WHIOCE PUBLISHING PTE. LTD.
PROVIDING
FIRST-CLASS SCIENTIFIC INFORMATION
FOR TOP SCHOLARS

2025 Volume 3, Issue 11
Contemporary Education Frontiers
ISSN:3029-1879 (Online)
ISSN: 3029-1860 (Print)

Research on Optimization Paths for the Whole Life Cycle Engineering Management of Low-Carbon Buildings

Dan Wang*
Hainan Vocational University of Science and Technology, Haikou 571126, Hainan, China

Author to whom correspondence should be addressed.

Abstract: Against the backdrop of the green transformation and dual-carbon goals in the construction industry, comprehensive lifecycle engineering management for low-carbon buildings has become increasingly crucial. This paper examines the entire process, from planning and design, construction, operation and maintenance, to demolition and recycling, to analyze the core characteristics of low-carbon management and key control points at each stage. It identifies current challenges such as inadequate technology implementation, weak process control, and poor management coordination across phases, and proposes optimization strategies focusing on stage-specific improvements, collaborative mechanisms, standard development, and digital management systems. The findings provide theoretical insights and practical recommendations for enhancing low-carbon construction management and achieving carbon reduction and efficiency improvements throughout the entire project lifecycle.

Keywords: Low-carbon buildings; Full life cycle; Engineering management; Carbon reduction

Online publication: Dcecmber 20, 2025

1. Introduction

As requirements for green and low-carbon development in the construction industry continue to rise, the traditional segmented and extensive project management model can no longer meet the demands of low-carbon building construction. Low-carbon buildings emphasize minimizing energy consumption and carbon emissions throughout their entire life cycle, necessitating comprehensive project management coverage, multi-stage coordination, and refined control. Currently, low-carbon construction project management in China still faces challenges, such as a disconnect between design and construction, lax control during the operational phase, and low resource recovery rates during demolition, all of which undermine overall low-carbon benefits. This paper adopts a full life-cycle perspective to systematically explore optimization pathways for project management, aiming to facilitate the low-carbon, standardized, and efficient development of the construction industry.

2. The connotation of full life cycle engineering management for low-carbon buildings

2.1. Definition of the core scope of full life cycle engineering management

Low-carbon building lifecycle engineering management transcends the limitations of traditional construction management, which focuses solely on the construction phase. It extends its scope forward to include project planning, design, and scheme comparison, and backward to encompass construction, operation and maintenance, renovation and renewal, and ultimately demolition and recycling, forming a comprehensive closed-loop management system. Its scope encompasses not only traditional quality, schedule, cost, and safety management, but also incorporates carbon emission accounting, energy efficiency, selection of green building materials, and ecological and environmental protection as core management objectives, shifting engineering management from a single focus on economic benefits to a coordinated integration of economic, social, and ecological benefits.

The clarification of the full life cycle management framework emphasizes the continuity and integrity of the management process, effectively preventing issues such as fragmented stages, dispersed responsibilities, and inadequate oversight. In terms of management entities, it integrates multiple stakeholders, including those involved in construction, design, engineering, supervision, operation, and post-demolition phases, to establish a cross-stakeholder collaborative management model.

2.2. The integration logic between low-carbon goals and engineering management

The integration of low-carbon objectives with engineering management follows an inherent logic characterized by hierarchical goal transmission, dynamic phase adaptation, and practical implementation supported by technology. It breaks down overall carbon reduction targets across all phases, design, construction, operation, and demolition, transforming abstract low-carbon requirements into actionable, controllable, and measurable management tasks. Engineering management ensures the realization of low-carbon goals through process optimization, institutional constraints, technology selection, and organizational coordination. In turn, these low-carbon objectives drive the transformation and upgrading of management models, propelling the shift from traditional extensive management toward refined, green, and digital approaches.

The deep integration of these two approaches is manifested in the comprehensive restructuring of value across the entire lifecycle: during the design phase, solutions are optimized with low-carbon principles; during construction, processes are regulated through low-carbon management standards; during operation, low-carbon maintenance enhances efficiency; and during demolition, low-carbon disposal enables resource recycling. Engineering management no longer focuses solely on construction speed and cost control, but instead uses carbon emission intensity, energy consumption levels, and environmental impact as key evaluation criteria [1].

2.3. Key focus areas and internal interconnections of low-carbon management at each stage

The key control priorities across each stage of a low-carbon building's entire life cycle exhibit distinct phase-specific characteristics. During the design phase, the focus is on source control, emphasizing building layout optimization, passive energy-saving design, selection of green building materials, and implementation of natural lighting and ventilation systems to establish a foundation for carbon reduction at the source. The construction phase concentrates on green construction practices, prioritizing sustainable construction organization, energy consumption management of construction machinery, comprehensive dust and noise control, and reduction and resource recovery of construction waste. The operation phase aims for low-carbon performance, focusing on dynamic energy consumption monitoring, intelligent equipment control, and refined operational management. The demolition phase emphasizes end-of-life recycling, with attention to classified recycling of construction waste, reuse of renewable materials, and safe disposal. These control priorities are interconnected, collectively forming a comprehensive low-carbon management system spanning the entire life cycle.

There exists a strong intrinsic linkage and transmission relationship between the various stages. The technical solutions determined during the design phase directly determine the project's overall emission reduction potential and low-carbon implementation pathway; the level of control during the construction phase directly influences the effectiveness of low-carbon technology deployment; energy consumption management during the operational phase determines the building's long-term low-carbon benefits; and the disposal methods during the demolition phase affect resource recycling and end-of-life emission reduction outcomes. Any control deficiency at any stage will propagate to subsequent phases and undermine overall low-carbon effectiveness.

3. Existing issues in low-carbon management across all life cycle stages

3.1. Insufficient implementation of low-carbon technology solutions during the design phase

As the foundational phase of low-carbon management, the design stage faces a significant disconnect between low-carbon principles and practical engineering implementation in some projects. Designers often prioritize building functional layouts, structural safety, and economic benefits, while neglecting critical low-carbon elements such as passive design, low-carbon building material applications, and energy-efficient construction techniques. Consequently, low-carbon designs remain largely conceptual and fail to translate into actionable, implementable solutions. Some designs indiscriminately incorporate advanced low-carbon technologies merely to meet regulatory requirements, disregarding local climate conditions, construction feasibility, and operational costs, thereby hindering their successful implementation.

Meanwhile, the design phase generally lacks quantitative carbon emission calculations and comparative assessments throughout the entire lifecycle, making it impossible to conduct scientific comparisons between different technical solutions and leaving project selection without sufficient data support. Most projects fail to establish cross-disciplinary and cross-phase collaboration mechanisms, with inadequate preliminary communication among design, construction, and operation teams. This results in design outcomes that fail to align with on-site construction conditions and subsequent operational requirements, hindering the implementation of low-carbon measures and the achievement of energy consumption control targets.

3.2. Lack of carbon emission process control during the construction phase

The construction phase is a critical period for concentrated carbon emissions in building projects. However, most projects currently employ extensive management practices, lacking comprehensive dynamic monitoring of energy consumption by construction machinery, transportation and waste of building materials, dust and wastewater treatment, and energy usage of temporary facilities. This results in unclear baseline carbon emission figures, incomplete data, and a lack of precise basis for control measures. Low-carbon objectives are often marginalized in construction organization designs, with prominent issues including material waste, high energy consumption, and haphazard disposal of construction waste. Green construction measures frequently remain superficial and fail to yield tangible outcomes.

The construction phase involves numerous stakeholders with complex, overlapping processes, yet lacks unified low-carbon management standards and coordinated working mechanisms. The responsibilities of project owners, contractors, and supervisors are poorly defined, hindering effective collaborative oversight. In some projects, efforts to meet deadlines and control costs have led to the deliberate simplification or even elimination of low-carbon measures, resulting in actual carbon emissions far exceeding planned targets.

3.3. Non-standard low-carbon management during the operation and demolition phase

The building operation phase is the longest in duration and consumes the largest total energy, yet most projects still employ traditional management models, lacking systematic energy consumption monitoring platforms, intelligent control systems, and low-carbon operation and maintenance protocols. The operational efficiency of equipment such as lighting, air conditioning, and water supply/drainage systems is low, resulting in significant energy waste. Some property management personnel lack specialized knowledge and operational skills in low-carbon practices, leading to improper use of energy-saving equipment and making it difficult to maintain long-term stable low-carbon operations.

Low-carbon management during the demolition phase remains poorly regulated. Building demolitions lack scientific planning and systematic classification and disposal mechanisms, resulting in the direct disposal of large quantities of recyclable components and low resource recycling rates. This process also generates dust and solid waste pollution, leading to high end-of-life carbon emissions [2]. Most projects have not established low-carbon assessment systems for the demolition phase, and there are no mandatory regulatory requirements for waste recycling and harmless treatment.

4. Optimization strategies for the full life cycle management of low-carbon buildings

4.1. Low-carbon pre-planning optimization method in the design phase

During the design phase, comprehensive low-carbon upfront planning should be implemented, incorporating carbon reduction targets as core criteria in scheme comparisons. Priority should be given to passive design strategies such as natural ventilation, natural lighting, and rational orientation, while fully integrating regional climate and environmental conditions to minimize subsequent energy demands for equipment and control carbon emissions throughout the building's entire lifecycle at the source. Based on the project's regional climate characteristics, resource endowment, site conditions, and intended functions, energy-efficient technologies and green building materials with strong compatibility should be scientifically selected, balancing low-carbon benefits, project costs, and construction feasibility.

A multi-disciplinary collaborative design mechanism should be established, involving the participation of architecture, structural engineering, mechanical and electrical systems, and operations and maintenance teams during the preliminary scheme discussion stage. Technical requirements and implementation priorities across different disciplines should be effectively coordinated to ensure that the final design outcomes achieve a balance between construction feasibility and operational convenience. In addition, a full lifecycle carbon footprint assessment tool should be implemented to simulate, quantify, and comprehensively compare carbon emissions across different design schemes, thereby enabling the selection of solutions with superior low-carbon benefits and economic efficiency. This approach can establish a solid foundation for low-carbon management at the initial stage of the project and provide reliable evidence and technical support for low-carbon practices throughout the construction and operational phases.

4.2. Green construction and energy consumption control during the construction phase

During the construction phase, a comprehensive green construction management system should be established. This involves optimizing construction organization designs, rationally planning material transportation routes and site layouts, and minimizing ineffective transportation, secondary handling, and material waste to achieve low-carbon management at the organizational level. Priority should be given to low-energy-consumption and low-emission construction machinery and equipment, while adopting intensive workflow organization and assembly-line construction methods to reduce equipment idling, redundant operations, and labor waste, thereby effectively lowering energy consumption and carbon emission intensity throughout the construction process. Comprehensive management of dust, noise, and wastewater must be strengthened, with strict implementation of requirements for construction waste sorting, recycling, and resource utilization to minimize the impact of construction on the surrounding environment.

A dynamic monitoring mechanism for construction carbon emissions should be established to implement real-time surveillance of large machinery, temporary power usage, key energy-consuming equipment, and critical construction processes. Such a mechanism can enable the timely tracking of carbon emission fluctuations, as well as the early warning, identification, and correction of emission exceedances. In addition, the low-carbon management responsibilities of all participating construction entities should be clearly defined, while energy conservation and carbon reduction indicators should be incorporated into the construction performance evaluation system. The on-site supervision and verification functions of supervisory units should also be strengthened to ensure effective implementation of low-carbon management measures. Furthermore, digital technologies such as BIM and the IoT should be utilized to achieve visualized control of the construction process, thereby ensuring the comprehensive implementation of green construction measures and maintaining carbon emissions during the construction phase in a stable, controllable, and manageable state.

4.3. Establishing a long-term low-carbon operation and maintenance mechanism during the operational phase

During the operational phase, an intelligent energy consumption monitoring platform should be established to collect, statistically analyze, and dynamically track real-time data on resource consumption, including electricity, water, gas, and heat. This enables precise identification of abnormal energy consumption points and prompt implementation of targeted control measures. Operational strategies for mechanical and electrical equipment should be optimized, with the adoption of energy-saving approaches such as smart lighting, variable frequency control, time-of-use energy supply, and zoned management. These measures enhance the operational efficiency of HVAC, water supply and drainage, and power distribution systems, while continuously improving the building's energy profile.

Training for operational management personnel in professional skills and low-carbon concepts should be strengthened to enhance their capabilities in low-carbon operations and maintenance, energy efficiency analysis, and emergency response. Such efforts can facilitate the transformation of traditional operation and maintenance models from reactive repair approaches to proactive energy conservation and predictive management. In addition, regular low-carbon operation assessments and energy efficiency diagnostics should be conducted for buildings, while operation and maintenance plans should be dynamically optimized according to actual usage conditions. These measures can continuously unlock the potential for energy conservation and carbon reduction and establish a sustainable closed-loop management mechanism of "monitoring–analysis–optimization–re-monitoring." As a result, low-carbon management standards during the operational phase can be continuously improved, ensuring long-term low-carbon, efficient, and stable operation throughout the entire lifecycle of the building [3].

5. Establishment of a low-carbon construction project management and assurance system

5.1. Improvement of the collaborative mechanism for low-carbon management throughout the entire process

A multi-stakeholder collaborative low-carbon management mechanism covering the entire project process should be established to create a low-carbon governance platform involving design, construction, supervision, and operation entities. The responsibilities, work interfaces, and control procedures of each participating party should be clearly defined to break down information barriers across different stages and enable the efficient sharing of carbon emission data, technical solutions, and management measures. In addition, cross-stage communication and coordination mechanisms should be improved through the establishment of regular consultation and feedback systems. Such measures can ensure the accurate transmission of design intentions to the construction phase and the effective feedback of construction experiences to the operational phase, thereby preventing problems such as management disconnection, inconsistent objectives, and conflicting measures among different stages.

A dedicated low-carbon management position should also be established to coordinate the decomposition of low-carbon objectives throughout the entire lifecycle, including process supervision, data accounting, and performance evaluation, thereby ensuring specialized responsibility and comprehensive management coverage across all stages. Furthermore, a long-term mechanism that combines incentives with constraints should be developed by directly linking low-carbon management outcomes to the credit ratings of participating entities, project performance evaluations, and individual assessments. This approach can fully motivate all stakeholders to proactively implement carbon reduction measures and continuously improve low-carbon management effectiveness.

5.2. Development of low-carbon technology and management standards system

Low-carbon technical standards and management guidelines covering all phases, from design and construction to operation and demolition, should be refined by clearly defining technical approaches, the selection of green building materials, energy consumption limits, carbon emission targets, and end-to-end control requirements. Such refinement ensures that low-carbon management is implemented in accordance with established standards, regulations, and verifiable documentation. In addition, the harmonization of key standards for green building material certification, energy-efficient equipment adoption, and carbon accounting methodologies should be accelerated to standardize low-carbon technology applications, enhance the standardization, universality, and comparability of technical implementation, and reduce management confusion, technical barriers, and additional costs caused by inconsistent standards [4].

A comprehensive lifecycle carbon accounting and evaluation system should also be established and improved by refining methodologies and tools for carbon footprint measurement, data statistics, impact assessment, and energy efficiency benchmarking. This can provide a scientific, quantitative, and traceable basis for management optimization. Furthermore, the promotion and implementation of industry standards and the dissemination of mature low-carbon technologies should be strengthened through the organization of technical exchanges and professional training. The deep integration of engineering management models with low-carbon standards should be facilitated, thereby comprehensively enhancing the standardization, systematization, and regulation of low-carbon management across the construction industry.

5.3. Application of the digital project management and control platform

Leveraging digital technologies such as BIM, big data, the Internet of Things, and cloud computing, we have established an integrated lifecycle management platform for low-carbon buildings. This platform enables comprehensive management across the entire process, including design simulation, construction monitoring, operational energy consumption analysis, demolition planning optimization, and carbon footprint tracking. By collecting real-time key data on carbon emissions, energy consumption, materials, and equipment at each stage, the platform facilitates the development of visual, simulative, and intelligent early-warning management models, significantly enhancing management precision, response speed, and scientific decision-making capabilities.

The digital platform enables cross-phase and cross-departmental data sharing and intelligent analysis, assisting managers in optimizing resource allocation, adjusting construction plans, and regulating energy consumption loads, thereby effectively reducing ineffective energy consumption and unreasonable emissions. Equipped with features such as intelligent early warning, process traceability, performance evaluation, and statistical analysis, the platform promptly alerts to issues like excessive carbon emissions, management deficiencies, and abnormal energy consumption and urges corrective actions. This facilitates the transition of project management from experience-driven to data-driven approaches, providing robust technical support for refined and efficient lifecycle management of low-carbon buildings.

6. Conclusion

Low-carbon building lifecycle management serves as a crucial driver for achieving green and low-carbon development in the construction industry, spanning the entire process from design and construction to operation and demolition. Current challenges, including inadequate low-carbon controls, insufficient coordination, incomplete standards, and low digitalization levels, continue to hinder overall carbon reduction effectiveness. By optimizing management strategies across phases, enhancing collaborative mechanisms, refining standard systems, and establishing digital platforms, the low-carbon management level throughout the entire lifecycle can be systematically improved. Moving forward, continuous innovation in management models and deep integration with advanced technologies are essential to strengthen integrated chain-wide oversight, thereby continuously enhancing the efficiency of low-carbon construction project management and supporting the construction industry's transition toward sustainable, low-carbon, and high-quality development.

Disclosure statement

The author declares no conflict of interest.

References

[1] Chen F, 2025, Comparative Analysis of Low-Carbon Building Technologies based on Life Cycle Assessment. China Strategic Emerging Industries, 2025(29): 150–152.

[2] Song X, Zhai S, Wang Y, 2023, Research on Low-Carbon Development Strategies for Construction Projects Throughout Their Full Life Cycle Under the “Dual Carbon” Goals. Construction Economics, 44(3): 11–17.

[3] Lin X, 2024, Analysis of Low-Carbon Development Strategies for the Full Life Cycle of Construction Projects under the “Dual Carbon” Background. China Building Decoration and Renovation, 2024(6): 86–88.

[4] Sun H, Wen D, Lü Z, et al., 2024, Carbon Emission Accounting of Low-Carbon Buildings Throughout their Entire Life Cycle under the “Dual Carbon” Goals. Project Management Technology, 22(8): 91–96.