Research on Landscape Material Selection and Sustainable Design under Low-Carbon Principles

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Abstract: Amidst the intensifying issues of global climate change, low carbon ideas have become an urgent trend and direction for promoting urban construction and landscape design toward sustainable development. As basic components of landscape design, the selection and application of horticultural materials not only affect carbon emissions during construction but also limit the overall ecological benefits and service life of landscapes. The purpose of this paper is to systematically introduce the principles and criteria for evaluating landscape materials in accordance with low-carbon concepts. It endeavours towards investigating application routes for low-carbon materials in hardscape and softscape components, followed by the design strategies of low carbon landscapes with emergence in green building materials. Through case studies and theoretical synthesis, the paper focuses on life cycle assessment, localized material utilization, and green technological innovation as key features of future landscape design. The results of the research reveal that rational selection of materials and promotion of scientific landscape design can actually achieve a significant reduction in carbon emissions, improve the quality of ecological environment, and provide practical routes for achieving an industrial green transformation. This will provide a reference for landscape designers, practitioners and policy makers, helping to promote greening sustainable development in the low carbon framework of social economic.

1. Introduction

With intensifying global climate change and carbon emission pressures, low-carbon development has become a widely recognized consensus and action goal internationally [1]. The “carbon peak and carbon neutrality” strategy in China will shape the future for landscape architecture industry [2]. As an essential discipline of urban development, landscape architecture plays a critical role in ecological regulation, environmental beautification and cultural preservation but also greatly influences environmental sustainability via carbon emissions produced during the material selection, construction and maintenance phases [3]. From the perspective of research testing life cycle assessment, green material development or energy-saving technology applications, domestic and international scholars have studied sustainability related to landscape design [4]. But systematic low-carbon related research—especially how to practice low-carbon material selection in different landscape types and integrate the concept of low-carbon from design, construction, to maintenance—is still a gap needed to be filled.

Based on the low-carbon-oriented principle, this paper first details the basic principles and evaluation criteria for landscape material selection [5]. It then bridges to application pathways for low-carbon materials in the field of landscape design by covering their potential utilization in hardscapes, softscapes, and new green building materials. At last, from the case study and strategy research, it gives a comprehensive method and development direction for low-carbon landscape design [6]. This study is intended to serve as theoretical reference and practical inspiration for sustainable construction of the landscape, as well as a conceptual basis for green transformation in this industry.

2. Principles for Selecting Landscape Materials Under Low-Carbon Concepts

When choosing landscape materials, the focus should be on Life Cycle Assessment (LCA) [7] in

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accordance with low-carbon principles. Materials create carbon emissions in the mining, refining, shipping and building processes as well as their ongoing maintenance, and should be considered holistically for their full lifecycle environmental costs. Life-cycle assessment is a more scientific measure of a material's low-carbon value than simply focusing on economics or aesthetics. Renewable timber and permeable pavers require less energy to produce/use and contribute toward environmental regulation, making them specifically well-suited for low-carbon landscapes [8]. To evaluate the environmental impact of landscape materials, the carbon emission is calculated using the following formula:

$$C=\sum_{i=1}^{n}(E_i \times F_i) \quad (1)$$

The life-cycle carbon footprint of a material can be expressed as:

$$CF=\sum_{j=1}^{m}\left(M_j \times e_j\right)-R \quad (2)$$

To compare different materials, a normalized carbon intensity index is defined:

$$CI=\frac{C_{mat}}{A \times T} \quad (3)$$

The focus needs to move towards using materials that are locally sourced where possible so as to minimize the carbon footprint associated with transportation. By choosing common landscaping material such as stone, timber and soil from local sources, it reduces the energy expenditure of transport logistics and matches to local environmental characteristics, realizing both ecological balance and cultural harmony [9]. In addition, the use of local materials provides greater flexibility on site, reducing project duration and waste further maximizing low-carbon advantages.

Materials should have high recyclability and circularity value as one of the key ideas in low-carbon design [10]. The accumulation of solid waste in the urban mining environment has led to an inefficient use of resources and pollution. Although these purposes limit their aesthetics and strength, technological advancement and design consideration allow the effective use of these materials for pathways, paving and landscape features.

Safety of the material and ecological viability are just as much principal selection parameters as well. Low-carbon approaches fulfill a broader purpose than carbon mitigation alone, preventing human illness and promoting ecosystem health through implementation pathways. Landscape resources are to be non-toxic, innocuous and will decompose while interacting positively with neighbouring vegetation, water bodies, and soil ecosystems. Flood waters should flow steadily without interruption to prevent flooding in urban areas, while paving enhances infiltration of rainwater and increases the quality of microclimate. Only such safety- and ecologically-adaptive choices become genuinely cohesive with both low-carbon aims and sustainability.

3. Practical Application of Low-Carbon Materials in Landscape Design

Motivated by low-carbon ideals, landscape design pulls away from conventional materials. This approach not only makes it eco-friendly but also resource-conserving as a result of diverse material mixing and advanced technologies. The part of landscape design where low-carbon materials are applied mainly presents three aspects: The focus of soft landscaping is on low-carbon plant selection and the use of optimized soil substrates, which can increase carbon sequestration capacity and stormwater retention; technology development makes new green building materials more involved in landscape design, as well as energy-saving technologies. The use of photovoltaic building materials and biodegradable composites allows for further new possibilities in the field of sustainable garden design.

3.1 Application of Low-Carbon Materials in Hardscapes

Within hardscape design, permeable paving materials are the epitome of the low-carbon ethos; Not only do permeable bricks, permeable concrete, and ecological sand-based materials significantly reduce stormwater runoff and urban flooding but also recharge groundwater by infiltration and improve microclimate conditions. These materials use recycled aggregates or industrial waste as raw materials throughout the production process extending resource consumption and carbon emissions while balancing functionality and environmental sustainability.

Renewable timber is a key building material for hardscapes, often used in structures such as boardwalks, pergolas and seating. In contrast, certified sustainably harvested timber or treated reclaimed wood reduce the strain of overcision on forest resources and retain some natural texture and ecological affinity in use. Careful selection of wood species and treatment methods can allow to save resource by prolonging service life of product that have much less carbon footprint than frequent replacements.

Using waste concrete and construction debris in hardscape construction has gained steam. Discarded concrete can be processed into roadbed fill or recycled aggregate through mechanical crushing and screening, which greatly reduces carbon emissions and ecological damage by the extraction of natural sands and gravel. It not only realize resource recycling but also provides low-cost and low-energy solutions for horticultural engineering projects.

Also low-carbon significance lies in innovative applications of metals and new composite materials in hardscapes. Recyclable steel and aluminum arise as metals with greater utility in terms of reusability and biodegradable composites enter the marketplace bringing new options for landscape features and structural elements alike. These materials show more diversity, such as providing comprehensive performance of strength, aesthetics and environmental sustainability, which leads hardscapes towards low-carbon and sustainable development.

3.2 Selection of Soft Landscaping and Ecological Substrates

As the primary component of soft landscaping, plant selection based on low-carbon principles is imperative to optimize the carbon sequestration ability and ecological functions of gardens. They use native plants and low-care varieties that resist drought and poor soils, meaning less resource consumption like water and fertilizers are needed, while feeding the ecological stability of plant communities. Multi-tiered, species-prioritized vegetative promulgation systems can provide an aesthetically superior horizon potential while enhancing the quadruplication of CO_2 metabolic absorption and sequestration for dualistic exchange on low-carbon and environmental objectives. In soft landscape design, the net carbon sequestration potential of vegetation is estimated as:

$$CS = \sum_{k=1}^{p} (B_k \times r_k) - M \quad (4)$$

The rainwater regulation capacity of an ecological substrate is modeled as:

$$Q = P \times A \times \phi \quad (5)$$

Replanting and instilbing groundcover plants is another significant step to mitigate carbon emissions. Extensive conventional lawns demand significant irrigation, fertilization, and periodic mowing for their upkeep and generate a large carbon footprint. Replacing patches of lawn with low-carbon grass species, wildflower mixes — or plantings that include drought-tolerant groundcovers — not only lowers the energy budget in upkeep but also promotes biodiversity and expands the function of our ecological landscape.

Selection and optimal improvement of ecological substrates are the fundamental bases for soft landscaping. Organic fertilizers, straw fibers, or industrial byproducts used as soil amendments improve the permeability of soils and nutrient retention in soils, reducing carbon emissions from chemical fertilizer use. Low-carbon methods for landscaping materials are also enhanced with local sourcing of substrate materials for energy efficiency related to transportation.

Rain gardens and green substrate systems are becoming an innovative direction for low-carbon landscapes. When implemented as rainwater conservation systems in urban areas, they can mitigate surface runoff while enhancing the local habitat environment by constructing rainwater retention ponds, infiltration ditches and substrate layers for vegetation. It integrates water storage, purification and landscape beautification functions into one which can be a solution of low-carbon and ecological urban landscaping value.

3.3 Innovative Green Building Materials and Technologies

By combining novel green building materials and ecological technology, the eco-friendly materials are emerging as one of the key technical paths for low-carbon landscape design under new scenarios and conditions. These landscape structures can provide both energy and ecological functionalities through the integration of photovoltaic (PV) materials. Notably, PV pergolas and ground pavements not only supply clean energy to garden lighting and equipment operation but also enhance spatial actualization and the aesthetic level of technology under reducing carbon emissions.

Biocomposites are more and more used in landscape ornaments and temporary structures. Composed primarily of bio-based polymers, biodegradable plastics or agri waste, these materials break down quickly in nature leaving no post-disposal environmental burden compared to older substances. Their generally low weight and malleable nature also allow for more sculptural and artistic possibilities in landscape architecture. Figure 1 shows the distribution of lifecycle carbon emissions among various representative green building materials, Figure 1 illustrates the distribution of emissions across several representative materials:

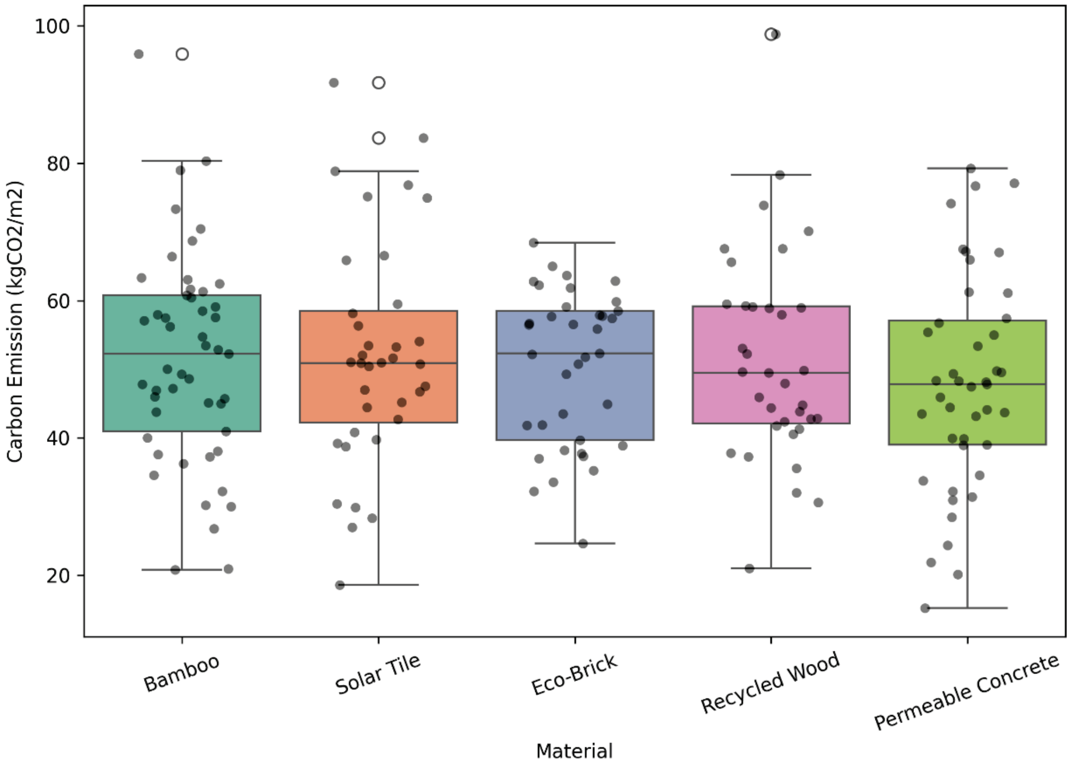

Figure 1 Lifecycle Carbon Emission Comparison of Green Materials

Emerging green insulation and translucent materials provide these new ways to conserve energy in landscape design. Low-emissivity glass (i.e., Low-E Glass), porous ceramics, and ecological translucent membranes are some examples of materials used for technologies to optimize thermal and lighting conditions, reducing dependency on artificial lighting and cooling systems. Such materials provide comfort while greatly reducing energy consumption within structures like greenhouse designs, leisure walkways or urban public spaces.

As the incorporation of high-Tech materials and digital technologies into landscape architecture enters a smart low carbon age. By using smart substrates that automatically adapt breathability and permeability in relation to temperature and humidity, as well as composite building materials embedded with IoT sensors for energy monitoring, the management of landscape environments can become more precise. This applies the new green building materials and innovative technologies to make landscape design gradually the transition from traditional ecological aesthetics toward a comprehensive low-carbon, intelligent sustainable development transformation.

4. Comprehensive Strategies and Case Studies in Low-Carbon Landscape Design

Selecting materials based on low-carbon concepts prioritizes energy conservation and emissions reduction, while overall planning and spatial construction requires systematic sustainable strategies in landscape design. In this way, the core spirit of landscape and its clear ecological value can be reflected through ecological, technological and aesthetic elements to meet functional needs while minimizing negative environmental impacts and building a harmonious relationship between human society and nature, we define the overall sustainability index of a landscape project as a weighted sum of credits in ecology, and social benefits:

$$SI = \alpha E + \beta Ec + \gamma S \quad (6)$$

A holistic landscape design is an approach to integrate low-carbon materials organically for sustainable development. Green goals are not reached just by using low-carbon materials. Spacial organization, circulation planning and functional zoning must be tuned together in with material properties of design along ecological lines. For example, in design of public plaza drainage layouts, arranging permeable paving near natural plants helps to purify stormwater runoff but also improves ecological landscape services on site. This multidisciplinary approach reinforces a systems view towards integrating low-carbon targets at each point in the design process.

One of the major purposes of urbanization is low-carbon landscape ideas, which is why more carbon-neutral landscapes are often implemented in urban public spaces. In recent years, a number of cities have begun to include green building materials and ecological design techniques in their parks, street green corridors, and waterfront areas. (Rain gardens) projects in some cities, for example, rely on drought-tolerant plants and permeable substrates to facilitate natural infiltration and storage of individual blocks of rainwater instead of overextending municipal drainage systems. For example, some ecological parks use the rubble of discarded concrete and recycled timber for landscape structures to reduce the cost of construction and highlight principles of green low-carbon design. These criminogenic examples show us that low-carbon landscapes offer ecological benefit, combined with positive social demonstration effects. Figure 2 presents the comprehensive evaluation of low-carbon landscape design strategies across multiple dimensions, including carbon reduction, water conservation, thermal comfort, biodiversity, and economic benefits:

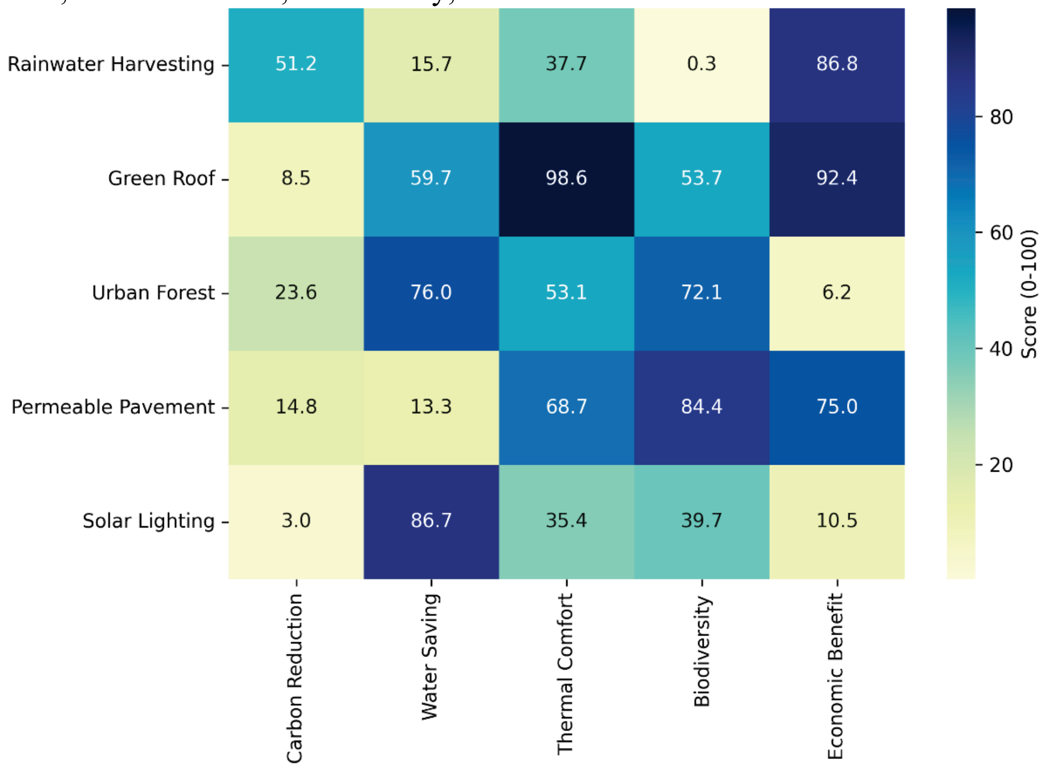

Figure 2 Comprehensive Benefits of Low-Carbon Landscape Strategies

From a landscape design industry development standpoint, low-carbon landscape design presents fresh challenges and opportunities for new concepts to be developed by designers and practitioners. Designers need to have broad-based knowledge cutting across areas of materials science, ecology and even engineering technology. The industry should also advocate for policies and standards that promote low-carbon materials, establish carbon emission assessment systems and refine green building material certification mechanisms. Under the influence of technological innovation and institutional system, low-carbon landscape design will evolve from a single case to common practice, which further promotes the green transformation of the whole horticultural industry.

5. Conclusion

The new transformation and challenge have emerged, against the background that low-carbon development has become a global consensus. It systematically summarizes the principles of low-carbon concept for landscape material selection, and analyze its corresponding applications in hardscape and softscape elements, while directing to innovative developing paths for new type green building materials and technologies. The key principles for the selection of low-carbon materials should be life cycle assessment, local utilization, recyclable property and ecological adaptability. In practice, careful use of various low-carbon materials and technologies—like permeable paving, native plants, recycled concrete and photovoltaic building materials—can drastically lower carbon emissions while retaining or enhancing the ecological benefits and social value of landscapes.

According to the case studies, low-carbon landscapes are environmentally valuable and can produce exemplary responses in urban public space construction, promoting wider diffusion and application of green concepts. Currently, the use of low-carbon materials is limited by cost, technology availability and incomplete standard systems. This calls for designers and industry practitioners to continuously innovate advances through interdisciplinary integration. It is not only an important measure to deal with climate change, but also an inevitable trend of the green transformation of the horticultural industry. We will also strengthen research and evaluation on performance of low-carbon materials, as well as policy support and industry standards. This will promote the deep integration of green building materials and smart technology, and realize the coordinated development of ecological value, social benefits, economic efficiency in landscape architecture.

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