore	2013	BCA	Singapore BIM Guide Version 2.0
South Korea	2010	Ministry of Land and Oceans	Architectural BIM Guideline

The current situation of BIM standards that have been published abroad is shown in Table 1. By summarizing and analyzing the published BIM standard systems abroad [10], it was found that they are mainly divided into two levels: firstly, aiming at national or industry level standards, represented by the NBIMS in the United States, providing standards and guidance for the implementation of BIM from two aspects: software technology and industrial implementation; Secondly, basing on a certain BIM software platform, with the goal of standardizing and unifying the implementation process of BIM projects, represented by the implementation guidelines based on specific software developed in the UK and Singapore.

2.2. Current Status of BIM Standard System in China

The "Unified Standard for the Application of Building Information Models" is the highest-level BIM standard in China, and the preparation of other standards must follow its provisions. It provides unified regulations for the establishment, sharing, and application of building information models in various stages of the full lifecycle of engineering projects, including model data, model exchange and sharing, model application, project or enterprise specific implementation, etc. In addition, it also includes two basic data standards: the "Building Engineering Information Model Storage Standard", corresponding to the IFC standard; The Classification and Coding Standards for Building Engineering Design Information Models, which corresponds to the IFD standard. The execution standards specify the specific content of model application, delivery, and other aspects during the design and construction stages.

The CBIMS standard system was proposed by the BIM research group at Tsinghua University, which is divided into three parts: technical specifications, solutions, and application guidance [11]. From the perspective of the CBIMS standard system framework, there are certain similarities between CBIMS and NBIMS, such as the relevant regulations made at the basic data and application levels. However, the difference lies in the emphasis on achieving standardization in the establishment and assembly of digital elements at the application level of CBIMS, in order to break the bottleneck of digital resources in BIM.

The current domestic BIM standard system can be divided into three levels: one is the BIM national standard system, which mainly refers to and draws on international BIM standards while taking into account domestic building regulations and construction management process requirements; The second is the CBIMS standard system, which mainly discusses the BIM standard system framework from the perspective of informatization and theoretical level; The third is the local or industry BIM standards, which mainly stipulate the unified application of BIM in different regions and industries.

3. Research on BIM Standard System Framework for Underground Engineering

The establishment of a standard system is the fundamental guarantee for the implementation of BIM technologies. In order to ensure the development of the BIM standard system framework for underground engineering within a reasonable range, the following compilation principles can be comprehensively considered: Firstly, the development of the BIM standard system framework for underground engineering should run through the full lifecycle of underground engineering, and must comply with China's national BIM standards system, while also balancing and coordinating with the technical standards of the underground engineering; Secondly, the established standard system must be complete, compatible, and scalable; Thirdly, the BIM standard system framework should guarantee that the professional information model shared with underground engineering is modified and improved, and its unique professional information model is supplemented and defined.

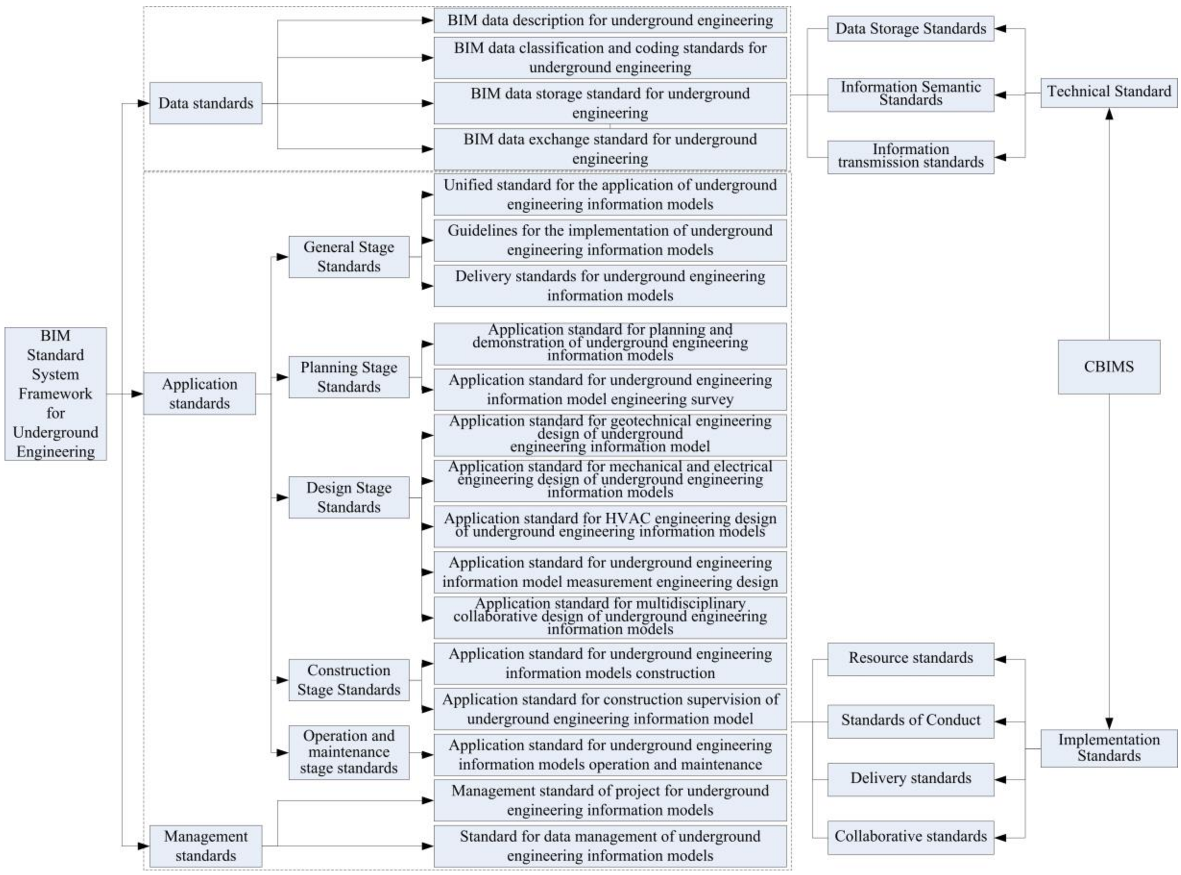

Figure 1. Framework diagram of BIM standard system for underground engineering.

The BIM standard system framework for underground engineering needs to comprehensively consider the overall planning of the project, multiple needs, and other aspects. It requires scientific classification, clear hierarchy, reasonable structure, and a certain degree of decomposability and scalability. At the same time, various standards within the standard system framework should be clearly divided according to content, coordinated and unified with each other, Easy to manage, meeting the full lifecycle application requirements of underground engineering project planning and argumentation, collaborative design, stability analysis, construction simulation, operation and maintenance. Overall, the establishment of the BIM standard system framework for underground engineering was based on data flow, work stages, professional application requirements, and management methods, with a focus on the full lifecycle technology application and management. It can be generally divided into three parts: BIM data standards, BIM application standards, and BIM management standards, which can be seen in Figure 1.

3.1. BIM Data Standard System for Underground Engineering

The BIM data standard system for underground engineering mainly provides standards for the standardization and consistency of data throughout its full lifecycle, facilitating the exchange and storage of BIM data, and achieving data sharing and reuse of BIM data based on different participants, work stages, and application platforms. In addition, it can also be used to guide and standardize professional software development. The BIM data standard system for underground engineering can be divided into: data description standards, classification and coding standards, storage standards, and exchange standards.

The data description standards, mainly used to standardize the semantic concepts in underground engineering, such as complete names, definitions, abbreviations, detailed descriptions, associated concepts, and their implementation in data storage and exchange standards, and need to correspond to classification and coding standards; The data classification and coding standards, mainly refers to the classification methods and coding rules of object entities and the information they carry in the underground engineering information model, which is the foundation for improving data availability and usage efficiency; The data storage standards, which used for storing data information throughout the full lifecycle, while promoting the application of BIM data at all stages, participants, and specialties. Specifically, based on the logical and physical organization of geometric and non-geometric information in BIM data defined by the resource layer and core layer in the IFC standard, it serves as the format for underground engineering BIM data. Then, using the external reference association mechanism developed by IFC, the semantics of underground engineering BIM information are linked to the IFC model to achieve effective storage of data information by extending the IFC standard; The data exchange standards, mainly applicable to information exchange and sharing among different professions and stages. To ensure that the information model data can be accurately and efficiently used by the data receiver after delivery and exchange, the consistency, coordination, and correctness of the data should be checked.

3.2. BIM Application Standard System for Underground Engineering

The BIM application standard system for underground engineering is mainly used to guide and standardize the application of BIM technology between different stages and professions, covering planning and argumentation, scheme comparison, collaborative design, analysis and optimization, construction organization, operation and maintenance, and other BIM technology usage guidelines. It can be divided into general stage, planning stage, design stage, construction stage, and operation and maintenance stage standards.

The general stage standards contain unified standards, implementation guidelines, and delivery standards for the application of underground engineering information models. Among them, the application of unified standards aims to standardize the basic requirements for the application of BIM technology in underground engineering, clarify common requirements for model creation, use, and management in each stage, ensure effective sharing and transmission of models and information in each stage, and focus on the work after the start of BIM technology, as well as guidance and specifications for software aspects; Implementation guidelines are used to guide the application and implementation of BIM models throughout the entire lifecycle of underground engineering, focusing on the preparation before the start of BIM technology and the preparation of hardware and personnel organization; The delivery standards are used to guide the flow and delivery process of information models for different professions at different stages, as well as the accuracy requirements for information models at outcome nodes. Relevant provisions for archiving during the design and construction stages are also included.

The planning stage standards include underground engineering information model planning and demonstration application standards, engineering survey application standards. Among them, the application standards for planning argumentation should be applicable to the application of BIM technology and the creation, use, and management of information models related to underground engineering planning argumentation and construction proposal; The application standards for engineering surveying can be divided into two categories: the application standards for engineering surveying and mapping geographic information models and the application standards for geological information models. The former is mainly used to standardize surveying and mapping geographic information models, and requires the collection, processing, and application of basic surveying and mapping geographic information data in underground engineering; The latter mainly specifies the basic content, modeling methods, image libraries, and quality evaluation of geological information models.

The design phase standards include underground engineering information model geotechnical engineering design application standards, mechanical and electrical engineering design application standards, HVAC engineering design application standards, non-standard engineering design application standards, measurement engineering design application standards, and multidisciplinary collaborative design application standards. Mainly used to guide and standardize the establishment, use, and management of information models within and between various professions, with special provisions for application platforms, model accuracy, flow delivery, quality evaluation, collaborative design, etc.

The construction phase standards include underground engineering information model construction application standards and construction supervision application standards. The construction application standards should contain the creation, use, and management of underground engineering information models in construction application management, deepening design, construction simulation, prefabrication, progress management, budget and cost management, quality and safety management, resource management, completion acceptance, and other aspects. The application standards for construction supervision should propose requirements for the creation, use, and management of underground engineering construction supervision information models from aspects such as data import, construction supervision control, and achievement delivery.

The operation and maintenance stage standards stipulate the application of BIM technology in the operation and maintenance phase of underground engineering, including personnel and equipment management, space management, maintenance management, safety and emergency management, etc.

3.3. BIM Management Standard System for Underground Engineering

The underground engineering BIM management standard system mainly includes underground engineering information model project management standards and data management standards, covering the organizational methods, process control, and information management of the entire process of underground engineering BIM project implementation, including implementation promotion, management process, responsibility division, policy guarantee, project information management regulations, and data security management requirements.

The underground engineering information model project management standards, which mainly standardize the organization and implementation process, including BIM implementation planning, implementation methods, responsibility allocation, policy guarantees, organizational models, and general guidelines for project information management; The underground engineering information model data management standard, which mainly responsible for managing the creation, use, and archiving of various types of data for underground engineering BIM projects, including the definition of roles

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and permissions, data exchange, data format, data usage, data processing, data archiving, and data security management requirements.

4. Analysis of Engineering Examples

Due to the large content of the framework, it is difficult for one or two projects to fully cover the entire content of the standard system framework. Therefore, this paper only explores the feasibility of the BIM standard system framework in underground engineering during the design stage of a certain underground station.

4.1. Application of storage standards

According to the analysis of storage standards earlier in this paper, the storage standard should adopt the IFC standard and achieve the storage of data information by expanding the IFC standard. Taking construction progress information as an example, in order to achieve three-dimensional visualization of the complexity of construction progress, a project progress information model was developed based on IFC unified expression. The algorithm flow structure of this model is shown in Figure 2.

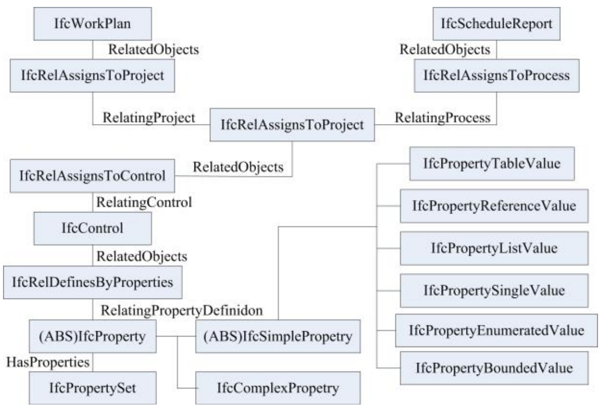

Figure 2. The algorithm flow structure of project progress information model.

In the progress control information model of this project, the IfcSchedulReport is used to describe the actual construction progress process, and the actual cost, resources, and quality management are also included in the IfcSchedulReport progress report. IfcScheduleDeviation, which describes progress deviation, mainly compares planned progress with actual progress and provides a basis for progress control. The relationship between the IfcRelAssignsToProject entity and the IfcWorkPlan entity can be established through the IfcRelAssignsToProject entity. On the other hand, the construction progress controlled can be described by IfcControl. Due to the complex nature of control, IfcProperty is used to describe the properties of the control. IfcPropertySet describes the performance that can be dynamically extended for construction. IfcSimpleProperty is used to describe the properties of an object, which derive properties that can be set by IfcPropertyBoundedValue etc. By developing an application based on a comprehensive progress information model, model information, including progress information, can be obtained for progress control.

4.2. Creation of engineering models

Classify and code the various components of the project in the early stage of model creation, determine storage standards, and facilitate professional communication, collaborative design, and division of work areas for engineering designers during the model creation process. Figure 3 and Figure 4 show the electromechanical pipeline and local enlarged entity model, respectively.

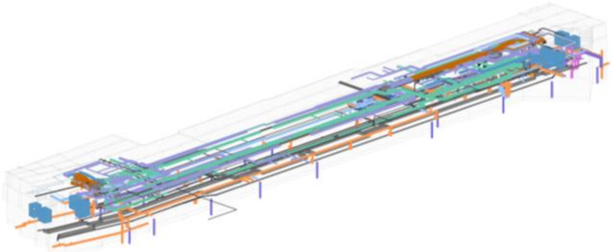

Figure 3. The mechanical and electrical pipeline information model.

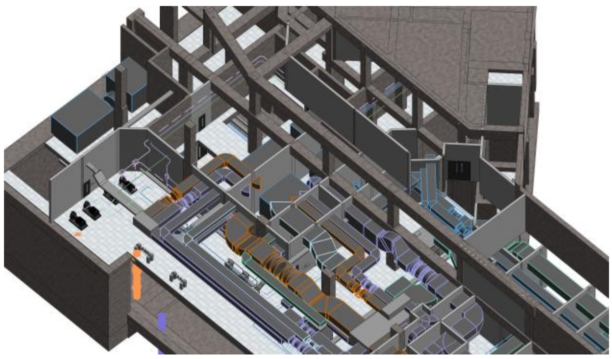

Figure 4. The local enlarged entity engineering information model.

This paper mainly examines the BIM multidisciplinary collaborative design application with collision inspection as the theme based on the multidisciplinary collaborative design standards in the standard systems. The summary of design conflicts and errors found during collision inspections in various disciplines is shown in Table 2. A total of 79 items were found, including 45 for architectures, 24 for structures, and 10 for pipelines. According to calculations, collaborative design and collision detection applications conducted under the multidisciplinary collaborative design standards can help save 48 days of project duration and 300 thousand yuan of material costs, indicating that the standard system has significant engineering value in saving project costs and duration.

Table 2. The summary of collision inspection results.

Speciality	Soft Collision	Hard Collision	Total
Architecture	21	24	45
Structure	13	11	24
pipeline	10		10
	Total		79

In addition, this paper compares the new ventilation system design mode developed based on Dynamo under the application standards of mechanical and electrical engineering with the traditional mode. Taking the ventilation system design of the high-voltage distribution room in this project as an example, the results are shown in Table 3.

Table 3. The time of each work stage under new and traditional modes (Minute).

Workflow	Parameter Extraction	Calculation	Calculation Sheet	Fan Selection	HVAC Information	Design	Dimension
New mode	0.1	0.1	0.1	0.1	0.1	10	2
Traditional mode	3	5	15	25	10	50	5

From Table 3, it can be seen that the new mode takes about 12 minutes, while the traditional mode takes about 113 minutes. The design efficiency of the new mode is about 9 times that of the traditional mode. It indicates that under the application standards of mechanical and electrical engineering design, combining BIM can significantly reduce mechanical labor and improve overall design efficiency.

5. Conclusion

In order to effectively enhance the intelligence construction capabilities of underground engineering and promote the practical application of BIM, the establishment of the BIM standard system framework is an urgent problem that needs to be solved. This paper studies the status of BIM standard system both domestically and internationally. Combined with the CBIMS, it studies the BIM standards for underground engineering and their system framework division from three levels: data standards, application standards, and management standards. This standard system framework conforms to the national BIM standards and specifications, has strong scalability, and can correspond to the technical standards and implementation standards of the CBIMS. Taking the BIM standard system framework for an underground engineering application as an example, case studies were conducted on the application of storage standards and the creation of models. The results show that through the application of the standard system framework established in this paper, the project has achieved significant improvements in progress management, collaborative design, and pipeline optimization during the BIM technology application process. However, the establishment and improvement of standards is a long-term task. On the premise of ensuring the scientific and practical nature of the standard system, it is necessary to optimize, revise, and supplement it in the later stage by combining practical application and experience summary of engineering projects. It is also necessary to keep up with the times, incorporate more new technologies and fields into the standard system framework, make the BIM standard system framework for underground engineering more and more perfect, and ultimately form a systematic system to achieve a positive cycle.

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