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Research on the Innovation of Smart Construction Project Management Models Based on Big Data

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Abstract: With the accelerated digital transformation of the construction industry, the innovation of smart construction project management models based on big data has become a key pathway to improving efficiency and quality in engineering projects. This study focuses on the deep integration of big data technologies throughout the entire lifecycle of construction. By establishing dynamic data collection, intelligent analysis, and decision-support systems, it enables real-time monitoring and precise control of project schedule, cost, quality, and safety. The research proposes a data-driven collaborative management framework that effectively addresses the "information silo" problem inherent in traditional models, providing a replicable innovative paradigm for high-quality development in the construction industry.

Keywords: Big data; smart construction project; management model innovation

Introduction

Traditional construction project management models often face challenges such as information lag and low coordination efficiency when handling complex engineering tasks, thereby restricting the high-quality development of the construction industry. With the deep penetration of big data technologies, their massive data-processing and intelligent-analysis capabilities inject new momentum into project management. This paper focuses on management model innovation for smart construction projects based on big data, aiming to construct a data-driven dynamic management system to enhance management accuracy, optimize resource allocation, and promote the transformation and upgrading of the construction industry toward intelligent development.

1. Theoretical Foundations and Literature Review

1.1 Core Concepts and Connotations of Smart Construction

(1) Smart construction is a new construction model driven by digitalization and intelligence, integrating

technologies such as BIM, IoT, AI, and big data. Through the integration of full-lifecycle data, it enables collaborative management across the design, construction, and operation phases. For example, BIM is used to build three-dimensional visual models, IoT sensors collect real-time onsite data, and AI algorithms and big data analytics optimize resource allocation, thereby breaking information silos throughout the construction process[1].

(2) Compared with traditional construction models, smart construction demonstrates significant advantages in efficiency, cost, and quality. Traditional models rely on manual experience, feature fragmented processes, and suffer from delayed information transmission, often resulting in rework. In contrast, smart construction achieves dynamic monitoring through technological integration—for example, AI predicts construction risks and big data optimizes schedule planning. According to relevant studies, smart construction can shorten project duration by 15%–20% and reduce costs by approximately 10%.

1.2 Current Application Status of Big Data Technology in Project Management

(1) The data collection stage has formed a multi-dimensional system: sensors monitor concrete strength and equipment operating conditions in real time; drones capture panoramic images of construction sites to support schedule verification; BIM models integrate design drawings, material lists, and other static data, enabling the linkage of dynamic and static information.

(2) Data analysis focuses on optimizing the entire project lifecycle. Predictive algorithms estimate material demand and price fluctuations, optimization models adjust construction sequences, and risk warning systems identify safety hazards. For instance, a metro project used big data analytics to avoid pipeline-conflict risks in advance.

(3) Research hotspots at home and abroad center on building data-sharing platforms and optimizing AI algorithms, but limitations remain: domestic studies emphasize technical applications yet lack unified data-security standards, while international research focuses on theoretical innovation but shows limited applicability to local construction scenarios.

1.3 Limitations of Existing Project Management Models

(1) Linear management processes exhibit strong lagging effects. Under the sequential "design–construction–operation" model, design issues discovered during construction must be traced back and modified, causing schedule delays. For example, a residential project suffered a two-month delay due to rework caused by layout design defects.

(2) Significant data barriers exist among departments. Design teams use CAD drawings, construction teams rely on scheduling software, and operation teams use independent management systems. The incompatible data formats require manual conversion during information transfer, which easily leads to data distortion.

(3) Dynamic adjustment mechanisms are lacking. Traditional models follow the initial plan, unable to respond quickly to material price fluctuations, weather changes, and other unforeseen variables. For instance, a bridge project experienced a 12% cost overrun because the steel price increase was not addressed through timely procurement adjustments.

2. Construction of a Big-Data-Driven Smart Construction Management Model

2.1 Principles of Model Design

The design of the model should be guided by four core principles:

First, data connectivity, which aims to break data barriers among the design, construction, and operation phases and across departments, enabling seamless data flow throughout the entire lifecycle. Second, real-time performance, relying on IoT technologies to collect onsite data in real time, ensuring synchronized updates of progress and quality information to support dynamic adjustments. Third, traceability, which involves establishing a data-traceability mechanism that records the full process of data generation, transmission, and application, facilitating problem identification and responsibility attribution. Fourth, intelligent decision-making, which uses data-analysis results to generate precise recommendations, reducing reliance on manual experience and enhancing the scientific rigor and efficiency of decision-making.

2.2 Model Framework Design

(1) **Data Layer:** Centered on "BIM + IoT + GIS," this layer enables multi-source heterogeneous data collection and integration. BIM provides three-dimensional building models and design data; IoT

collects real-time data such as equipment operation status and environmental parameters through sensors and drones; GIS integrates geospatial information. Together, they transform structured data (e.g., material lists), semi-structured data (e.g., construction logs), and unstructured data (e.g., onsite images) into a unified format, laying the data foundation for subsequent analysis.

(2) **Platform Layer:** A cloud-platform architecture is used to build a centralized data-storage and processing hub, accompanied by a data-governance mechanism. The cloud platform supports massive data storage, high-performance computing, and multi-terminal access; meanwhile, data governance—through cleaning, standardization, and de-identification—ensures data quality and prevents redundant or erroneous data from affecting analytical results.

(3) **Application Layer:** This layer focuses on intelligent analytics in four core modules: schedule, quality, cost, and safety. The schedule module compares planned versus actual progress to identify delay risks; the quality module monitors material performance and construction-process compliance; the cost module performs real-time expenditure calculations and alerts users to overspending trends; the safety module analyzes onsite hazard data and issues timely warning notifications[2].

(4) **Decision Layer:** Supported by machine-learning algorithms, this layer enables dynamic optimization and risk prediction. By analyzing historical and real-time data, it dynamically adjusts construction schedules and resource-allocation plans while identifying risks such as safety incidents or cost overruns in advance, providing targeted decision support for project managers.

2.3 Key Technical Support

(1) **Big-data mining and analytical algorithms:** For example, deep-learning models can process onsite image data to detect construction-compliance violations; association-rule mining can identify correlations between material procurement volume and cost fluctuations, providing a basis for procurement-plan optimization and enhancing the efficiency of data-value transformation.

(2) **Digital-twin technology:** This technology creates a virtual model that mirrors the physical project, enabling simulations of construction workflows and equipment operating conditions to detect conflicts and process defects in advance. For instance, simulating the concrete-pouring process of a high-rise building can help optimize pouring sequences and timing, reducing rework on site.

(3) **Blockchain technology:** Through decentralized storage and encryption algorithms, blockchain ensures data immutability and trusted sharing, solving cross-department data-trust issues. In the material-supply chain, for example, blockchain records data related to procurement, transportation, and inspection, ensuring authenticity and reliability in material traceability.

3. Innovative Applications of the Big-Data- Driven Smart Construction Project Management Model

3.1 Innovations in Schedule Management

(1) **Real-time schedule monitoring and dynamic resource allocation:** IoT sensors collect real-time data on equipment operating conditions, worker attendance, and task-completion progress, which are transmitted synchronously to the cloud platform. Combined with BIM models, the platform visualizes deviations between actual and planned schedules. When delays occur in a particular task (e.g., rebar-tying progress lagging behind), the system automatically analyzes resource gaps and dynamically reallocates idle rebar workers and equipment nearby, thereby reducing resource waste and preventing schedule delays[3].

(2) **Schedule prediction model based on historical data:** By integrating historical schedule data from similar projects (such as construction durations for high-rise structural works or finishing stages) and combining variables such as geological conditions, weather data, and personnel allocation, a schedule prediction model is established using machine-learning algorithms. The model updates predictions in real time—for example, automatically extending the outdoor-work duration during heavy rainfall—and issues early warnings of potential schedule risks, supporting project managers in formulating appropriate response strategies.

3.2 Innovations in Quality Management

(1) **Automated quality-defect identification and traceability analysis:** Computer-vision technology and deep-learning algorithms analyze onsite images and video data to automatically detect quality defects

such as concrete cracks and excessive rebar spacing. By leveraging the traceability mechanism in the data layer, the system quickly identifies the stage in which the defect occurred (e.g., improper pouring procedures, incorrect material ratios) and the responsible personnel, providing a basis for quality rectification and accountability while reducing missed inspections and subjectivity associated with manual inspections.

(2) **Full-lifecycle tracking of material quality:** Blockchain technology records the complete lifecycle data of materials—from production and procurement to transportation and on-site usage—including material specifications, production batches, inspection reports, and entry dates. Managers can retrieve material information by simply scanning a code. When a batch of materials is found to be non-compliant, the system automatically traces the exact locations where the materials were used, enabling rapid identification of affected areas and preventing quality hazards caused by substandard materials.

3.3 Innovations in Cost Management

(1) **Cost-overrun early warning and optimization recommendations:** Real-time data on material procurement prices, labor costs, and equipment rental expenses are collected and compared with the budget. When the cost overrun of a specific work item reaches the warning threshold (e.g., exceeding 5%), the system automatically triggers an alert. Using big-data analytics to identify the causes of the overrun (such as material price increases or low labor efficiency), the system generates optimization recommendations—such as switching suppliers or adjusting construction teams—to help managers control costs in a timely manner.

(2) **Supply-chain collaboration and optimized resource allocation:** A collaborative supply-chain platform is established to integrate data from suppliers, construction enterprises, and logistics companies, enabling information sharing across all supply-chain stages. Through association-rule mining algorithms, the system analyzes the relationship between material demand and supply cycles—for example, predicting peak cement demand in advance and coordinating suppliers for early stock preparation to avoid schedule delays caused by material shortages. At the same time, resource allocation is optimized by reallocating idle construction equipment to related projects with urgent needs, improving overall resource-utilization efficiency.

3.4 Innovations in Safety Management

(1) **Personnel-behavior analysis and hazard early warning:** AI-enabled surveillance cameras analyze workers' behavior on construction sites to automatically detect dangerous actions such as failing to wear safety helmets or climbing structures improperly, and to push warning notifications to both managers and the individuals involved. Combined with data from environmental sensors (e.g., toxic-gas concentration, foundation-pit settlement values), the system provides early warnings of fire, collapse, and other safety hazards, enabling preventive measures to be activated in advance.

(2) **Intelligent decision support for emergency response:** An emergency-response database is developed to store information on handling procedures for various types of safety incidents (such as electric shocks and fires) as well as the locations of rescue resources (e.g., fire extinguishers and first-aid kits).

4. Implementation Path and Safeguard Measures for the Big-Data–Driven Smart Construction Project Management Model

4.1 Technical Implementation Path

(1) **Short term:** Data collection and foundational platform construction. Priority is given to deploying IoT sensors, drones, and other data-capturing devices to cover key dimensions such as progress, quality, and safety. Simultaneously, a cloud-based foundational platform is established, including the design of the data storage architecture and initial development of data-cleaning tools, enabling the preliminary integration and standardization of multi-source data.

(2) **Midterm:** Development of core modules and pilot applications. Focusing on progress, cost, quality, and safety, core management modules are developed with intelligent analytical functions (e.g., schedule prediction, cost early warning). One to two small- or medium-scale projects are selected for pilot implementation to verify the practicality of the modules. Based on pilot feedback, algorithmic models and user interfaces are further optimized to improve module adaptability.

(3) **Long term:** Full-process intelligence and ecosystem development. Data from all modules are integrated to achieve full life-cycle data interconnection.

Technologies such as digital twins and blockchain are introduced to enhance intelligent decision-making and data-security mechanisms. Collaboration with upstream and downstream enterprises in the industry chain is strengthened to build a data-sharing ecosystem, promoting large-scale adoption across the industry.

4.2 Management Safeguard Measures

(1) Organizational restructuring. A dedicated data management department is established to oversee data-standard formulation, platform maintenance, and cross-departmental data coordination. The rights and responsibilities between the data team and the design, construction, and operation departments are clearly defined to avoid fragmentation in data management.

(2) Standardized system development. Unified data-interface standards are formulated to achieve seamless integration among BIM, IoT, GIS, and other systems. Specifications for smart construction models are established to clarify data collection frequency, storage formats, and analytical indicators, ensuring data quality and consistency in application.

(3) Talent development and cross-departmental collaboration mechanisms. Training programs are offered to cultivate interdisciplinary talent in big data and construction, covering both technical operations and data-analysis capabilities. A cross-departmental collaboration mechanism is implemented, including weekly data-coordination meetings that facilitate real-time communication between design, construction, and data teams to resolve issues arising in data application.

Conclusion

As a core carrier of digital transformation in the construction industry, smart construction projects rely on innovative management models that directly influence industry efficiency and sustainable development. Through the deep integration of big-data technologies, this study establishes a new management system characterized by dynamic perception, intelligent decision-making, and coordinated optimization, effectively addressing information barriers and resource misallocation issues inherent in traditional models. Looking forward, with technological iteration and scenario expansion, smart construction will continue to drive the industry toward greater efficiency, sustainability, and lean development.

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