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Research and Application of Building Engineering Intelligent Review System Based on BIM and Rule Engine

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Abstract: The research aimed to construct an intelligent review system for construction projects based on Building Information Modeling (BIM) and rule engines. By establishing a BIM data standard system and utilizing Structured Naming Language (SNL) to formalize review rules, combined with model visualization and scene recognition technology, a cloud native platform with automated review capabilities has been developed. The pilot application shows that the system can effectively improve the efficiency and accuracy of planning and construction drawing review, providing a feasible technical solution for digital engineering review.

Keywords: Building Information Modeling (BIM); Rule engine; Intelligent review

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1. Introduction

With the deepening implementation of the "14th Five Year Plan" for the development of the construction industry and the announcement of the list of pilot cities for intelligent construction by the Ministry of Housing and Urban Rural Development in 2022, promoting the digital transformation and intelligent upgrading of the construction industry has become a clear direction for industry development. The traditional construction project review mode highly relies on manual interpretation of two-dimensional drawings, which has problems such as low efficiency, inconsistent standard implementation, and easy omissions, making it difficult to meet the higher requirements of modern construction industry system for quality and efficiency. Building Information Modeling (BIM) technology, as an important carrier of engineering digitization, has provided the possibility for achieving automation and intelligence in the review process. However, achieving machine understandable and executable expression of normative provisions, and building a review system capable of automatic reasoning and recognition, remains the core technical challenge currently faced. Therefore, researching intelligent review systems based on BIM and rule engines has urgent practical significance for implementing national intelligent construction policies, improving engineering review efficiency, and ensuring engineering quality and safety.

2. Overall architecture design of BIM intelligent review system

2.1. System architecture design principles

The architecture design of this system follows the principles of cloud native and modularization, ensuring that the platform has high scalability, flexibility, and reliability. The system is centered around microservices, encapsulating core capabilities such as data management, model parsing, and rule engines as independent services to achieve loose coupling and on-demand deployment of services. Openness is an indispensable principle, and the system supports international common data formats such as IFC, and is committed to cloud based lossless parsing and integration of multi-source heterogeneous BIM models, breaking the dependence on specific modeling software. This is in line with the requirements for data integration and interoperability in the optimization of digital review processes for construction drawings [1]. In terms of technical architecture, knowledge graphs are used as the underlying storage and organization method for BIM data, revealing the complex relationships between components through semantic modeling, providing an efficient data query and relationship reasoning foundation for intelligent review. Security runs through the entire design process, with full process permission control and operational traceability of model data to ensure the integrity and immutability of data during circulation and review.

2.2. Division of system functional modules

The system is divided into seven core functional modules based on the intelligent review business process. The BIM data standard service module is responsible for maintaining unified classification codes, attribute sets, and delivery standards, providing benchmarks for model quality. The model parsing and conversion module undertakes the cloud based lightweight parsing and conversion tasks of multi format BIM models, and outputs unified structured data. The model visualization and rendering module provides lightweight browsing, interaction, and linkage functions for web-based 2D and 3D models. The review rule engine module is the intelligent core of the system. Based on structured SNL rule descriptions, it performs automatic compliance checks and logical reasoning. Its precise analysis and execution of professional provisions such as fire safety regulations are the key technical support for achieving efficient and accurate review [2]. The review scenario management module utilizes graph technology to achieve pre identification and tagging of review scenarios, improving the efficiency of rule matching and review. The review result management and reporting module visualizes, categorizes, and generates reports on the review results. The system integration and interface module provides a standardized channel for data exchange and business process integration between the platform and external systems, such as CIM platform, project management system.

3. BIM data standards and model processing techniques

3.1. Construction of BIM data standard system

The BIM data standard system is the cornerstone for ensuring information interoperability and automated review. The system is built around a unified component classification and coding rule, clarifying the identification and organizational logic of various model elements. The attribute parameter standard defines inherent information such as material and size of components, and extends the attributes that need to be filled in by the design end, standard attributes directly extracted from the model, and derived attributes obtained through geometric and business rule deepening calculations. The definition of these calculated attributes is crucial for achieving automated review of architectural design specifications [3]. The model geometry standard standardizes the geometric representation methods and spatial relationships of components, ensuring visual consistency and computational accuracy of the model. The data format and exchange standards have established an open data environment centered around

IFC, supporting cross platform, full lifecycle information lossless transmission. This comprehensive standard framework provides a unified data specification for model quality assessment, engineering quantity statistics, and full process collaboration, which is a prerequisite for achieving intelligent review.

3.2. Cloud parsing and storage technology for multi format models

Faced with multi-source heterogeneous BIM model data, cloud parsing technology is committed to achieving format generalization processing that is decoupled from the native modeling software environment. The core of this technology is to deeply parse the data structures and encoding methods of mainstream formats such as RVT and DGN, and convert them into a unified intermediate data format within the system. Synchronize the simplification and optimization of model data during the parsing process, and improve network transmission and parsing efficiency by removing redundant information, optimizing data organization and compression techniques. At the data storage level, the system breaks through the limitations of traditional relational databases or pure file storage, explores the lightweight and flat transformation of IFC standards, and innovatively adopts knowledge graph technology for the organization and management of BIM data. This graph-based storage maps components, attributes, and their complex relationships to nodes and edges, providing efficient support for semantic based complex queries, rapid extraction of sub models for business scenarios, and deep relational reasoning. To ensure the security and credibility of data during this process, distributed ledger technology can be introduced to authenticate key operations and enhance the credibility of review results, thereby greatly improving the flexibility, security, and intelligence level of data utilization [4].

4. Rule engine and intelligent review method

4.1. Structured expression of multiple review rules

4.1.1. Specification description method based on SNL

To achieve machine-readable and executable functionality, the review rules are formally described using Structured Naming Language (SNL). This method converts design specifications written in natural language into standardized computer statements, clearly defining the types of components, key attribute requirements, and spatial and logical relationships that must be satisfied between components in the model. For example, the review provisions for fire separation distance can be transformed into logical assertions that measure and compare the geometric positional attributes of specific component categories (such as walls, doors, and windows). This unified description format based on SNL provides precise and error free instruction input for the review rule engine, which is the core technical foundation for achieving a leap from manual interpretation to automated and intelligent review. Its purpose is to solve the efficiency bottleneck and subjective deviation problems caused by relying on manual item by item verification in the traditional review process, ensuring the consistency and ambiguity of machine understanding of normative provisions [5].

4.1.2. Construction and management of review rule library

The construction of the review rule library began with a systematic review of mandatory provisions and industry standards in stages such as reporting for construction and construction, and reviewing construction drawings. Collaborating with experts in the professional field and BIM engineers, the selected articles are translated and structured using SNL language to form an initial set of atomic rules. The rule library adopts a hierarchical classification architecture for management, which can be organized in multiple dimensions based on professional fields (such as architecture, structure, fire protection), applicable stages, and regulatory sources, supporting efficient retrieval and reuse of rules. The rule library management system provides version control, state management, and dependency analysis functions for rules, ensuring that relevant rules can be quickly located and iterated during specification updates, maintaining the timeliness and accuracy of the rule library. This systematic rule management mechanism is crucial for responding to dynamic updates of normative provisions and ensuring the authority and compliance of review criteria [6]. It is an institutional guarantee for the reliable operation and industry recognition of intelligent review systems, providing dynamic knowledge support for the continuous evolution of intelligent review.

4.2. Review the scene recognition and reasoning mechanism

4.2.1. Scene feature extraction and tagging

The foundation of reviewing scene recognition lies in transforming complex review articles into computable scene features. By deeply analyzing the semantics of the text, extracting the professional fields involved, target component types, key attribute constraints, and spatial or logical relationships between components, a feature triplet centered on "subject relationship object" is formed. These features define specific review contexts, such as "evacuation stairs–minimum net width–greater than or equal to the specified value". After uploading the model, the system scans and matches the BIM model based on a predefined scene feature classification system, identifies local parts of the model that match specific feature combinations, and automatically attaches corresponding scene labels to them. This tagging process logically aggregates originally scattered components based on review intent, laying the foundation for subsequent targeted and efficient rule execution. Its effectiveness has been verified in practical projects such as the Nanjing Construction Drawing BIM Intelligent Review System, significantly improving the automation level of review [7].

4.2.2. Model mapping and review reasoning

The effectiveness of scene recognition heavily relies on the graphical representation of BIM models. Model visualization transforms traditional BIM data into a semantic network consisting of "nodes" (representing component instances) and "edges" (representing relationships between components). This transformation explicitly expresses and stores complex relationships such as component properties, spatial topology, and system associations. In the review reasoning stage, the rule engine does not need to directly process the original geometric model, but operates on the labeled scene subgraphs. The engine traverses nodes and edges in the graph to verify whether their attributes meet the conditions specified by SNL rules, and uses graph query and inference algorithms to discover implicit associations and conflicts. For example, by analyzing the topological relationship between fire zones and evacuation routes, automatic inference of whether evacuation distances are compliant can help systematically identify and warn of complex spatial logic problems that are easily overlooked in traditional manual reviews [8]. This graph-based reasoning mechanism significantly enhances the ability and efficiency of reviewing complex spatial and logical relationships.

5. System implementation and pilot applications

5.1. Development of BIM intelligent review platform

5.1.1. Implementation of platform core function modules

The platform is based on a microservice architecture and integrates seven core functional modules to support the entire process of intelligent review. The data standard service module maintains component classification, coding, and attribute rules, providing a unified benchmark for model quality. The model parsing service realizes cloud conversion and lightweight processing of multi-source BIM formats, and outputs structured model data. The model rendering service provides online browsing and interaction capabilities for 2D and 3D models in a web environment. The rule engine service serves as the system brain, loading and executing structured review rules based on SNL language. The scenario management service utilizes knowledge graph technology to achieve automatic recognition and tagging of review scenarios. Review and analyze the coordination of various modules in the service, and perform specific compliance checks and conflict detection. The results reporting service visualizes the review results and generates structured review reports. Each module works together through standardized interfaces to form a complete automated review loop, marking a profound transformation of the construction drawing review mode from traditional manual led to intelligent and systematic direction [9].

5.1.2. Application of 2D and 3D graphic modeling linkage technology

To solve the problem of disconnection between 2D drawings and 3D models in traditional review, the platform has implemented deep 2D and 3D model linkage technology. This technology automatically extracts the type, position, and size information of components such as walls, doors, and windows in CAD drawings through drawing element recognition algorithms. Establish precise spatial correspondence between 2D graphics and 3D model components using coordinate mapping relationships. Reviewers can select specific elements on the 2D drawing, and the system automatically locates and highlights the corresponding model components in the 3D view, synchronously displaying all their attribute information. This technology not only greatly facilitates the consistency review of graphics and models, enabling the rapid detection and localization of design conflicts and expressions that do not match, but also provides an intuitive and efficient human-computer interaction interface for core review functions. This technology demonstrates significant advantages in dealing with specialized reviews involving complex spatial relationships, such as compliance verification of sponge city facility layout and vertical design. It can effectively assist reviewers in understanding design intent and verifying technical details, improving the accuracy and efficiency of the entire review process [10].

5.2. Pilot application and effect analysis

5.2.1. Pilot program for review of regulatory and construction applications

During the planning and application stage, the system conducted pilot applications for the issuance of construction project planning permits. The pilot focuses on automated verification of key planning indicators such as building area, building height, plot ratio, and green space ratio. The platform automatically extracts the geometric and attribute information of relevant components by parsing the BIM model submitted for construction, and performs indicator calculation and compliance comparison based on preset SNL rules. The application results show that the system can quickly and accurately complete the review of various planning and control indicators, transforming the large amount of repetitive work that originally relied on manual accounting into an automated process that can be completed in seconds. This not only significantly improves the efficiency of initial review of construction materials, reduces repeated modifications caused by human calculation errors, but also provides objective and quantitative technical review basis for planning and management departments, strengthening the scientific and standardized nature of planning and management.

5.2.2. Pilot project for construction model review

The pilot project for construction drawing review mainly focuses on compliance inspections with mandatory regulations such as fire safety, civil air defense, and structural safety. The platform has loaded a review rule library for local standards such as the "Design and Delivery Standards for Building Information Modeling", which systematically reviews the integrity of BIM model components, design depth, and implementation of regulatory provisions during the construction phase. The pilot verified the effectiveness of the system in detecting common design issues such as integrity of fire compartments, insufficient evacuation width, and inadequate fire resistance limits of components. Through automated review, a large amount of basic and standardized specification clause inspection work can be efficiently completed, allowing reviewers to focus their energy on more complex engineering judgments and design optimization suggestions. This effectively enhances the comprehensiveness and accuracy of construction drawing review, providing a powerful technical tool for ensuring project quality and safety from the source.

5.3. System performance and economic benefit analysis

5.3.1. Achievement of main technical indicators

System performance is measured through a series of quantifiable technical indicators. In terms of model processing capability, the platform has successfully achieved cloud parsing and lightweight conversion of BIM models generated by mainstream software such as Revit and ArchiCAD, supporting smooth online browsing of GB level models. The rule engine has efficient reasoning ability and can complete rule matching and result output in seconds for typical review scenarios containing hundreds of components. The system supports concurrent user access and maintains response times in sub seconds, ensuring a collaborative review experience for multiple users. In terms of accuracy, the structured rule expression and graph-based reasoning mechanism based on SNL significantly improves the accuracy of the system's review of clearly defined normative provisions compared to traditional manual sampling, especially in the verification of spatial relationships and quantitative indicators, demonstrating stable and reliable performance.

5.3.2. Economic and social benefit evaluation

The application of this system has generated significant comprehensive benefits. At the economic level, automated review significantly reduces the time cost of manual verification of drawings and specifications, freeing reviewers from repetitive labor and focusing on higher value technical decisions, directly reducing the manpower investment and time cycle of project review. Early detection and correction of design errors have avoided rework and changes during the construction phase, resulting in significant indirect economic benefits. In terms of social benefits, the system has improved the standardization and transparency of the review process, enhanced the ability to control engineering quality, and helped prevent safety risks from the source. Its promotion and use have promoted the deep application of BIM technology and the digital transformation of the construction industry, providing key technical support for building a collaborative, efficient, and intelligent new construction model.

6. Summary

A set of intelligent review methods and technical systems based on BIM and rule engines have been systematically constructed to meet the practical needs of intelligent review in construction engineering. The research has established a system architecture centered on cloud native and openness, and developed BIM data standards covering component classification, attribute parameters, and data exchange, laying the foundation for information interoperability and automated review. By introducing SNL language to achieve structured description of review rules and combining knowledge graph technology for semantic storage and scene recognition of BIM models, the accuracy and efficiency of review reasoning have been effectively improved. On this basis, the BIM intelligent review platform developed integrates core functions such as multi format parsing, rule engine, and 2D/3D linkage, forming a complete review loop. The pilot application in stages such as planning and construction drawing review has shown that the system can significantly improve review efficiency and quality, reduce labor costs and error rates, and demonstrate good technical feasibility and application value. This research achievement provides a practical and feasible technical path and practical reference for promoting the intelligent transformation of construction project review, and has positive significance for promoting the digital development of the construction industry.

Disclosure statement

The author declares no conflict of interest.

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