

Strategies of Architectural Landscape Design Based on the Concept of Carbon Neutrality

Zhuyimin Xu

Southeast University Cheng Xian College, Nanjing, Jiangsu, China

250322123@cxy.seu.edu.cn

Abstract. This study explores the application of carbon neutrality principles in architectural landscape design to address global climate change challenges. Through analysis of the correlation between architectural landscape design and carbon emissions, including the impacts in aspects such as material selection, energy consumption, and construction techniques, this paper proposes architectural landscape design strategies based on the concept of carbon neutrality. These strategies encompass site planning, plant configuration, material application, and water resource management to reduce lifecycle carbon emissions in building landscapes. The research also addresses challenges such as cost, technology, and public awareness in implementing carbon neutrality concepts, proposing corresponding solutions. The findings hold significant implications for achieving sustainable development in architectural landscape design, providing theoretical and practical references for the industry's low-carbon transition.

Keywords: Carbon Neutrality; Architectural Landscape Design; Carbon Emission; Design Strategy; Sustainable Development.

1. Introduction

1.1 Research Background

Global climate change has a profound impact on natural ecosystems and poses a serious threat to the sustainable development of human society and economy. In this context, "carbon neutrality", as the core strategy to address climate change, has been incorporated into the national development strategy framework of many countries around the world.

"Carbon neutrality" refers to achieving a dynamic balance between carbon emissions and carbon absorption through coordinated efforts in reducing greenhouse gas emissions and enhancing carbon sink capacity, ultimately reaching net-zero emission goals. Its core lies in systematically regulating human activities and mitigating climate change through ecological restoration. Specific implementation pathways include: 1) Direct emission reduction (reducing energy intensity and improving energy efficiency); 2) Indirect emission reduction (policy regulation and low-carbon technological innovation); 3) Carbon sink enhancement (vegetation restoration and soil carbon storage development). As a core strategy for global sustainable development, this framework provides theoretical paradigms and practical approaches for addressing climate change and promoting green transformation. Practical applications encompass optimizing urban green space systems' carbon sink functions in landscape architecture. The goal aims to achieve net-zero greenhouse gas emissions by synergistically advancing emission reduction and carbon sink capacity enhancement, thereby effectively curbing global warming trends.

Notably, urban spaces account for over 70% of global carbon emissions during rapid urbanization [5]. Integrating carbon neutrality principles into architectural landscape design is therefore not only an inevitable trend for the industry's development but also a crucial pathway to achieving global sustainable development goals. With projected population growth and ongoing urbanization, the challenge of reducing urban space emissions is becoming increasingly urgent. As key players in systematic design, landscape architects play vital roles in realizing carbon neutrality targets. By systematically integrating green infrastructure such as parks, tree-lined avenues, rain gardens, and ecological habitats, we can significantly reduce carbon intensity, enhance regional carbon sequestration capacity, and synergistically optimize rainwater management and flood prevention.

This demonstrates that landscape design holds both significant potential and responsibility in implementing carbon neutrality strategies. However, current emission control efforts in this field have yet to meet expectations, urgently requiring scientific design approaches and technological solutions to achieve systematic improvements.

1.2 Problem Statement

Traditional architectural landscape design faces significant carbon emission challenges, with impacts extending across the entire lifecycle from material production and construction to operation and maintenance. The manufacturing and transportation of hard materials like metals and stone exacerbate these issues through high energy consumption and emissions. Water resource waste remains another major drawback, particularly evident in irrigation systems and water feature maintenance where over-reliance on municipal water supply not only drives up costs but also indirectly generates carbon emissions. Additionally, lighting systems consume excessive energy, while inefficient lighting fixtures contribute substantial CO₂ emissions.

The aforementioned issues highlight the necessity and urgency of integrating carbon neutrality concepts into landscape design. Scientific landscape design can effectively reduce carbon emissions throughout a project's entire lifecycle while enhancing ecological and social benefits. Specific strategies include prioritizing low-carbon building materials and optimizing energy efficiency through technological means to minimize emissions. However, the application of carbon neutrality concepts in landscape design remains in its early exploratory phase, lacking systematic strategies and policy support. This gap provides a critical entry point for this study.

1.3 Research Objectives

This study proposes architectural landscape design strategies rooted in carbon neutrality principles to address emission challenges. It systematically explores how low-carbon concepts can be integrated into site selection planning, plant configuration, material application, and water resource management to reduce carbon emissions. By evaluating the technical feasibility and environmental benefits of these strategies, the research provides theoretical foundations and practical guidance for the industry, ultimately advancing the achievement of carbon neutrality goals.

In addition, the study focuses on the challenges in the implementation process, including increased costs, technical bottlenecks and lack of public awareness, and proposes corresponding solutions, providing scientific design methods for practitioners and decision-making reference for policy makers, and promoting the comprehensive application of the carbon neutrality concept in the industry.

2. Literature Review

2.1 Correlation Analysis between Architectural Landscape Design and Carbon Emissions

2.1.1 Material Selection and Carbon Emissions

In architectural landscape design, material selection plays a pivotal role in determining a project's overall carbon footprint. Traditional building materials like cement and steel typically involve high carbon emissions during production and transportation. Take cement as an example: its manufacturing process not only consumes massive amounts of energy but also releases substantial CO₂ emissions through the chemical reactions in limestone calcination and high temperature energy demands [3]. Steel production relies on energy-intensive industrial processes such as iron ore reduction and high-temperature smelting, resulting in significant greenhouse gas emissions. Carbon emissions from material transportation, particularly long-distance logistics, further exacerbate environmental burdens. Therefore, material selection is crucial in architectural landscape design, as it fundamentally shapes a project's carbon footprint. Prioritizing low-carbon or locally sourced materials can reduce production and transportation emissions, thereby supporting carbon neutrality goals.

2.1.2 Energy Consumption and Carbon Emissions

Energy consumption in architectural landscape operations, particularly in lighting and irrigation systems, constitutes major carbon emission sources. The high electricity consumption of lighting, which relies on fossil fuels, exacerbates carbon footprints. To reduce emissions, designers can adopt energy-efficient lighting fixtures, smart control systems, and natural light sources to improve energy efficiency. Irrigation systems also consume significant amounts of energy, especially in arid regions. Their dependence on municipal water not only intensifies water resource pressures but also increases related carbon emissions [11]. Optimizing irrigation strategies like rainwater harvesting technology can conserve water resources while reducing energy consumption and carbon emissions. Enhancing energy efficiency enables architectural landscape design to minimize environmental impact while meeting demands.

2.1.3 Construction Technology and Carbon Emissions

Construction techniques significantly influence carbon emissions in architectural landscape design, primarily through three dimensions: machinery operation, waste disposal, and project management. First, fuel-powered construction equipment releases substantial amounts of carbon dioxide and other harmful gases during operations, posing serious threats to air quality and ecosystem stability. Second, waste treatment serves as a critical emission source which improper disposal methods not only occupy land resources but also release greenhouse gases through natural decomposition or incineration processes [13]. Additionally, inefficient construction practices lead to resource wastage and excessive energy consumption, exacerbating carbon footprints. Construction companies should prioritize high-efficiency equipment and optimized workflows to reduce energy use. Simultaneously, establishing waste recycling systems can minimize emissions through resource circulation, thereby promoting sustainable development.

2.2 Research Progress of Architectural Landscape Design and Carbon Emission

In recent years, scholars both domestically and internationally have conducted extensive research on the correlation between architectural landscape design and carbon emissions. Early studies primarily focused on single-factor analyses, such as energy consumption during building material production or waste emissions during construction phases. As research progressed, the academic community gradually recognized the complexity and diversity of carbon emissions throughout the entire lifecycle of architectural landscapes, initiating multidimensional investigations into influencing factors [2]. Li Jing et al. (2021) proposed achieving energy-saving and emission reduction goals by reducing the full lifecycle carbon footprint of green spaces, while emphasizing the critical role of plant configuration and water feature design in enhancing carbon sink capacity [1]. Sun Fangyuan (2023) further highlighted that hard landscape design must balance functionality and environmental protection, avoiding unnecessary carbon emissions caused by excessive paving and ornamentation[6]. Technologically, emerging applications have become research hotspots, including smart irrigation systems, renewable energy utilization, and rainwater harvesting technologies that effectively reduce operational carbon emissions in architectural landscapes[8]. Overall, existing studies have laid a solid foundation for understanding the mechanisms linking architectural landscape design with carbon emissions, while identifying key directions for future research.

2.3 Existing Research Gaps

While research on carbon emissions in architectural landscape design has made some progress, systematic integration of carbon neutrality concepts remains significantly underdeveloped. The primary challenge lies in the lack of comprehensive design strategy frameworks in existing literature, which predominantly focus on individual technical aspects while severely lacking integrated studies on full lifecycle carbon management [4]. Furthermore, the application potential of emerging technologies like artificial intelligence and big data in optimizing decarbonization pathways has not been fully explored, with empirical research remaining critically scarce[6]. Additionally, limited

public awareness of low-carbon landscapes poses a major constraint, as this research direction is still in its infancy and requires substantial empirical data support. This study aims to bridge these research gaps by constructing a systematic decarbonization strategy framework and deepening explorations of technological application pathways, thereby providing innovative theoretical frameworks and practical approaches for implementing carbon neutrality goals in landscape design.

3. Architectural Landscape Design Strategies Based on the Concept of Carbon Neutrality

3.1 Site Selection Strategy

Site selection directly impacts carbon emissions, and climate and topographic science-based site selection can reduce energy consumption. For instance, in windy areas, optimizing building orientation and window placement reduces mechanical ventilation needs; in sunny regions, meticulous daylighting design minimizes artificial lighting frequency. Constructing natural drainage systems on slopes saves energy while enhancing ecological sustainability. Protecting existing ecosystems as carbon sinks is crucial to avoiding damaging natural carbon reservoirs (e.g., forests or wetlands) to reduce CO₂ emissions. Prioritize low-ecological-sensitivity areas in site selection, preserve vegetation and water bodies, and integrate ecological conservation measures (e.g., ecological corridors) to boost biodiversity. This strengthens carbon absorption capacity and creates resilient, healthy environments.

3.2 Plant Configuration Strategy

3.2.1 Carbon Sequestration Plant Screening

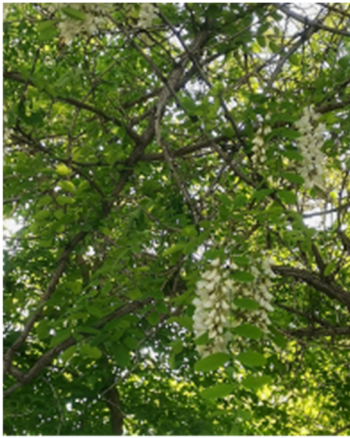


Figure 1. Black Locust



Figure 2. Ficus Virens



Figure 3. Oleander

As one of nature's primary carbon sink carriers, the scientific configuration of plants in architectural landscape design plays a crucial role in achieving carbon neutrality goals. Different plant species exhibit significant variations in carbon sequestration capacity, making the selection of high-efficiency carbon-fixing species a vital approach to enhance regional carbon sink capabilities. For example, in tree design: trees like black locust (Figure 1), Ficus virens (Figure 2), and oleander (Figure 3) each demonstrate daily carbon fixation rates exceeding 10g/(m²·d). Increasing the population density of these high-carbon-fixation plants can boost the carbon sequestration efficiency of plant communities. While some herbaceous plants have weaker individual carbon fixation capacity, their rapid growth characteristics make them effective supplementary carbon sinks [12]. Moreover, plants primarily achieve carbon sequestration through photosynthetic processes that assimilate and fix CO₂ while continuously accumulating organic matter—processes regulated by multiple factors including species characteristics and environmental conditions. Therefore, in landscape design

practice, it's essential to optimize the combination of carbon-fixing plants based on local climate characteristics and soil conditions to maximize the system's overall carbon sink functionality.

3.2.2 Optimize Planting Methods

Planting design plays a pivotal role in enhancing carbon sequestration efficiency. Multi-layered and community planting systems, by mimicking natural ecosystem structures, can significantly boost carbon absorption capacity. Multi-layered planting integrates trees, shrubs, and herbaceous plants to create vertical carbon absorption gradients, while community planting leverages ecological interdependence among species to synergistically enhance biomass accumulation and carbon sequestration. Research confirms that these configurations effectively strengthen urban green space's carbon sink capacity and optimize local micro-climates, providing a viable pathway toward achieving carbon neutrality goals.

3.3 Material Application Strategy

3.3.1 Low Carbon and Environmental Protection Materials

In architectural landscape design, material selection directly impacts a project's lifecycle carbon emissions. Traditional materials like cement and steel often involve high energy consumption and carbon emissions during production, making the promotion of low-carbon eco-friendly materials crucial for achieving carbon neutrality goals. Sustainable options such as recycled materials and bamboo are gaining attention due to their energy-efficient production processes and environmental benefits. For instance, recycled concrete that is made from reclaimed construction waste (Figure 4) not only reduces resource waste but also significantly cuts production emissions. Bamboo, a fast-growing plant known for its high strength and biodegradability, is widely used in landscape paving and furniture manufacturing. These materials not only help reduce carbon footprints but also inject green innovation into architectural landscape design.



Figure 4. Permeable bricks made of artificial stone recycled from construction waste

3.3.2 Material Recycling

Waste management in architectural landscape design constitutes a significant source of carbon emissions, making material recycling crucial for achieving carbon neutrality goals. By repurposing discarded materials, we can not only reduce the demand for new production but also decrease greenhouse gas emissions from landfilling or incineration. For instance, recycled wood can be transformed into decorative elements, while plastic waste may be converted into weather-resistant paving materials [10]. Furthermore, designers should prioritize materials' disassemblability and recyclability during planning stages to enable efficient reuse in later phases. This circular economy approach not only minimizes resource consumption but also provides robust support for sustainable development in architectural landscape design.

3.4 Water Resources Management Strategy

3.4.1 Rainwater Collection System

Water resource management constitutes a vital component in achieving carbon neutrality goals within architectural landscape design, with rainwater harvesting systems playing a pivotal role. By designing and implementing such systems (Figure 5), we can effectively reduce reliance on external water sources, thereby decreasing carbon emissions from water transportation and treatment processes. These systems typically include rainwater collection devices, storage facilities, and purification equipment, which can be utilized for landscape irrigation and cleaning purposes, significantly reducing tap water consumption. Moreover, rainwater harvesting systems help alleviate urban stormwater runoff pressures and improve regional aquatic ecosystems. Research indicates that properly designed rainwater harvesting systems can reduce landscape water usage by over 30%, providing a practical solution for water resource management under carbon neutrality initiatives.

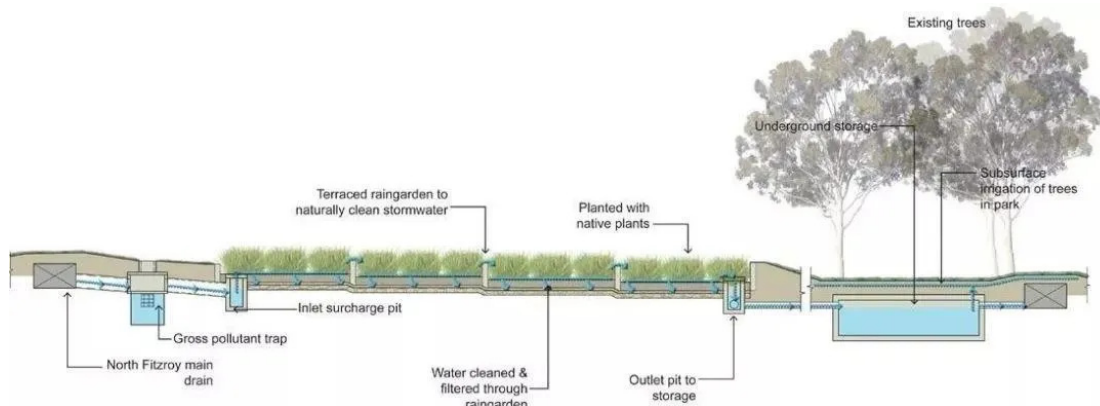


Figure 5. Schematic diagram of landscape garden rainwater collection system

3.4.2 Recycling Technology

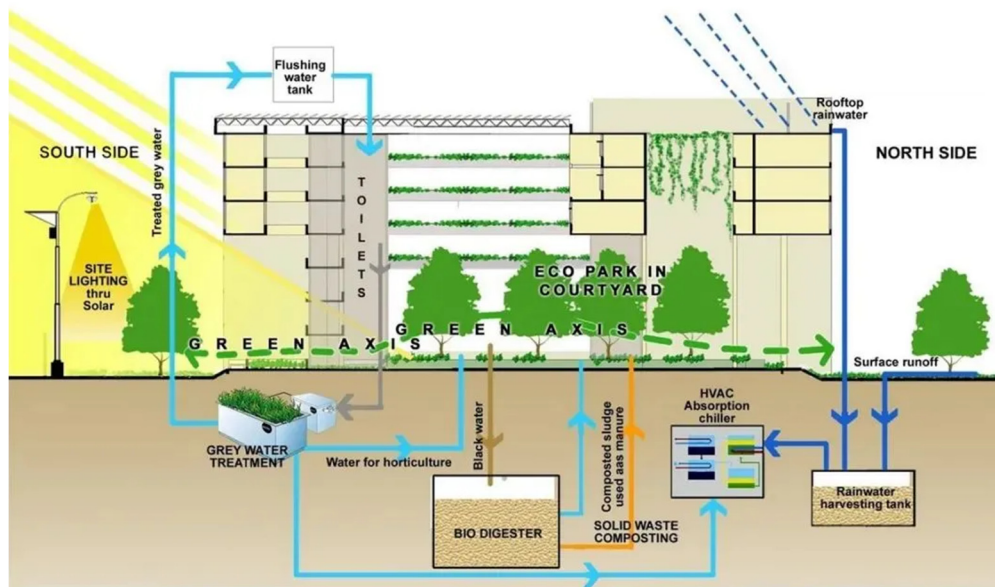


Figure 6. Schematic diagram of water resources recycling

Beyond rainwater harvesting systems, water recycling technologies such as greywater reuse demonstrate significant potential in architectural landscape design. Through treatment of domestic wastewater or mildly contaminated water, this technology converts it into reusable water that meets specific application standards for non-potable uses like irrigation and toilet flushing (Figure 6). Not

only does this approach reduce reliance on fresh water resources, but it also decreases energy consumption and carbon emissions during wastewater treatment. Furthermore, recycling systems help establish closed-loop water ecosystems while enhancing water utilization efficiency. In practical implementation, designers should strategically deploy recycling facilities based on project requirements and local conditions to maximize water resource utilization while minimizing carbon emissions.

4. Challenges and Countermeasures of Carbon Neutrality Concept in Architectural Landscape Design Implementation

4.1 Cost Challenges and Responses

The implementation of carbon neutrality concepts in architectural landscape design faces significant cost challenges, primarily due to the high prices of low-carbon materials and the substantial costs associated with adopting new technologies. Although eco-friendly materials like recycled materials and bamboo demonstrate energy efficiency advantages during production and transportation, their market prices typically surpass those of traditional building materials such as cement and steel. Moreover, the application of renewable energy technologies further increases initial investment costs. For instance, solar photovoltaic panels require considerable installation and maintenance expenses, while their efficiency in certain regions remains below expected levels due to climatic constraints [7]. Meanwhile, the introduction of intelligent systems that include smart irrigation systems and carbon emission monitoring devices also demands substantial upfront investments and technical support costs [2].

To alleviate cost pressures, government subsidies (such as fiscal incentives or tax breaks) can effectively lower the application costs of low-carbon materials, thereby encouraging the adoption of sustainable technologies. Through systematic optimization strategies which include site selection that leverages natural conditions to reduce energy consumption, use native carbon-fixing plants to minimize transportation and maintenance costs. Establish rainwater harvesting systems to decrease reliance on municipal water supplies which could make operational costs significantly reduced. Combined policy support and technological improvements can synergistically overcome systemic barriers in advancing carbon neutrality goals.

4.2 Technical Challenges and Responses

In the process of achieving carbon-neutral architectural landscape design, technical challenges cannot be overlooked. Particularly prominent are the unstable application of new energy technologies and the imperfections in carbon emission monitoring systems. The instability of renewable energy technologies mainly manifests in the intermittent nature and geographical limitations of solar, wind, and other renewables. Their utilization efficiency is often affected by weather conditions and geographical location, making it difficult to meet continuous and stable energy demands[5]. Furthermore, current carbon emission monitoring technologies remain in their developmental stage, lacking unified standards and methodologies. This makes it extremely challenging to accurately quantify the carbon emissions throughout the entire lifecycle of architectural landscapes [9].

To address technological bottlenecks in achieving carbon neutrality goals, strengthening R&D collaboration with global partners is crucial. It's imperative to increase investment in new energy technologies, particularly focusing on breakthroughs in energy storage systems to resolve intermittent renewable energy supply issues. Simultaneously, standardization of carbon emission monitoring technologies should be accelerated through unified benchmarking frameworks. Developing intelligent analytics platforms that integrate big data and AI will enable real-time tracking and precise analysis of emissions. By implementing carbon footprint tools like i-Tree, Pathfinder, and Donghe Software (as shown in Figure 7), landscape architecture can significantly enhance data collection efficiency, visualization capabilities, and quantitative analysis, providing scientific support for design

decisions. Through multilateral cooperation and technological innovation, we must jointly establish a technical framework for carbon-neutral oriented architectural landscape design.



Figure 7. Pathfinder Carbon Calculator

4.3 Public Perception Challenges and Responses

The public's limited understanding of carbon neutrality in architectural landscape design remains a key barrier to its widespread adoption. A prevalent misconception stems from the public's one-sided belief that carbon neutrality is solely applicable to industrial sectors, overlooking its crucial role in building and landscape design. This cognitive gap results in low public engagement and difficulty in forging social consensus, ultimately hindering the practical implementation of this concept in related fields.

To enhance public awareness, educational campaigns and demonstration projects have proven to be effective strategies. Key measures include: conducting systematic dissemination of carbon neutrality fundamentals and real-world cases through specialized lectures, science exhibitions, and social media platforms to strengthen environmental consciousness; developing model projects like "Zero-Carbon Smart Neighborhoods" that visually demonstrate low-carbon technology applications, thereby stimulating public engagement; encouraging community participation through surveys and workshops to deepen understanding and build consensus. These multi-dimensional educational initiatives and practical demonstrations effectively overcome cognitive barriers, establishing a social foundation for the widespread adoption of carbon neutrality concepts in architectural landscape design.

5. Outlook of Development Trend of Architectural Landscape Design Based on Carbon Neutrality Concept

5.1 Integration with Emerging Technologies

With technological advancements, emerging technologies such as artificial intelligence, big data, and the Internet of Things are profoundly transforming architectural landscape design, paving innovative pathways toward achieving carbon neutrality goals. Specifically, data-driven smart irrigation systems optimize scheduling strategies to significantly reduce water consumption and energy waste. Big data-based carbon emission monitoring technologies track project lifecycle data, providing scientific foundations for design decision optimization. AI systematically selects high-carbon sequestration plant combinations during landscaping processes to maximize site carbon sink potential. Virtual reality (VR) and augmented reality (AR) technologies assist designers in accurately

simulating carbon emission performance across different solutions, enabling optimal selection. The deep integration of these technologies has substantially enhanced design efficiency and environmental sustainability. Their widespread adoption urgently requires interdisciplinary collaboration to drive paradigm shifts in the industry.

5.2 Build Intelligent and Low-carbon Landscape Space

Future architectural landscape design will emphasize intelligent applications to achieve efficient energy utilization and carbon emission control while meeting aesthetic and comfort requirements. The core of smart low-carbon landscape spaces lies in technological integration and system optimization, creating a dynamic balanced ecosystem that minimizes carbon footprints (Figure 8). For instance, in energy management, photovoltaic technology combined with smart grids enables self-sufficient electricity supply, reducing dependence on fossil fuels [9]. Intelligent lighting systems adjust brightness through sensors to lower energy consumption.

In plant configuration and water resource management, intelligent solutions enhance carbon sequestration efficiency while reducing waste. By integrating multi-layered planting with smart irrigation and rainwater harvesting systems, the Nanjing Stone City District utilizes LID technology and smart monitoring to maximize rainwater utilization and reduce reliance on municipal water supply. Smart sensors continuously monitor plant health, improving survival rates and ecological benefits.

In terms of user experience, smart low-carbon spaces prioritize comfort and engagement. Music therapy and aromatic plants create therapeutic environments to enhance physical and mental well-being. A carbon credit system encourages public participation in low-carbon behaviors, fostering sustainable lifestyles. This human-centered philosophy drives the Sustainable Development Goals (SDGs). Intelligent technologies provide opportunities for architectural landscape design and chart the course for future development [11].



Figure 8. Intelligent low-carbon landscape space effect

6. Conclusion

This study systematically explores implementation strategies for carbon neutrality in architectural landscape design, aiming to reduce carbon emissions and enhance carbon sink capacity. Site selection focuses on maximizing natural conditions, such as optimizing locations to reduce energy consumption while protecting ecosystems. Plant configuration prioritizes native species with strong carbon sequestration capabilities, while optimized planting strategies improve carbon capture efficiency and biodiversity. Material application emphasizes promoting low-carbon materials (such as recycled materials and bamboo) and recycling waste resources. Water resource management utilizes rainwater harvesting and reclaimed water reuse technologies to minimize resource waste and associated carbon emissions. These strategies provide a systematic solution for achieving carbon neutrality goals.

This study has the following limitations: lack of long-term tracking of strategy implementation effects; data constraints affecting carbon reduction potential assessment; insufficient application of emerging technologies. Future research should strengthen long-term monitoring and evaluation;

deepen exploration of emerging technologies; promote interdisciplinary collaboration; and encourage public participation.

References

- [1] Li Jing, Wu Jiaming, and Wang Wenqing. Landscape Architecture Planning and Design Strategies Under the Carbon Neutrality Goal [J]. *Landscape Architecture*, 2022,29(5):45-51.
- [2] Yang Jun; Xu Guangda. Exploring Urban Landscape Design under the Perspective of Carbon Neutrality [J]. *Beautify Life*, 2023(28):136-138.
- [3] Zhang Di. Low-carbon Landscape Design in the Context of Carbon Neutrality [J]. *Flowers*, 2024(8):70-72.
- [4] Li Xiaolan. Carbon Neutrality and Landscape Design [J]. *Modern Horticulture*, 2023,46(13):129-131.
- [5] Zheng Xi. Carbon Neutrality and Design Strategies [J]. *Landscape Architecture*, 2022,29(5):8-9.
- [6] Sun Fangyuan. Analysis of Landscape Design Pathways Based on Low-Carbon Concepts [J]. *Urban Intelligence*, 2022, (21):154-156.
- [7] Li Qiang. Analysis of Development Directions in Architectural Design under the Carbon Neutrality Context [J]. *Architectural and Decoration*, 2024(5):10-12.
- [8] Liu Xiaoxue & Wang Jian. Ecological Landscape Design and Construction Explorations Based on "Carbon Peak and Carbon Neutrality" [J]. *Doors & Windows*, 2023(22):76-78.
- [9] Hu Luyao; Zhong Chunni. Urban Block Landscape Design Strategies from the Perspective of "Carbon Neutrality": A Case Study of Nanjing Stone City Block [J]. *Green Technology*, 2022,24(11):70-74.
- [10] Wu Ying. Innovative Design Research on Community Public Space Landscape Micro-Renovation Based on Low-Carbon Concepts [J]. *Journal of Jiamusi Vocational College*, 2023,39(8):91-93.
- [11] He Xian. Application of Green Building Design Concepts in Carbon Neutrality Context [J]. *Industrial Science and Technology Innovation*, 2023,5(1):14-16.
- [12] Hu Die and Wang Menglin. Research on Low-Carbon Rural Landscape Design from the Perspective of Carbon Neutrality [J]. *Art & Science*, 2022,35(6):203-205.
- [13] Tang Ye. Landscape Architecture Planning and Design under the Background of Carbon Neutrality [J]. *New Materials & New Decoration*, 2022,4(21):41-43.
- [14] Qu Fuyi. Discussion on Carbon Neutrality Strategies in Public Landscape Design for Low-Carbon City Construction [J]. *Residential Industry*, 2024, (3):25-28.