# Architecture Design of Intelligent Construction Data Management System Based on BIM

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**Abstract.** At present, the traditional construction industry is gradually transitioning towards intelligence, informatization, and greening. The intelligent construction technology based on Building Information Modeling (BIM) continues to penetrate into various stages of the construction life cycle, effectively improving the efficiency, quality, and sustainability of the construction industry. As the cornerstone of the intelligent construction system, data management is not only related to the efficiency and cost of intelligent construction, but also closely linked to process optimization, quality assurance, information security, decision support, and intelligent upgrading. This study sorted out the role of BIM technology in the entire process of construction and the problems faced by BIM data management, and established a unified, systematic, and scientific BIM intelligent construction information model. From the four levels of application, management, elements, and features, it mainly solves the problems of whether the top-level design is reasonable, whether the key application areas are covered, whether the application cycle and key technologies are focused, and whether the data sources and types are accurately classified in intelligent construction data management; On the basis of the data model, a BIM intelligent construction data management system was constructed, which manages the data system in four stages of the entire life cycle, namely design, manufacturing, construction, and operation, and explains its data system and management methods. Simultaneously analyze the problems and deficiencies in current BIM intelligent construction data management, and finally look forward to the development prospects of future data management systems.

**Keywords:** Data management; BIM; Intelligent construction; Life cycle

## 1 Introduction

Nowadays, the rapid development of information and artificial intelligence technologies is driving the transformation and upgrading of the construction industry. This accelerates the integration of digitalization, networking, and intelligence, thereby ensuring


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high-quality and sustainable development. Consequently, the concept of "intelligent construction" has emerged. The realization of this intelligent construction model is widely seen as an essential pathway for the construction industry's transformation and upgrading in the context of Industry 4.0, and an inevitable trend for achieving high-quality development in the industry [1]. In November 2022, the Ministry of Housing and Urban-Rural Development (MOHURD) selected 24 cities, including Beijing, Tianjin, and Chongqing, to carry out pilot projects for intelligent construction, actively exploring new pathways for the transformation and development of the construction industry [2].

BIM technology is widely used throughout all stages of the intelligent construction lifecycle, providing data and information across the entire lifecycle of engineering projects, including design, manufacturing, construction, and operation and maintenance. To optimize the construction process and standardize building quality, it is crucial to manage all data involved in smart construction, including BIM data. At present, intelligent construction data management faces challenges such as missing data, inconsistent data structures, and variations in data quality and accuracy. Data security and privacy protection are also significant issues. Additionally, BIM technology, as a core component of digital transformation in the engineering and construction industry, has long been heavily reliant on European and American BIM software, which has constrained the development of modeling large-scale models and data management [2].

The core essence of digital transformation for construction enterprises is to build construction data throughout the entire lifecycle, analyze and reuse this data, and ultimately achieve a data-driven digital operation model [3]. Data is the foundation of informatization. Currently, the data generated during the construction process is managed by different construction units and is used only for basic tasks such as documentation and project quantity calculations. As a result, the value of this data is significantly underestimated and fails to realize its full potential in project management [4]. In the management of building construction project quality, Hou Jie [5] and colleagues proposed using data warehouse technology to integrate a comprehensive quality information collaboration system. This would ultimately create a quality-focused information database to support the quality management of construction enterprises. In terms of data security management, Wang Jiye [6] and colleagues developed a blockchain-based data security sharing network system to address issues related to centralized DNS control and trust. Additionally, Deng Xiaohong [7] and others employed technologies such as digital watermarking, data encryption, and electronic signatures to address data security concerns for spatial geographic information in Nanjing. These measures aimed to protect data copyrights and provide preventive control over data. In terms of project schedule and cost, Zhang Lianying [8] and colleagues proposed an overall implementation plan for a BIM-based construction project schedule-cost collaborative management model. This approach provides both a theoretical foundation and technical support for developing an entity management system.

The above research focuses only on specific aspects or parts of the process in smart construction to improve data management, and does not achieve a high level of centralized management across the entire lifecycle of smart construction. To address this issue, this study constructs a unified, systematic, and scientific intelligent construction data and information model. Based on this model, it designs a BIM-based intelligent construction data management framework, which organizes the data system across the entire lifecycle—design, manufacturing, construction, and operation and maintenance. This framework explores an effective data management method that encompasses the entire project lifecycle.

## 2 BIM Intelligent Construction Data Information Modeling

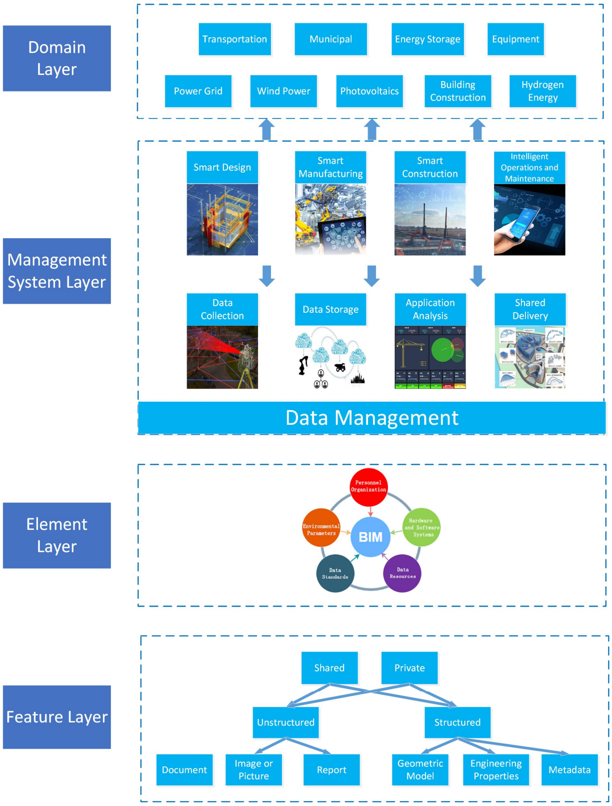


**Fig. 1.** BIM Intelligent Construction Information Modeling

A data information model refers to the processing of various data according to certain standards, and organizing and classifying it based on acquisition time and content. This approach aims to achieve data interconnection and interoperability across different industries, helping to establish a standardized data management system. Through a unified, systematic, and scientific intelligent construction data and information model, the quality and efficiency of design in intelligent construction can be significantly improved, construction management optimized, and the level of engineering operation and maintenance enhanced.

In this study, the BIM intelligent construction information model is divided into a four-tier hierarchy, as shown in Fig. 1. The first layer is the domain layer, which primarily describes the application areas of the information model, including housing, transportation, municipal infrastructure, power grids, wind power, and photovoltaic systems. The second layer is the management system layer, which is the core of the information model. It primarily addresses a series of key data management issues that the information model can solve across different phases of intelligent construction. Throughout the lifecycle of intelligent construction—encompassing intelligent design, intelligent manufacturing, intelligent construction, and smart operation and maintenance—information modeling can enhance the effective management of operational processes such as data collection, data storage, application analysis, and data delivery and sharing. The third layer is the element layer, which primarily describes the data source elements of the information model and the core role of BIM. This involves using BIM to integrate personnel organization, hardware and software systems, data resources, data standards, and environmental parameters. The data provided by these elements is then cleaned, integrated, and stored to form a unified data warehouse or data center, which is then supplied to the information model. The fourth layer is the feature layer, which primarily includes data sharing methods, data structures, and specific data formats.

## 2.1 Domain Layer

This information model focuses on the cutting edge of intelligent construction technology both domestically and internationally. It is grounded in practical experience and development needs in the field of intelligent construction and primarily supports data applications in sectors such as electric power, transportation, municipal infrastructure, housing construction, and energy storage.

## 2.2 Management System Layer

Data generated at each stage of the smart manufacturing lifecycle—comprising smart design, smart manufacturing, smart construction, and smart operation and maintenance—requires processes for data collection, storage, analysis, application, and delivery and sharing. Effective management of data resources throughout the data flow process. Data collection is the first step in the data flow process. Adhering strictly to standardized criteria during data collection can enhance the efficiency of the entire data flow. Data storage must ensure both data integrity and security while also meeting the requirements for data processing and analysis. Data analysis can monitor, evaluate, and predict construction status and processes to support project decision-making and optimization. Data sharing requires establishing unified data specifications and standards to enable integration and interoperability of data from different sources and types, achieving effective data sharing and exchange.

### 2.3 Element Layer

BIM technology spans the entire lifecycle of intelligent construction, encompassing not only spatial information such as the geometry, size, and location of the building but also non-geometric information like building materials, structural performance, and cost estimates. The integration and sharing of this information provide a solid foundation for intelligent construction. The element layer is categorized using BIM techniques to organize data sources based on personnel organization, software and hardware systems, data resources, data standards, and environmental parameters, thereby clarifying and specifying the data sources.

### 2.4 Feature Layer

The feature layer classifies the data involved in the information model based on data sharing methods, data structure, and specific formats. It distinguishes between multi-party shared data and internal professional data, structured and unstructured data, and specific formats such as documents, images, and reports.

## 3 BIM Intelligent Construction Data Management System

### 3.1 Data Management Framework

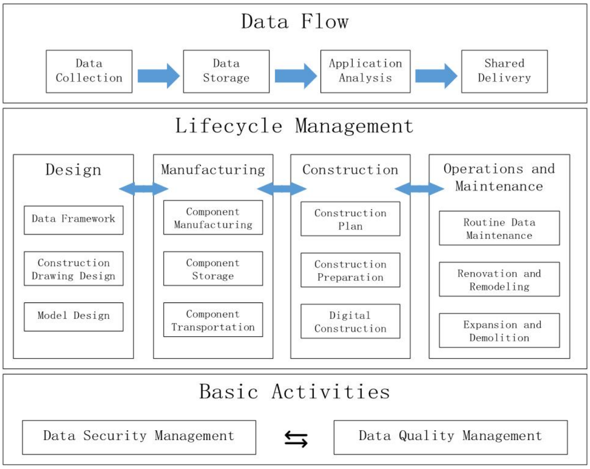


**Fig. 2.** Data management framework

This study describes a BIM-based data management framework for smart construction based on the aforementioned data and information model. It illustrates the interrelationships between various aspects of data management and clarifies the data management tasks in this field. As shown in Fig. 2, this data management framework is based on the management processes of data acquisition, storage, analysis, application, and delivery and sharing. It centers on full lifecycle management, which includes the design, manufacturing, construction, and operation and maintenance phases, with data security management and data quality management as foundational activities. In the full lifecycle, activities in the design phase include data architecture design, construction drawings, and model design. In the manufacturing phase, activities encompass component fabrication, storage, and transportation. During the construction phase, activities involve construction planning, preparation, and digital construction. In the operation and maintenance phase, tasks include daily data operations and maintenance, renovation and retrofitting, as well as expansion and demolition. These activities span the entire data lifecycle of smart construction, enhancing the understanding of management tasks and decision-making, and making the data more accessible and easier to use.

## 3.2 Data Flow System

### 3.2.1 Data Acquisition.

Data acquisition is a crucial component in implementing BIM intelligent construction. It primarily involves collecting data from various sensors, devices, and systems at the construction site and transmitting it to a data processing center for subsequent management and optimization. During data acquisition, considerations include the stability and real-time capability of data collection, its comprehensiveness and accuracy, as well as data security, privacy protection, flexibility, and scalability.

### 3.2.2 Data Storage.

Data storage involves storing information in various forms. Data storage objects include temporary files generated during data processing and information needed during processing. Analysis of the entire lifecycle of a construction project reveals that information types and data formats vary. Therefore, managing and storing this data in a structured manner to facilitate future use is one of the key functions of the data layer.

### 3.2.3 Analytical Applications.

Data analysis applications refer to the ability to perform basic functions such as querying, creating, updating, and deleting relevant information at the data layer. This ensures that different stages and participants can access the required data in a timely manner.

### 3.2.4 Delivery and Sharing.

Digital delivery refers to the use of BIM technology and other tools to provide construction units with digital delivery products and services. This approach addresses issues such as difficulties in data delivery and low utilization rates, creating new methods for data delivery. It aims to ensure the effective transmission and application of engineering information and achieve the digitization, integration, and visualization of completion delivery information. Data sharing enables different users to access and manipulate others' data, addressing the problem of data 'islands.' To facilitate data sharing, unified data standards need to be established. These standards can effectively resolve a range of issues and challenges in information management, significantly enhancing the management level of construction projects. The BIM data sharing and exchange technology route is illustrated in Fig. 3 [9].

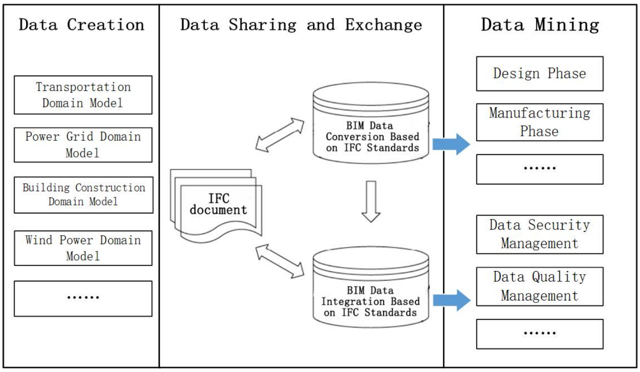


**Fig. 3.** BIM Data Sharing and Exchange Technology Route

## 3.3 Full Life Cycle Data Management

This paper divides the construction process of intelligent construction projects into four stages: design, manufacturing, construction, and operation and maintenance. Data management activities are conducted at each stage to ensure the smooth and efficient progress of the project and the effective utilization of data.

### 3.3.1 Design Phase Data Management.

The design phase is a crucial stage of the project and plays a decisive role in its overall success. Before entering this phase, it is essential to clearly understand the project's objectives and conduct a feasibility study. Relevant information needs to be collected, including the scope of the project's business and data, the surrounding market economic conditions, various associated costs, and safety and quality aspects. Finally, project analysis and decision-making are carried out to determine the specific construction plan.

In the design phase, the data architecture needs to be developed to map the data across the project and create a unified and consistent data view. Additionally, data modeling should be designed for construction solutions based on the specific project requirements. In the modeling process, designers from various disciplines can use Autodesk Revit series software to perform visual modeling of different buildings and structures. The collaborative capabilities of BIM-related software enhance the accuracy and convenience of the models created. In the design stage, it is also necessary to review the construction design drawings of the building project. This review includes not only the feasibility and rigor of the construction drawings but also checks for fire protection, civil defense, environmental protection, foreign-related issues, and aviation height impacts. Once the permits are obtained, bidding can proceed. The project will be subject to supervision regarding safety, quality, and other aspects. Additionally, relevant procedures for sewage discharge, environmental protection, temporary water, and temporary electricity must be completed. A project department should be established to organize and complete construction layout work, ensuring thorough preparation for the project's construction[10].

All data resources used in the above tasks must undergo data management. This involves establishing data standards and corresponding specifications for data architecture, construction drawing development, and data modeling. The goal is to ensure smooth data transfer between the business side and the manufacturing side.

### 3.3.2 Manufacturing Phase Data Management.

The manufacturing phase involves processing and producing buildings and components based on the design phase requirements. This includes working from design drawings, models, and specifications to process, produce, assemble, and test components. Quality control and standards monitoring are essential to ensure that components meet design specifications and provide accurate parts for subsequent construction. During the component production and manufacturing phase, the project is guided by lean construction theory. The BIM model established in the design phase is utilized through BIM technology for extraction and updating during the production phase, facilitating the information transfer between design and component manufacturing [11]. During the production and construction of components, adjustments to production volumes and standards can be made based on actual construction progress. This helps optimize material procurement and usage, reduces shortages or waste, improves manufacturing efficiency, and aims to achieve the ideal goals of zero defects and zero inventory. Data management enhances collaboration and information sharing among different teams, ensuring that everyone stays informed about the latest project status.

### 3.2.3 Construction Phase Data Management.

The construction phase involves applying the results of design and fabrication to the site, marking a crucial stage of the engineering project. During this phase, the construction team performs the construction and installation of buildings or structures based on the design drawings and manufactured components. Initially, it is essential to plan the utilization of the construction site according to the model and determine the construction plan. During the actual construction process, with the variety of component types involved, it is important to avoid errors such as using the wrong components or being unable to locate components. Therefore, real-time management of material resources at the construction site is essential. Utilizing BIM technology, construction progress data can be linked to construction objects, enabling visualization of construction data. This allows for real-time tracking of both construction progress and quality, and facilitates timely resolution of issues that arise during the construction process. BIM technology can simulate and analyze the construction plan, ensuring project quality and aiding in the optimal allocation of resources and space. This helps to eliminate conflicts and achieve the most effective construction plan and organization design. During the project construction process, it is also necessary for the construction team to adhere to the guidelines set out in the construction plan, provide adequate technical safeguards, and have professional supervisors conduct oversight and inspections based on the implementation of the design. Finally, adjustments to construction progress and quality are made based on site conditions, with enhanced safety management during the process to ensure that quality and progress remain unaffected. The data generated during the construction phase must undergo quality testing and analysis, including checks on data entry quality, data types, data formats, and data sources, to ensure it meets the data standards established during the design phase [12].

#### 3.2.4 Operation and Maintenance Phase Data Management.

After the building is constructed, it is necessary to operate and maintain the building project. The operation and maintenance phase is crucial for ensuring that the building or structure functions properly and remains sustainable over the long term. The operation and maintenance (O&M) phase is the longest stage in the building's entire life cycle, and it demands high accuracy and completeness in facility management data [13]. During this phase, the O&M team is responsible for daily management of the building, equipment maintenance, energy management, and other related tasks. The BIM model used during the construction phase can be directly applied to the operation and maintenance phase to facilitate data management. Daily monitoring of data quality is essential to ensure accuracy and reliability, along with regular assessments to enhance data quality. Data management during the operations and maintenance phase is crucial for the long-term use of a building project. It ensures proper building operation, reduces costs, improves efficiency, and minimizes adverse environmental impacts, all while protecting data security and privacy.

### 3.4 Assurance of Data Management Foundation

In addition to managing data at all stages of the entire life cycle of smart construction, basic data management tasks such as data quality management and data security management are also integral throughout the project.

#### 3.4.1 Data Quality Management.

Construction quality management is a crucial aspect of the construction process, directly affecting the overall quality of the building project. During construction, personnel must be aware of their responsibilities and obligations and adhere strictly to relevant construction regulations to ensure the safety and stability of the building [14]. In engineering projects, different construction stakeholders focus on various aspects of quality information. BIM-assisted quality management offers significant convenience to all parties involved. By leveraging BIM, quality management benefits from enhanced information flow, which improves efficiency, effectiveness, and comprehensiveness. Relying on BIM to transmit engineering quality information serves as an effective link between various stages, ensuring the integrity of the information while enhancing its accuracy and timeliness [15]. To achieve the accuracy, completeness, and consistency of BIM data, measures such as model review, model testing, and model coordination can be implemented.

### 3.4.2 Data Security Management.

Data security is fundamental to creating an intelligent construction environment, ensuring the integrity and confidentiality of data. In full life-cycle data management, data security encompasses the protection of all stakeholders, particularly regarding data that involves individuals' privacy rights. Attention must be given to all aspects of data flow, including data collection, storage, analysis, application, and sharing. As shown in Fig. 4, the following aspects need to be considered in managing data security:

- Privacy protection is necessary for data throughout the entire life cycle of intelligent construction.
- During data collection, security considerations may necessitate adjustments to data accuracy.
- In the data storage process, encryption should be used, and network security measures such as firewalls and intrusion detection systems should be implemented.
- When releasing and sharing data, manual scrambling or anonymization techniques can be applied.

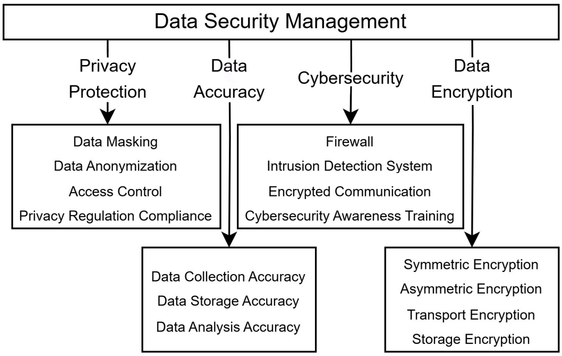


**Fig. 4.** Data Security Management

## 4 Conclusion and Outlook

Throughout the life cycle of intelligent construction, there are numerous participants, including design units, material suppliers, construction units, and operation units. When data and information flow and are shared among these participants, improper communication can lead to data loss or delays in transmission. Given that the BIM model can serve as a data carrier and technical support throughout the entire life cycle, this study focuses on BIM technology, a core tool in intelligent construction. It establishes a unified, systematic, and scientific framework for intelligent construction data management. By integrating BIM-based data and information models with full life-cycle data management, this framework aims to comprehensively manage data across various stages—design, manufacturing, construction, and operation and maintenance. It enhances capabilities in data collection, storage, analysis, and sharing. This approach not only improves project safety and cost-efficiency but also significantly reduces information transfer time and enhances project management efficiency. With the rapid advancement of new-generation information technologies and the expanding range of application scenarios, intelligent construction based on BIM technology will undoubtedly drive the construction industry toward higher levels of digitalization and intelligence.

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