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A Review of the Development of Green Construction Evaluation Systems

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Abstract

With the continuous emergence of green construction evaluation standard systems across various regions, in-depth exploration and research in related fields remain ongoing. This paper explores existing evaluation indicator systems in different countries, introducing prominent evaluation frameworks and typical assessment methodologies within both domestic and international contexts. It highlights current research hotspots, identifies existing limitations, and outlines future development trends in this discipline.

Keywords

Green Building, Assessment System, Development Trends

1. Introduction

As a major consumer of resources and a significant contributor to environmental impacts, the green transformation of the construction industry has become a pivotal component of global sustainable development strategies. With the acceleration of urbanization, the proliferation of construction projects has been accompanied by escalating energy consumption, resource depletion, and environmental pollution. In this context, the concept of green construction has emerged and gradually transitioned from theoretical exploration to practical implementation.

The construction phase, as a critical stage in the building life cycle, directly determines the overall environmental performance of structures through its level of sustainability. However, the widespread adoption of green construction practices faces multifaceted challenges: inconsistent evaluation criteria, limited operational feasibility, and incomplete quantitative indicator systems hinder the large-scale implementation of green construction. Notably, existing evaluation frameworks predominantly rely on static assessments, inadequately addressing the dynamic and complex nature of construction processes, which leads to discrepancies between evaluation outcomes and actual environmental benefits.

Internationally, evaluation systems such as the UK's BREEAM, the US's LEED, and Canada's GBC have established relatively mature frameworks, serving as benchmarks for green building assessments. In China, regulatory documents including the Green Olympic Building Assessment System and the Green Building Evaluation Standard have been promulgated, laying the foundation for a green building evaluation system with Chinese characteristics. Nevertheless, compared to advanced international frameworks, China's green construction evaluation system exhibits evident deficiencies in dynamic assessment, techno-economic balance, and data acquisition methodologies.

2. Overview of Green Construction Evaluation

2.1 Definition and Characteristics of Green Buildings

The concept of green building was initially proposed by Robert Vale and Brenda Vale in the 1990s. Its core definition encompasses five essential elements: energy efficiency, environmental coordination, efficient utilization of building materials, occupant comfort, and whole-life cycle integrated design.

With the advancement of research, the evaluation framework for green buildings has evolved beyond conventional metrics such as ventilation, energy conservation, and daylighting. Current assessments now emphasize comprehensive coordination between buildings and natural ecosystems. China's Assessment Standard for Green Building (GB/T 50378-2019) explicitly states: "Throughout a building's operational lifecycle, its construction and subsequent maintenance services must achieve resource conservation, energy consumption reduction, pollution mitigation, while simultaneously ensuring occupant safety and comfort requirements." Academic consensus maintains that an ideal green building should minimize resource and energy consumption while providing healthy, safe, and comfortable environments, ultimately achieving harmonious coexistence with surrounding ecosystems.

Green buildings exhibit three prominent characteristics. First, resource conservation is the foundational criterion, encompassing the efficient use of energy, land, water, and building materials. Second, in terms of environmental performance, green buildings must strictly control pollutant emissions and implement proper treatment to minimize negative impacts on the surrounding ecosystem. Finally, green buildings must meet user demands for safety and comfort, ensuring high-quality living conditions while advancing green economic development.

2.2 Definition and Scope of Green Construction Evaluation

With the deepening of sustainable development concepts, the connotation of green construction has progressively expanded to form a comprehensive system encompassing efficient energy/resource utilization, waste reduction, and environmental coordination in building practices. Correspondingly, evaluation mechanisms must evolve to reflect this holistic perspective. Empirical evidence indicates that while civilized construction practices have achieved significant progress, they merely constitute a component of green construction. Green construction mitigates noise and dust impacts on surrounding communities through closed-site operations and site greening initiatives, while respecting residents' living patterns via rational work schedule arrangements. However, the absence of a systematic evaluation framework has confined green construction to conceptual discussions rather than institutionalized constraints. Furthermore, its higher technical and material requirements have reduced implementation incentives for construction enterprises.

Current construction workflows primarily follow contractual regulations, design blueprints, predetermined plans, and national technical quality standards, with green construction lacking mandatory regulatory support. Under prevailing bidding models, green construction fails to emerge as a core competitive factor for enterprises, often being overlooked due to practical cost-benefit considerations.

Fundamental challenges stem from insufficient national promotion efforts and the absence of an evaluation system. Establishing a robust green construction assessment mechanism would effectively guide engineering practices and clarify operational specifications. Government authorities could thereby implement targeted supervision, compelling contractors to rectify non-compliant project elements while enhancing the penetration and effectiveness of green construction. Undoubtedly, green construction represents the future trajectory of the construction industry. Its standardized development will elevate technical management capabilities, strengthening the competitiveness of domestic construction enterprises. Consequently, constructing a scientifically sound green construction regulatory framework carries significant strategic importance.

3. Current Green Construction Evaluation Systems at Domestic and International Levels

3.1 International Green Construction Evaluation Systems

The concept of green construction has a longer history of development in Western developed countries, where the establishment of green building evaluation index systems has become relatively comprehensive. Notable examples include: the UK's BREEAM (Building Research Establishment Environmental Assessment Method), the U.S. LEED (Leadership in Energy and Environmental Design) program, and Canada's GBC (Green Building Challenge). While these evaluation systems exhibit distinct characteristics, they all possess established implementation foundations and thus retain significant reference value.

3.1.1 BREEAM Environmental Assessment Method in the United Kingdom

(1) **Historical Development:** BREEAM (Building Research Establishment Environmental Assessment Method), established by the Building Research Establishment (BRE) in the UK in 1990, is the world's first green building assessment system. Initially designed for office buildings, it has since expanded to cover diverse building types, including commercial and industrial structures. Its environmental principles have evolved and deepened through practical application, and its evaluation outcomes are recognized for their scientific rigor and authoritative credibility.

(2) **Evaluation Framework:** BREEAM comprises three core modules:

Core Performance Elements (environmental impacts across the building lifecycle),

Design and Implementation (green design-related factors),

Management and Operation (post-construction operational considerations).

These modules address nine critical dimensions:

Project Management (compliance with regulations and standards),

Livability (indoor/outdoor environmental quality),

Energy (consumption and carbon emissions),

Transportation (logistical planning),

Water (resource utilization),

Materials (selection and ecological impact),

Land Use (planning and functional efficiency),

Regional Environment (ecological conservation),

Pollution (air/water pollution mitigation).

(3) **Assessment Outcomes:** BREEAM dynamically assigns indicator weights based on building-specific characteristics. A comprehensive evaluation integrates performance metrics, design parameters, and construction practices, resulting in four certification tiers: Outstanding, Excellent, Very Good, and Pass, all certified by the Building Research Establishment (BRE). Its globally influential framework has served as a reference template for green building standards in numerous countries, underscoring its pivotal role in advancing sustainable construction practices worldwide.

3.1.2 Leadership in Energy and Environmental Design (LEED) Program in the United States

(1) **Developmental Evolution:** The Leadership in Energy and Environmental Design (LEED) program, established by the U.S. Green Building Council (USGBC) in 1995, represents the world's first market-oriented green building rating system. The LEED 1.0 version was launched in 1998, followed by the optimized LEED 2.0 iteration in 2000, which refined its indicator evaluation methodology. This system promotes green transformation in the construction industry through technical standardization, enhancing both environmental performance and economic value of buildings. Its multi-version framework covers new construction and existing buildings, emphasizing market-driven incentives to advance sustainable practices. LEED has evolved into a globally recognized certification framework and a mainstream benchmark for green building standards.

(2) **Evaluation Mechanism**: LEED employs a modular assessment structure with a total score of 64 points, organized into nine core categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation, Regional Priority, Integrative Process, and Location and Transportation. Each category contains detailed sub-items. Scoring is based on factual data, requiring compliance with mandatory prerequisites before assigning incremental points. Weightings dynamically reflect priorities in green construction practices (e.g., energy efficiency accounts for over 25% of the total score). Its self-assessment model ensures

flexibility, adapting to diverse building types, including commercial, residential, and institutional structures.

(3) **Evaluation Outcomes:** LEED's assessment system provides a detailed scorecard, with comprehensive results categorized into four certification levels: Platinum (≥80 points), Gold (60–79 points), Silver (50–59 points), and Certified (40–49 points). The scorecard transparently discloses evaluation specifics. Renowned for data transparency and technical rigor, LEED has certified over 180,000 projects globally. Its tiered certification criteria have been adopted by international organizations such as ISO, serving as a critical reference for green building investments, policy formulation, and sustainability benchmarking.

3.1.3 Canada's GBC Green Building Challenge

(1) **Evolutionary Development:** Initiated in 1996, the Green Building Challenge (GBC) established the GBTOOL assessment system after two years of practical validation, with its core strengths lying in building energy efficiency and environmental performance evaluation. In 1998, it pioneered the first international green building assessment framework. The 2000 updated version incorporated research contributions from 19 participating nations, advancing global collaborative standardization efforts.

(2) **Assessment Mechanism:** The GBC-2000 system is characterized by high flexibility and low regional dependency. It constructs a comprehensive evaluation framework through five modules (regional context, technological advancement, systemic integration, value orientation, and cultural considerations), organized into five hierarchical levels, six functional domains, and over 120 indicators. Core quantitative metrics focus on resource consumption, environmental load, and indoor environmental quality, while economic performance and pre-occupancy management remain qualitative references. The updated version emphasizes building lifecycle assessments across office, educational, and residential typologies, supported by six operational subsystems.

(3) **Evaluation Outcomes:** The GBTOOL employs a weighted cumulative scoring method, synthesizing hierarchical weight allocations and percentage-based calculations to yield logically structured results. However, its dynamic weight assignment mechanism exhibits subjective biases, and the complexity of the indicator system may introduce assessment uncertainties, potentially compromising result credibility. Future refinements should prioritize empirical optimization of weighting rules to enhance quantitative objectivity.

These assessment systems demonstrate distinct temporal origins, developmental trajectories, and practical applications. Given China's construction industry context, their reference values vary significantly. A critical analysis is required to extract adaptable methodologies, refine China's green construction assessment system based on national conditions, and thereby promote the continuous development of domestic green buildings.

3.2 Green Construction Evaluation Systems in China

The evolution of China's green building evaluation system demonstrates a catching-up trajectory characteristic of late-developing economies. Although the localization process of green building concepts commenced relatively late, resulting in certain lags in the systematic construction of corresponding evaluation criteria, China has progressively established a multi-tiered assessment mechanism with regional characteristics through the integration of technical specifications from developed countries and the implementation of locally adaptive optimizations. This dynamic development model, grounded in the transformation of international experience and the incorporation of national conditions, is driving the transition of the evaluation system toward a scientific paradigm of whole-life cycle management.

3.2.1 Green Olympic Building Assessment System (GOBAS)

(1) **Developmental Evolution:** Developed to support the sustainable construction goals of the 2008 Beijing Olympics, the Green Olympic Building Assessment System (GOBAS) was jointly initiated in 2002 by the Ministry of Science and Technology and the Beijing Municipal Science and Technology Commission. As China's first green building evaluation framework tailored for large-scale sporting events, it established a quantitative assessment model covering the entire life cycle of Olympic venues (design-construction-operation and maintenance) through multi-institutional collaboration. This framework advanced the integration of green building technologies and the localization of standards.

(2) **Evaluation Mechanism:** The system employs a phased review mechanism across the entire project lifecycle, deconstructing the building process into four stages: planning (design bidding), design (technology selection), construction (structural assembly and equipment installation), and operation and maintenance. Each stage is subject to predefined thresholds for energy consumption, material use, pollution control, and other mandatory criteria. By requiring phased certification, the system enforces dual constraints on "process sustainability" and "outcome sustainability," culminating in the awarding of green building certification.

(3) **Assessment Outcomes:** The primary objectives focus on minimizing environmental pollution and optimizing resource efficiency. The scoring system categorizes indicators into two classes: Q-class (building environment quality and services) and L-class (environmental load and resource utilization). This dual-category framework enables quantitative evaluation across all project types.

3.2.3 Green Building Evaluation Standard (GBES)

(1) **Developmental Evolution:** To advance sustainable development in the construction sector, the Ministry of Housing and Urban-Rural Development (MOHURD) and the Ministry of Science and Technology jointly issued the Technical Guidelines for Green Buildings in 2005, marking the standardization of green building practices in China. This standard emphasizes technology integration and multi-objective coordination, establishing a lifecycle-oriented evaluation framework. Its comprehensive nature is reflected in the systematic quantification of complex building typologies and multi-dimensional performance metrics (energy efficiency, materials, environmental impact, etc.), positioning it as a pivotal policy tool for industry transformation.

(2) **Evaluation Mechanism:** Guided by international best practices and localized adaptation, the standard defines six core criteria:

Land Conservation and Outdoor Environment

Energy Efficiency and Utilization

Water Conservation and Resource Management

Material Efficiency and Resource Optimization

Indoor Environmental Quality

Operational Management

A modular evaluation framework ensures coverage of the entire lifecycle, balancing technical feasibility with economic viability. This structure creates a tiered control system that combines regulatory constraints with performance incentives.

(3) **Assessment Results:** The evaluation outcomes adopt a three-tier hierarchical classification:

Basic Control Indicators (mandatory minimum requirements),

General Performance Indicators (standard compliance benchmarks),

High-Standard Optional Indicators (advanced sustainability targets).

This progressive framework enhances precision in assessing varying levels of green performance, providing granular quantitative benchmarks for building certification.

4. Evaluation Methods and Technological Innovations

4.1 Classical Quantitative Models

In green construction evaluation systems, the Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) represent two widely adopted multi-criteria decision-making and efficiency assessment methods. These approaches respectively support green construction evaluation and optimization through subjective weighting and objective efficiency analysis.

Chen (2017), addressing the need to standardize and institutionalize green construction practices, proposed an AHP-based green construction evaluation method. By applying AHP and systems engineering theory, the study elaborated on model construction, parameter determination, and case-based scoring mechanisms for green construction evaluation. Practical case studies further demonstrated the method's applicability. Shen (2017) examined the National Grid's largest ongoing converter station project, employing AHP to calculate green construction indicators across three criterion layers: comprehensive green construction management, resource and energy utilization, and environmental load control. Through hierarchical weight analysis, a quantifiable evaluation system for earthwork engineering in green construction was established.

Chen (2014) introduced DEA into green construction evaluation, providing a detailed exposition of DEA principles and core models. Building upon domestic and international green building evaluation frameworks and field investigations, the study developed a DEA-based green construction evaluation index system. Empirical analysis was conducted using 16 unit projects from two large-scale developments—Guangzhou LT Plaza and ZJ City—to assess relative efficiency in green construction practices.

AHP and DEA exhibit distinct application scenarios in green construction evaluation. AHP employs hierarchical weighting and quantitative modeling to deliver structured, standardized assessment tools for complex engineering projects, particularly suitable for large-scale infrastructure requiring explicit indicator prioritization. In contrast, DEA focuses on input-output efficiency, utilizing multidimensional resource and environmental indicators to identify optimization potential in construction processes, making it more appropriate for cross-project efficiency benchmarking and dynamic management improvement.

4.2 Dynamic Assessment Technology

Green construction dynamic assessment technology is a technical system that integrates real-time data acquisition, a multidimensional indicator framework, and intelligent algorithms to continuously monitor and optimize resource utilization, environmental impacts, and management efficiency throughout the construction process. Its core objective is to enhance the sustainability of construction activities, reduce environmental burdens, and ensure engineering quality and economic benefits through dynamic feedback mechanisms.

For instance, a BIM-based Plan-Do-Check-Act (PDCA) dynamic model has achieved real-time optimization of construction processes. In the Wuhan Yangtze River Shipping Center project, platform-collected data enabled dynamic adjustments to energy-saving schemes, resulting in a 12% reduction in energy consumption (Tang, 2021).

Zhang (2018), based on an analysis of energy consumption management during the pavement construction phase of the Zhen-Dan Green Highway Project, conducted research on construction energy consumption monitoring technology. This work led to the development of a software platform for monitoring energy consumption during highway construction, providing technical support for energy consumption management in expressway projects. Additionally, an energy efficiency evaluation system for construction equipment was established, along with corresponding strategies for efficiency improvement.

Dynamic green construction assessment technology significantly improves the sustainability of construction processes through real-time feedback and intelligent optimization. Its success relies on three critical advancements: scientific indicator systems, automated data acquisition, and precise modeling algorithms.

4.3 Composite Weight Allocation Method

The composite weight allocation method integrates the advantages of subjective weighting techniques (e.g., Analytic Hierarchy Process [AHP], G1 method) and objective weighting approaches (e.g., entropy weight method, principal component analysis [PCA]) to establish comprehensive weights.

Li (2023) proposed a game theory-radar chart method that combines the G1 method (subjective) and entropy weight method (objective), reducing deviations caused by single-weight assignments and achieving a 95% consistency rate between evaluation results and actual scheme selection.

Fan (2023) utilized the order relation analysis (G1) method, entropy weight method, and combination weighting method to calculate subjective, objective, and composite weights for indicators. Dual connection number theory was applied to process mixed indicator data, while projection grey target decision theory was employed to determine the green construction level of evaluated objects. Results demonstrated that the model's evaluation outcomes were more rational, reliable, and aligned with practical conditions, offering a reference framework for similar assessments.

By harmonizing subjective and objective weighting, the composite weight allocation method effectively resolves conflicts between expert experience and data-driven approaches in green construction evaluation. It exhibits exceptional performance in addressing multi-level, dynamic, and regionally specific indicators.

5. Existing Issues and Challenges

5.1 Insufficient Dynamic Evaluation

Current evaluation systems predominantly rely on static indicators, lacking real-time feedback and optimization mechanisms during construction processes. The inadequacy of dynamic green construction evaluation manifests in dual deficiencies in spatiotemporal continuity and process synergy. Temporally, dependence on fixed-cycle assessments fails to capture instantaneous fluctuations in construction dynamics. Evaluative metrics neglect to establish dynamic inter-process transmission relationships, overlooking the cumulative environmental risks arising from technological interfaces. Furthermore, rigid parameter frameworks persist, with neither dynamic weight allocation adjustments across construction phases nor real-time warning mechanisms to address abnormal equipment energy consumption.

5.2 Techno-Economic Contradictions

High initial costs of green construction technologies, such as 10–15% increased investment for BIM platforms, deter corporate adoption (Hong, 2021). Production costs for advanced green materials (e.g., high-performance bio-based resins and ALC panels) exceed traditional materials by over 300%. For instance, bio-based resin technology requires continuous modification processes with substantial equipment investments (Pooria, 2023). Although lifecycle maintenance cost savings are achievable, upfront procurement expenses directly impact project budgets (Xue, 2014). Incremental initial costs for energy-efficient envelope technologies (e.g., external shading structures and dry-hanging polystyrene panel facades) range from 50-100 yuan/m^2, with dynamic payback periods of 13–15 years, incentivizing preference for short-return traditional solutions (Liu, 2016).

The core of the techno-economic contradiction lies in the trade-off between short-term financial constraints and long-term sustainability objectives. Policy optimization, technological innovation, and market mechanism synergies could gradually mitigate these conflicts, transforming green construction from a "cost burden" to a "value creation" paradigm.

5.3 Data Acquisition Challenges

Quantitative data collection faces threefold difficulties: high on-site monitoring costs, technical complexity, and insufficient data continuity. Lü (2015) demonstrated that real-time monitoring of total electricity consumption and tower crane energy demands requires intelligent meter deployment, yet small-scale projects often lack resources for expensive equipment procurement and complex circuit differentiation during multi-equipment operations, necessitating sophisticated sub-metering systems.

RFID-based tracking of reusable materials (e.g., formwork and scaffolding) incurs prohibitive tag costs and management system expenses for small projects (Feng, 2016). These challenges epitomize the tripartite conflict among technical feasibility, economic rationality, and managerial effectiveness. Resource-constrained small projects frequently enter a vicious cycle: "high monitoring costs → data scarcity → evaluation distortion → diminished improvement incentives."

6. Future Development Trends

6.1 Full Life-Cycle Integration of Carbon Emission Factors

With the advancement of the dual-carbon goals, carbon emission indicators will become the core element of evaluation systems. Existing studies have proposed incorporating secondary indicators such as "carbon reduction rates in material production, transportation, and construction phases" into evaluation frameworks, supported by quantitative formulas for precise assessment (Du, 2024). For instance, Shanghai Construction Group Fifth Engineering Co., Ltd. established a carbon emission-oriented evaluation system, demonstrating the correlation between carbon reduction effectiveness and construction scheme optimization.

Xiao (2024) addressed the comprehensive evaluation of green construction in municipal roads from a carbon reduction perspective. By integrating the characteristics of municipal road construction, a grey relational model based on combined weighting was developed. This model calculates the grey relational degrees between indicators and construction schemes for different road sections by synthesizing subjective and objective weights, enabling comparative analysis of green construction performance. Results confirmed the feasibility and scientific rigor of applying combined weighting-based grey relational theory to municipal road green construction evaluation, providing a reference for sustainable construction scheme design.

Future developments will expand carbon emission accounting from single construction phases to full life-cycle coverage, encompassing material production, transportation, construction, operation, maintenance, and demolition/recycling.

6.2 Intelligentization and Dynamization of Evaluation Methods

Current practices combine Analytic Hierarchy Process (AHP), Entropy Weight Method, Grey Clustering Method, and improved Radar Chart Method to enhance evaluation objectivity. For example, the Xinyi Expressway Electromechanical Installation Project adopted the AHP-CRITIC-Grey Clustering Method, achieving multidimensional weighting for objective evaluation outcomes. Future models will integrate Fuzzy Comprehensive Evaluation and Catastrophe Progression Method into dynamic evaluation frameworks to address complex construction scenarios (Zhai, 2024).

BIM technology, IoT sensors, and big data analytics will drive real-time and visualized evaluation systems. In prefabricated buildings, BIM optimizes construction schemes while enabling real-time monitoring of energy consumption and carbon emissions. The Ministry of Housing and Urban-Rural Development's revised guidelines propose establishing a "full-process digital control platform" to implement closed-loop data collection, analysis, and feedback mechanisms (Yang, 2024).

6.3 International Convergence of Standard Systems

Global standards such as Singapore’s Green Mark 2021 and the U.S. LEED have shifted toward performance-based assessments (e.g., actual energy consumption, indoor environmental quality) rather than solely focusing on technical measures (Deng, 2023). Li (2012) recommended developing a three-dimensional evaluation toolkit based on "region-building type-life cycle stage" to align with this trend. For example, Guangdong Province’s revised local standards for hot-humid climatic conditions have incorporated adaptive design principles from Singapore’s Green Mark (Xu, 2019). This convergence highlights the growing emphasis on context-sensitive, lifecycle-oriented evaluation frameworks in global construction practices.

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