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Construction of a Green Evaluation System for Prefabricated Buildings Based on BIM Technology from the Perspective of Carbon Footprint

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Abstract: Driven by the goal of carbon neutrality, prefabricated buildings, as an important form of green construction, have become a key focus in the study of lifecycle carbon footprint management. Based on this, this paper starts from the perspective of carbon footprint and combines the digital and visual advantages of BIM technology to construct a green evaluation system for prefabricated buildings. It explores the carbon emissions in each stage of the building and proposes corresponding improvement measures, aiming to provide necessary references for the low-carbon transformation of prefabricated buildings.

Keywords: Carbon footprint perspective; BIM technology; Prefabricated buildings

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1. Introduction

Under the background of global climate change, the construction industry, as a major source of carbon emissions, is in urgent need of decarbonization transformation. Prefabricated buildings, characterized by their standardized design and factory production, are regarded as a key to reducing on-site pollution. BIM technology, by constructing a three-dimensional digital model, can achieve seamless integration of design, construction, and operation and maintenance data and provide technical support for accurately tracking carbon emissions. Thus, it can effectively promote the transition of prefabricated buildings towards the goal of "zero-carbon construction" and provide a scientific basis for the low-carbon development of the industry.

2. Framework construction of the green evaluation system for prefabricated buildings based on BIM technology

2.1. Design of the indicator system

2.1.1. Primary indicators

Based on the framework of the whole-lifecycle theory, the green evaluation system for prefabricated buildings driven by BIM technology has established the following four primary-level evaluation dimensions: resource consumption, environmental impact, economic benefits, and technological innovation [1]. The resource consumption dimension systematically characterizes the utilization efficiency of materials, energy, and water resources throughout the entire lifecycle of a building, highlighting the orientation of resource conservation. The environmental impact dimension strengthens the goal of low-carbon environmental protection by quantifying carbon emission intensity, pollutant emission control levels, and ecological impact effects. The economic benefits dimension achieves dynamic synergy between economic sustainability and environmental benefits by comprehensively calculating the cost-benefit of the entire lifecycle and the economic value of carbon emission reduction. The technological innovation dimension drives a technology-led green transformation by measuring the breadth of BIM technology application, the maturity of intelligent management, and the ability to innovate in processes. These four dimensions are intercoupled and organically coordinated. Together, they construct a systematic evaluation framework that covers the entire chain of "design–production–construction–operation and maintenance," ensuring the scientific and systematic nature and practical operability of the evaluation results.

2.1.2. Secondary indicators

Under the systematic support of the primary evaluation framework, the secondary indicators are scientifically broken down into quantifiable operational dimensions. The resource consumption dimension is further divided into material utilization rate, the proportion of renewable energy, and the rate of water resource recycling. The environmental impact dimension covers carbon emission intensity per unit area, construction waste recycling rate, and indoor environmental quality indicators [2]. The economic benefit dimension includes the full-lifecycle cost, carbon trading revenue, and operation and maintenance energy-saving benefits. The technological innovation dimension involves BIM model accuracy, the coverage rate of intelligent management systems, and the innovation index of prefabricated construction technology. The above-mentioned secondary indicators, by accurately measuring the efficiency of resource utilization, the intensity of environmental load, the economic return benefits, and the level of technological advancement, provide a rigorous basis for the construction of tertiary indicators, thus systematically ensuring the clear-cut hierarchy and application-oriented nature of the evaluation system.

2.1.3. Tertiary indicators

As the refined implementation units of the evaluation system, tertiary indicators focus on standardized parameters that can be quantitatively monitored, ensuring the precision and operability of the evaluation process. In the dimension of resource consumption, key indicators include the reuse rate of prefabricated components, the proportion of solar water heating systems, and the utilization of non-traditional water sources [3]. The environmental impact dimension comprises the carbon emission simulation value during the design phase ($kgCO_2/m^2$), the dust emission concentration during the construction phase (mg/m^3), and the energy consumption intensity during the operation and maintenance phase ($kWh/m^2 \cdot year$). The economic benefit dimension involves the payback period of initial investment, the economic benefit of carbon emission reduction ($yuan/tCO_2$), and the proportion of reduced equipment failure rate. The technological innovation dimension covers the synchronization rate of BIM models with IoT data, the coverage rate of automated production lines, and the number of new connection node developments. The above-mentioned indicators precisely characterize the green performance of the entire lifecycle of a building through structured numerical values, providing a scientific and quantifiable evaluation benchmark for the low-carbon practice of BIM-empowered prefabricated buildings. This effectively supports the refined management and continuous optimization of green buildings.

2.2. Evaluation model and method

The green evaluation system for prefabricated buildings based on BIM technology constructs a systematic evaluation model by integrating dynamic carbon footprint accounting, multi-source weight allocation, and a comprehensive evaluation mechanism. The carbon footprint accounting module relies on the BIM platform and uses the lifecycle assessment method to extract structured data such as material quantities, component geometric parameters, and process parameters from the entire lifecycle dimension, ranging from raw material extraction, production and transportation, construction and installation to operation, maintenance, and demolition. It also couples with the regional carbon emission factor database to dynamically quantify the energy consumption intensity and total carbon emissions of each stage, forming a dynamic carbon emission inventory covering the entire lifecycle of the building [4,5]. In the weight determination phase, a strategy combining the analytic hierarchy process and the judgment of industry experts is adopted. By constructing a multi-dimensional judgment matrix that includes resource consumption, environmental impact, economic benefits, and technological innovation, the weight coefficients of indicators at each level are calculated to ensure that the weight allocation is both theoretically rigorous and practically applicable. In the comprehensive evaluation stage, the fuzzy comprehensive evaluation method or the TOPSIS method is preferred. The former deals with the fuzziness in the evaluation process through membership functions and is suitable for complex systems with multiple indicators and levels. The latter, based on the principle of sorting by the ideal solution, scientifically ranks the schemes by calculating their proximity to the best and worst solutions. Both methods can effectively integrate the BIM data characteristics and the weight system to output a comprehensive score of the green performance of prefabricated buildings and optimization paths, providing a precise and operable theoretical basis and practical support for low-carbon construction decision-making.

3. Key empowerment evaluation paths of BIM technology for prefabricated buildings from the perspective of carbon footprint

3.1. Design phase

Starting from the perspective of carbon footprint management, BIM technology, with its digital integration characteristics, provides a systematic optimization path for the design phase of prefabricated buildings, focusing on two major dimensions: component-level detailed design and dynamic carbon emission simulation. In terms of component optimization, the BIM model, relying on its three-dimensional parametric design mechanism, achieves the standardization and precise configuration of prefabricated building components. Specifically, by constructing a standardized component database and setting key parameters such as geometric dimensions, connection node topology, and material properties, the system can generate multiple-scheme decomposition models. Considering transportation loading constraints and lifting process requirements comprehensively, the system evaluates different decomposition strategies from multiple dimensions, covering key indicators such as component production efficiency, on-site assembly complexity, and material loss rate [6]. For example, simulation analysis based on the loading rate of transportation vehicles can optimize the volume of components to reduce the frequency of transportation, effectively reducing carbon emissions in the transportation phase. Meanwhile, the standardized component design significantly improves the reuse rate of factory molds, reducing energy consumption and construction waste generation in the production phase, thus achieving a substantial reduction in the lifecycle carbon footprint.

In the carbon emission simulation aspect, BIM technology deeply integrates a dynamic quantification module, which supports multi-dimensional comparison of carbon emissions for different design schemes. This module extracts data on component material quantities, construction process parameters, and energy consumption from the BIM model and couples with a regional carbon emission factor database to calculate the total carbon emissions across all stages, including design, production, transportation, and construction in real time. By parametrically adjusting core variables such as structural systems, material types, and connection methods, it generates comparative analysis curves of carbon emissions, providing data support for design decision-making [7]. Typical application cases include comparative analysis of the lifecycle carbon emissions of steel and concrete structures, as well as quantitative assessment of the impact of different insulation materials on energy consumption during the operation and maintenance phase of buildings. This drives the design mode to transition from experience-based to data-driven low-carbon transformation. This process not only enhances the precision of carbon emission reduction in the design phase but also constructs the theoretical framework and practical path for carbon management across the entire chain of prefabricated buildings.

3.2. Production phase

Based on the theoretical framework of carbon footprint assessment, BIM technology drives the low-carbon transformation of the production phase of prefabricated buildings through the construction of a data interaction system and a dynamic monitoring mechanism. In terms of data integration, the BIM model is dynamically coupled with the factory production system throughout the entire process, such as size specifications, material properties, and connection node topology. The geometric parameters of components are transmitted in real time to the numerical control production line through a standardized interface, accurately guiding automated cutting, welding, and assembly processes, effectively suppressing material waste caused by human-induced deviations. Meanwhile, the Internet of Things sensor network deployed at the production site continuously collects dynamic data such as equipment operating conditions, raw material consumption rates, and finished product pass rates, which in turn calibrates the production parameters in the BIM model, forming a closed-loop optimization mechanism of "design-manufacturing" [8]. For example, when the actual steel reinforcement quantity deviates from the model-predicted threshold, the system automatically triggers the adaptive adjustment of the reinforcement scheme to avoid material redundancy. If the mold wear rate exceeds the preset standard, the BIM model dynamically optimizes the maintenance cycle to reduce energy losses caused by unplanned shutdowns. In the carbon emission accounting aspect, the BIM platform integrates modules for real-time energy monitoring and dynamic correction of carbon factors to ensure high-precision quantification of carbon emission data. The intelligent metering terminals configured on the production line, including electricity meters and gas meters, continuously record energy consumption data at the process level. Coupled with the regional power grid carbon emission factor database, this enables real-time dynamic calculation of carbon emissions per component. When the energy structure of the factory changes, the system immediately updates the carbon emission factors and calibrates the accounting model to eliminate evaluation deviations caused by static factors. This dynamic control system not only makes the carbon footprint of the production phase visible and traceable but also provides precise data support and a theoretical basis for corporate process optimization decisions and energy structure transformation.

3.3. Transportation and construction phase

Starting from the theoretical framework of carbon footprint management, BIM technology drives the low-carbon control of the transportation and construction phases of prefabricated buildings through the collaborative mechanism of intelligent transportation route optimization and 4D construction process simulation. In terms of transportation optimization, the BIM platform integrates geographic information systems and real-time traffic flow data to build a dynamic route-planning model. Based on the size, weight, loading sequence, and transportation constraints of components, the model generates multiple route plans and quantifies the fuel consumption intensity and total carbon emissions of each plan. By comparing the congestion index of highways and urban roads and the carbon emission coefficient per unit distance, the model recommends route optimization plans that avoid peak traffic periods, effectively reducing additional energy consumption during idling [9,10]. Meanwhile, by optimizing loading strategies based on the size characteristics of components, the model improves vehicle space utilization, reduces transportation frequency and total mileage, and directly cuts the carbon footprint of the transportation phase. In the construction simulation aspect, the 4D construction simulation technology of BIM integrates the time dimension and resource scheduling data to realize the virtual rehearsal of the entire construction process. The system generates dynamic simulations of key processes such as component hoisting and node connection based on the BIM model, identifying structural collision conflicts and process interference risks in advance to avoid material waste and machinery idling caused by on-site rework. Specifically, by simulating the match between the working range of tower cranes and the storage position of components, the system optimizes the layout of the construction site to reduce secondary handling. By parametrically adjusting the working sequence of multiple trades, it eliminates process interference and reduces energy consumption. This "rehearsal-optimization" mechanism promotes a shift in construction carbon emission management from passive statistics to active control, significantly enhancing the carbon emission reduction efficiency and management precision of prefabricated buildings throughout their entire lifecycle.

3.4. Operation and maintenance phase

The deep collaborative integration of BIM and the Internet of Things (IoT) constructs a systematic support path for the full-lifecycle carbon management of prefabricated buildings during the operation and maintenance phase. Relying on a smart sensor network, the BIM + IoT integrated platform collects real-time data on the operation of building equipment, environmental conditions, and energy consumption, dynamically mapping this data to the BIM model to form a multi-dimensional real-time data layer. Through the spatial topological association mechanism of the BIM model, the system precisely binds energy consumption data to specific spatial units and equipment attributes, enabling targeted identification of high energy consumption areas. Coupled with a regional power grid carbon emission factor database, it quantifies the carbon emission intensity and distribution characteristics of each link in real time. When sensors detect abnormal fluctuations in the energy consumption of lighting circuits, the BIM model can immediately associate the type of lighting fixtures, their operating duration, and the corresponding carbon emissions, providing a basis for optimizing maintenance decisions, such as adjusting the timing of lighting on and off or implementing energy-saving equipment replacements [11,12]. At the same time, the facility management database, using the BIM model as a data carrier, integrates the full-lifecycle information of equipment, typically including purchase time, maintenance logs, and replacement cycles. Coupled with energy consumption monitoring data, it constructs a dynamic carbon footprint tracking system. This system supports the generation of carbon emission analysis reports based on multiple dimensions, such as time series, spatial distribution, and equipment categories, intuitively presenting the evolution patterns and key driving factors of carbon emissions during the operation and maintenance phase. For example, by comparing the carbon emission data of air-conditioning systems over different years, it is possible to quantitatively assess the effectiveness of energy efficiency improvements or the impact mechanisms of equipment aging on the carbon footprint. This provides empirical support for formulating refined low-carbon maintenance strategies, such as optimizing equipment start and stop parameters and promoting the application of distributed renewable energy sources, thereby achieving dynamic regulation and continuous optimization of carbon emissions during the operation and maintenance phase of prefabricated buildings.

4. Conclusion

In constructing the green evaluation system for prefabricated buildings based on BIM technology, by quantifying carbon emissions throughout the entire lifecycle and integrating multi-source data and dynamic models, the green evaluation can be transformed from being "result-oriented" to "process-controlled." This significantly enhances the accuracy of carbon emission accounting, thereby helping to achieve the ultimate goal of emission reduction for prefabricated buildings.

Disclosure statement

The author declares no conflict of interest.

References

[1] Shi Z, Zou E, Pi J, et al., 2025, Analysis of Carbon Footprint Model of Buildings Based on BIM. Building Mechanization, 46(04): 47–50.

[2] Li J, 2024, Analysis of Carbon Emissions and Carbon-Reduction Strategies in the Entire Life Cycle of Prefabricated Buildings. Building Safety, 39(11): 30–35.

[3] Yang W, Song P, Chen Z, et al., 2024, Research on Carbon Footprint of Prefabricated Concrete Buildings in the Materialization Stage Based on BIM Technology. Zhejiang Architecture, 41(02): 65–69.

[4] Song P, Lv Y, Qian Y, et al., 2023, Design and Application of BIM-Based Carbon Emission Calculation System for Prefabricated Buildings. Science & Technology Bulletin, 39(11): 28–32 + 39.

[5] Cheng X, Fu J, Xu J, et al., 2023, Influence of Component Parameters of Prefabricated Concrete Frame Structures on Carbon Emissions. Journal of Zhejiang Sci-Tech University (Natural Science), 49(03): 404–414.

[6] Gu Y, Hao J, Zhang J, et al., 2024, Analysis and Discussion on the Revision of Evaluation Indicators for Green Building Materials of Ready-Mixed Mortar. Concrete World, (12): 67–73.

[7] Tang Y, Mao X, Li J, 2024, Research on Carbon Footprint Accounting of Pallet Unit Box Life Cycle. Packaging Engineering, 45(21): 233–239.

[8] Zhou Q, Liu M, Zhang L, et al., 2024, Research and Practice on Carbon Footprint Accounting of Leather Products under the "Dual Carbon" Goal. Leather Science and Engineering, 34(06): 40–46.

[9] Tan X, Li H, Wang Z, et al., 2024, Analysis of Changes in the Carbon Footprint of Wheat Life Cycle in Different Provinces from 2015 to 2020. Chinese Journal of Agrometeorology, 45(08): 809–821.

[10] Zheng P, 2024, Carbon Footprint Measurement and Evaluation Methods of Photoelectric Display Products. Metrology & Measurement Technology, 51(07): 104–106.

[11] Yu M, Wang F, 2024, Comparative Assessment of the Life-Cycle Carbon Footprint of Hydrogen-Based Green

Industrial Products and Traditional Processes. Jiangsu Science & Technology Information, 41(07): 122–127.
[12] Tong S, Zhao K, Liang H, et al., 2024, Research on Carbon Footprint of Magnesium Alloy Rear-Hinged Door Based on Life-Cycle Assessment. Foundry Engineering, 48(02): 53–56.