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BIM-Based Low-Carbon Design and Operation & Maintenance Practices for the Full Life Cycle of Buildings in the Jidong Region

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Abstract

Against the backdrop of green and low-carbon development in the construction industry, the Jidong region-as a major industrial hub in northern China-has made the management of carbon emissions across the entire building lifecycle a key focus of industry development. Drawing on research conducted under the Undergraduate Innovation and Entrepreneurship Training Program, this paper examines typical buildings in the Jidong region and deeply integrates BIM technology into the entire lifecycle of architectural design, construction, and operations and maintenance. By leveraging the information integration, visualization analysis, and simulation optimization capabilities of BIM models, this study explores low-carbon implementation pathways for each stage of the building lifecycle. It proposes BIM-based low-carbon application solutions tailored to the regional characteristics of the Jidong region, providing technical references and practical insights for achieving the "dual carbon" goals in regional construction.

Keywords

BIM Technology; Building Lifecycle; Low-carbon Design; Low-carbon Operation and Maintenance; Jidong Region.

1. Introduction

With the comprehensive advancement of China's "Dual Carbon" strategy, the construction industry-as a key sector for carbon emissions-is inevitably undergoing a low-carbon transformation across its entire lifecycle. The Jidong region has developed a unique architectural layout and usage characteristics driven by industrial growth. Building types encompass a variety of forms, including commercial, industrial, and residential structures. However, due to the influence of the regional climate and energy structure, energy consumption and carbon emissions during the design, construction, and operation and maintenance phases are particularly prominent issues, and traditional building management models are no longer sufficient to meet low-carbon development requirements.

As a core tool for the digital transformation of the construction industry, BIM technology enables information sharing, collaborative management, and simulation optimization across the entire building lifecycle, providing an effective approach to addressing the challenges of low-carbon control at each stage of construction. This paper examines the actual conditions of building development in the Jidong region and, based on the practical application of the Guanglianda series of BIM software, explores low-carbon application methods for BIM technology across the design, construction, and operation and maintenance phases from a full building lifecycle perspective. It aims to develop a BIM low-carbon application plan tailored to the region's characteristics, thereby supporting the green and low-carbon development of the construction industry in the Jidong region.

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2. Research Foundation and BIM Application Framework

2.1 Research Foundation

This Supported by the Hebei Provincial Department of Education's Undergraduate Innovation and Entrepreneurship Training Program, this study uses typical buildings in Tangshan City, located in the eastern Hebei region, as a practical case study. Leveraging software such as Guanglianda GTJ Civil Engineering Quantity Surveying, GQI Mechanical and Electrical Quantity Takeoff, GCCP 6.0 Cloud Cost Estimation, and the Carbon Emissions Quantification Cloud Platform, this study completed foundational tasks including BIM model construction, engineering quantity takeoff[4], cost estimation analysis, and carbon emissions calculation. It provides practical technical support for the low-carbon application of BIM technology throughout the entire building lifecycle.

2.2 Framework for Low-Carbon Applications of BIM Technology

By integrating the characteristics of each phase of a building's lifecycle with the architectural development needs of the Jidong region, this framework establishes a three-phase BIM-based low-carbon application framework covering "design, construction, and operations and maintenance." Centered on a BIM model that integrates information across all disciplines, this framework leverages the model's capabilities-including information integration, clash detection, simulation analysis, and data verification-to optimize low-carbon design solutions during the design phase, implement low-carbon construction management during the construction phase, and achieve low-carbon energy consumption management during the operation and maintenance phase. Ultimately, this framework enables precise control of carbon emissions and promotes low-carbon development throughout the entire building lifecycle.

3. Design Phase: Optimization of Low-Carbon Building Solutions Using BIM

The architectural design phase serves as the starting point for managing carbon emissions across the entire building lifecycle, directly determining the baseline for carbon emissions during subsequent construction and operation and maintenance phases. This study utilizes BIM technology to construct a multidisciplinary information model and optimizes low-carbon design solutions across three key areas: building layout, building envelope, and MEP systems. All optimization measures take into account the climatic characteristics of the Jidong region-marked by cold winters and a long heating season-while aligning with requirements for the application of low-carbon materials and technologies.

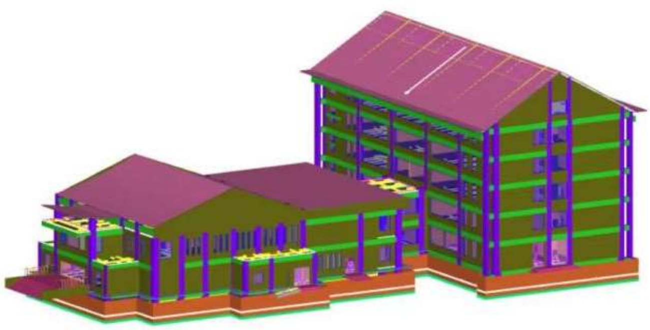

Fig. 1 Full Professional BIM Model Rendering

Using Guanglianda's GTJ and GQI software, a multidisciplinary BIM model was created covering architectural, civil, plumbing, HVAC, and electrical/lighting systems. This model integrates key information such as the properties of low-carbon building materials, energy consumption parameters of energy-efficient equipment, and regional climate data. Through the visualization capabilities of the

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BIM model, we conducted an intuitive analysis of the building's spatial layout, daylighting and ventilation conditions, and the routing of MEP systems. This identified potential issues in the design phase that could lead to high energy consumption and carbon emissions, thereby providing direction for optimizing low-carbon solutions.

(1) Regarding building layout optimization, BIM models are used to simulate natural lighting and ventilation effects. By incorporating the solar angles and wind patterns characteristic of the Jidong region, the placement, dimensions, and spacing of windows are optimized to maximize the use of natural energy. This reduces energy consumption requirements for heating, lighting, and ventilation systems while also controlling the window-to-wall ratio to minimize thermal bridges and improve the building's overall thermal performance.

(2) For low-carbon design of building envelopes, performance parameters and carbon emission attributes of various low-carbon insulation materials are imported into the BIM model[3]. Materials suitable for the climate of the Jidong region-such as autoclaved aerated concrete blocks, rock wool insulation boards, and triple-pane ultra-clear insulated glass-which feature low thermal conductivity and low carbon emissions, are prioritized. The insulation design of exterior walls, doors, windows, and roofs is optimized to enhance the overall thermal performance of the building envelope.

(3) When planning low-carbon mechanical and electrical systems, utilize the spatial positioning and clash detection functions of the BIM model to optimize the layout of mechanical and electrical piping and ductwork, reducing their length and the number of bends to minimize energy losses during system operation. Simultaneously, prioritize the selection of low-carbon, energy-efficient equipment such as energy-saving air conditioners and ground-source heat pumps. By integrating building functional zoning, pre-configure zone control schemes for the mechanical and electrical systems within the model, laying the foundation for precise energy consumption management in subsequent phases.

4. Construction Phase: BIM-Based Management of Low-Carbon Construction

Carbon emissions during the construction phase primarily stem from the consumption of construction materials, energy use by construction equipment, and on-site construction management. This study leverages the collaborative management and simulation optimization capabilities of BIM technology, combined with carbon reduction requirements such as sourcing materials locally and using low-carbon materials, to implement low-carbon control measures during the construction phase and reduce carbon emissions throughout the process[5].

Based on the BIM model and integrated with the Guanglianda GCCP 6.0 cloud-based cost estimation platform, precise quantity takeoff for the construction project is completed, generating a detailed list of construction material requirements to avoid waste caused by estimation errors. Simultaneously, the BIM model records the entire lifecycle of construction materials-including procurement, transportation, and usage-prioritizing local, low-carbon, and eco-friendly building materials to reduce carbon emissions from material transport. For key materials such as rebar and concrete, the BIM model optimizes cutting plans and pouring paths; for low-carbon materials like autoclave-cured aerated concrete blocks and bamboo-wood composites, specialized construction application plans are developed to improve the overall utilization rate of all materials.

In the optimization of construction equipment and processes, integrate the construction schedule to rationally plan the arrival times, usage locations, and operating durations of construction equipment within the BIM model, thereby avoiding equipment idling; select construction equipment with appropriate energy consumption, prioritizing new energy and low-energy-consumption equipment. BIM technology is utilized to simulate and analyze construction processes, identify conflicts and inefficiencies, and optimize workflows to reduce material and energy waste caused by rework. Leveraging the visualization and collaborative management capabilities of BIM models[2], material storage, site layout, and construction access routes are optimized to minimize material handling distances. Information sharing among all construction stakeholders is facilitated to improve communication efficiency, thereby achieving low-carbon and high-efficiency operations on-site.

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5. Operations and Maintenance Phase: BIM-Based Energy Management for Low-Carbon Buildings

The operation and maintenance phase accounts for the highest proportion of carbon emissions throughout a building's entire life cycle. The Jidong region experiences long, cold winters and hot summers, resulting in high heating and cooling loads for buildings; therefore, low-carbon management during the operation and maintenance phase is crucial for achieving overall carbon reduction in buildings. This study uses the BIM information model as the foundational data carrier. By integrating a carbon emissions measurement cloud platform with building performance simulation and analysis tools, and incorporating concepts for the application of new energy sources such as solar photovoltaics and solar water heating, it establishes a management system for energy consumption estimation, carbon emissions assessment, and low-carbon optimization during the operation and maintenance phase[1].

By integrating the BIM model with the Guanglianda carbon emissions measurement cloud platform and the building performance analysis platform, and importing static baseline data-such as building envelope parameters, MEP equipment selection parameters, and HVAC and lighting system configurations-this study simulates and quantifies energy consumption levels and total carbon emissions during the O&M phase, taking into account the climatic characteristics and regional energy structure of the Jidong region. Through statistical analysis of carbon emissions across different functional zones and energy-consuming systems, identify key areas with high energy consumption and emissions during the O&M phase, providing data support for the formulation of targeted carbon reduction measures.

Regarding low-carbon optimization during the operation and maintenance phase, leveraging the information integration and simulation capabilities of the BIM model, the project optimizes operational strategies for building energy systems by zone and time period. By aligning with building usage requirements, it establishes reasonable energy management plans to reduce unnecessary energy consumption, particularly developing tailored low-carbon operational strategies to address the heating demands of the Jidong region. Utilize the BIM model to centrally manage the models, parameters, locations, and system configurations of MEP equipment, establishing comprehensive equipment information archives to provide foundational data support for subsequent O&M management, maintenance planning, and energy efficiency comparison analyses.

To address the low-carbon retrofitting needs of existing buildings in the East Hebei region, we conduct simulation analyses of retrofit schemes-such as improving the thermal insulation of building envelopes, replacing energy-saving equipment, and integrating renewable energy systems-based on BIM models. We quantitatively compare the energy-saving effects and carbon reduction benefits of different schemes to select the optimal retrofit solution that is both technically feasible and economically viable, thereby providing precise technical guidance for the green and low-carbon retrofitting of existing buildings.

6. The Practical Value of BIM Technology in Low-Carbon Applications Throughout the Building Lifecycle

The application of BIM technology to low-carbon design, construction, and operation and maintenance throughout the full life cycle of buildings in the Jidong region has not only enabled precise control of carbon emissions at every stage of construction but has also driven the digital and green transformation of the regional construction industry. Its practical value is primarily reflected in three aspects.

(1)Technical Value: By leveraging BIM's information integration and collaborative management capabilities, information silos across all phases of the building lifecycle have been broken down, enabling coordinated low-carbon management across all stages and enhancing the scientific rigor and precision of building carbon emission control.

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(2) Practical Value: Leveraging the practical application of the Guanglianda software suite, a BIM-based low-carbon implementation plan tailored to the regional characteristics of the Jidong area has been developed, providing a replicable and scalable practical framework for the low-carbon development of various building types within the region.

(3)Industry Value: This initiative has driven the deep integration of BIM technology with low-carbon development in the construction sector, facilitating the transition of the construction industry in the Jidong region from traditional high-energy-consumption and high-carbon-emission models to digital and low-carbon models, thereby supporting the regional construction industry in achieving its "dual carbon" goals.

7. Conclusion and Outlook

This paper takes typical buildings in the Jidong region as its research subject. Building on the research conducted under the Undergraduate Innovation and Entrepreneurship Training Program, it integrates BIM technology into the design, construction, and operation and maintenance phases of a building’s entire life cycle, exploring low-carbon application pathways and practical implementation plans for each phase. The study demonstrates that BIM technology can effectively address issues such as information silos and imprecise control in managing carbon emissions throughout a building’s entire life cycle. Through the model’s information integration, simulation optimization, and collaborative management functions, it enables design optimization during the architectural design phase, process control during construction, and energy consumption management during operation and maintenance, ultimately achieving low-carbon development across the building’s entire life cycle. In the future, BIM technology can be further integrated with emerging technologies such as the Internet of Things (IoT), big data, and digital twins to build a low-carbon intelligent management platform for the entire building lifecycle, enabling real-time monitoring, dynamic early warning, and intelligent optimization of carbon emissions; simultaneously, the BIM-based low-carbon application scheme developed in this study can be extended to a wider range of building types in the East Hebei region, continuously refining a low-carbon building technology system tailored to regional characteristics, and providing stronger technical support for the green, low-carbon, and high-quality development of the construction industry in the East Hebei region.

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