

Development and Practical Exploration of Prefabricated Buildings from a Green Environmental Perspective

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Abstract: *As global environmental awareness increases, the concept of green building has gradually become a development trend in the construction industry. Prefabricated buildings, as an efficient and environmentally friendly building model, have significant advantages in energy saving, emission reduction, and improving construction efficiency. From the perspective of green environmental protection, this paper explores the development and practical paths of prefabricated buildings. Firstly, it outlines the concept and characteristics of green buildings and prefabricated buildings, analyzing the advantages of combining the two; then, it reviews the development status and technological progress of prefabricated buildings domestically and internationally; finally, it proposes specific practical paths for green prefabricated buildings, including the selection and application of green building materials, green construction technologies and processes, adaptability to different climatic conditions, and the management and maintenance of green buildings. The research results show that prefabricated buildings from a green environmental perspective have broad development prospects. Through technological innovation and management optimization, sustainable building development can be achieved.*

Keywords: *Green environmental protection, prefabricated buildings, green buildings, technological progress, practical paths*

1. Introduction

In the context of increasingly severe global environmental issues, the concept of green buildings has emerged, aiming to reduce the negative impact of buildings on the environment and promote sustainable development. Prefabricated buildings, as a prefabricated, modular building method, are gaining increasing attention in the industry due to their advantages in resource conservation, construction efficiency improvement, and environmental protection. Combining the concept of green buildings with prefabricated buildings can maximize the environmental benefits throughout the building's life cycle.

This study aims to explore the development paths and practical applications of prefabricated buildings from a green environmental perspective. By systematically analyzing the integration points of green building concepts and prefabricated buildings, reviewing the development status and technological progress of prefabricated buildings domestically and internationally, it proposes practical and operational green prefabricated building paths. The necessity of this research lies in promoting sustainable development in the construction industry through the organic combination of green environmental concepts and prefabricated buildings, meeting the growing demand for environmental protection.

2. Integration of Green Environmental Protection and Prefabricated Buildings

2.1 Overview of Green Building Concepts

Green building concepts are architectural design and construction methods centered on environmental protection and resource conservation. The goal is to reduce energy consumption, lower environmental pollution, and enhance the health and comfort of living and working environments throughout the building's lifecycle through proper planning and utilization of natural resources. Green buildings emphasize sustainability, considering various stages of a building's lifecycle, including site selection, design, construction, operation, maintenance, and demolition, to achieve efficient resource utilization and minimal environmental impact.

The core principles of green building include energy conservation, water conservation, material

conservation, environmental protection, and improvement of indoor environmental quality. These principles are implemented through specific measures such as the application of renewable energy, efficient equipment, optimized building design, and the use of eco-friendly materials. For example, technologies and materials like solar photovoltaic power generation, rainwater harvesting systems, high-efficiency insulation materials, and low volatile organic compound (VOC) paints help achieve green building goals. Additionally, green buildings emphasize intelligent management, using information technology for energy monitoring, environmental monitoring, and intelligent control, further enhancing the environmental performance and efficiency of buildings.

2.2 Concept and Characteristics of Prefabricated Buildings

Prefabricated buildings involve the prefabrication and modularization of building components, which are then quickly assembled on the construction site. Compared to traditional construction methods, prefabricated buildings have notable characteristics such as shorter construction cycles, strict quality control, and minimal environmental impact. The core of prefabricated buildings lies in the production of prefabricated components and efficient on-site assembly, reducing the complexity and uncertainty of on-site construction while significantly lowering construction waste and noise pollution.^[1]

Prefabricated buildings mainly include forms such as precast concrete components, steel structures, and wood structures. Their specific characteristics are as follows:

Efficient Construction: The prefabricated components of prefabricated buildings are produced in factories, with on-site assembly work significantly shortening the construction cycle and improving construction efficiency.

Quality Assurance: Standardized production and quality control in factories ensure high precision and quality of components, reducing construction errors.

Environmental Protection and Energy Efficiency: Prefabricated buildings reduce resource waste and environmental pollution during on-site construction. The high reuse rate of prefabricated components aligns with sustainable development requirements.

Flexible Design: The modular design of prefabricated buildings allows for more flexible and diverse architectural designs, quickly adapting to market demands and functional changes.

2.3 Integration Points of Green Building and Prefabricated Building

The integration of green building concepts and prefabricated buildings is an important pathway to achieving sustainable development in the construction industry. The integration points mainly include:

Efficient Resource Utilization and Energy Conservation: Prefabricated buildings reduce material waste and energy consumption through factory prefabrication, aligning with the energy-saving principles of green buildings. Additionally, prefabricated buildings can better utilize efficient insulation materials, energy-saving doors and windows, and renewable energy systems to enhance overall building energy efficiency.

Minimization of Environmental Impact: Prefabricated buildings reduce on-site construction time, lowering noise and dust pollution, thus protecting the ecological environment of the construction site and its surroundings. This aligns with the green building goal of being environmentally friendly and reducing pollution.

Application of Sustainable Building Materials: Prefabricated buildings can extensively use green and eco-friendly materials such as low-carbon cement, recycled steel, renewable wood, further reducing the carbon footprint and environmental load of buildings. Additionally, the modular design of prefabricated buildings facilitates dismantling and reuse, adhering to the circular economy concept of green buildings.^[2]

Intelligent Management and Operation: Both prefabricated buildings and green buildings emphasize the application of intelligent technology. Through intelligent monitoring systems and energy management systems, efficient operation and maintenance of buildings can be achieved. For example, intelligent environmental monitoring systems can monitor indoor air quality, temperature, and humidity in real-time, ensuring a healthy and comfortable indoor environment.

3. Development of Prefabricated Buildings from a Green Environmental Perspective

3.1 Development Status of Prefabricated Buildings Domestically and Internationally

In recent years, prefabricated buildings have rapidly developed globally, becoming an important part of the construction industry. Driven by green environmental protection concepts, prefabricated buildings have not only achieved industrialization and modernization but also effectively reduced environmental load, promoting sustainable development.

3.1.1 International Development Status

Internationally, prefabricated buildings have become a significant direction for the development of the construction industry in many countries. Nordic countries like Sweden and Finland are known for their mature prefabricated building technology and strict environmental standards. Sweden's prefabricated building market penetration rate exceeds 80%, with success mainly attributed to standardized design, modular production, and efficient construction management systems. Additionally, Japan has also seen mature development in prefabricated buildings, mainly using steel structures and precast concrete components, showing superior seismic performance in earthquake-prone areas.

In the United States, although the development of prefabricated buildings started later, the concept has gradually gained attention with the popularization of green building ideas. Prefabricated buildings in the U.S. are mostly used in residential and commercial buildings, especially in multi-story and high-rise buildings. European countries like the UK and Germany are also actively promoting prefabricated buildings, with governments supporting policies and financial incentives to encourage the application and marketization of prefabricated building technology.

3.1.2 Domestic Development Status

In China, the development of prefabricated buildings has experienced a process from initiation to rapid growth. Since the State Council issued the "Guiding Opinions on Vigorously Developing Prefabricated Buildings" in 2016, various local governments have introduced a series of policies and measures to promote the development of prefabricated buildings. China's prefabricated building market has rapidly expanded, with application fields continuously expanding to include residential, office buildings, schools, hospitals, and more.^[3]

The development of prefabricated buildings in China is mainly concentrated in several major cities and economically developed regions, such as Beijing, Shanghai, Shenzhen, and Guangzhou. These areas have advantages in policy support, technological research and development, and market demand, with a significant increase in the number and scale of prefabricated building projects. Domestic construction enterprises actively introduce advanced international technologies and combine them with local conditions to gradually form a prefabricated building technology system suitable for China's national conditions.

3.2 Technological Progress of Green Prefabricated Buildings

The technological progress of green prefabricated buildings is crucial for achieving sustainable development in the construction industry. Through continuous innovation and optimization, prefabricated buildings have made significant achievements in the field of green environmental protection, mainly in the following aspects:

3.2.1 Green Building Materials

Green prefabricated buildings focus on environmental protection and sustainability in material selection. The application of green building materials such as low-carbon cement, recycled steel, renewable wood, and eco-friendly insulation materials significantly reduces the carbon footprint of buildings. For example, low-carbon cement reduces carbon dioxide emissions during production, and recycled steel reduces resource consumption and environmental pollution by recycling waste steel. The use of renewable wood not only has excellent carbon sequestration capabilities but also provides superior insulation and soundproofing for buildings.

3.2.2 Prefabricated Components and Modular Design

Prefabricated components and modular design are the core technologies of prefabricated buildings. Through factory production of prefabricated components, a high-precision, high-quality, and efficient construction process can be achieved. Modular design allows for more flexible building structures that

can be combined and expanded according to different needs. The standardized production of prefabricated components and modular design not only improves construction efficiency and reduces material waste but also significantly lowers environmental pollution at construction sites.

3.2.3 Intelligent Construction Technology

The application of intelligent construction technology makes prefabricated buildings greener and more efficient. The use of Building Information Modeling (BIM) technology in prefabricated buildings allows for precise design, construction, and management, improving the overall efficiency of building projects. Intelligent construction equipment and monitoring systems, such as drone inspections, automated hoisting, and sensor monitoring, can monitor construction progress and quality in real-time, ensuring a safe and environmentally friendly construction process.

3.2.4 Energy Saving and Emission Reduction Technology

Green prefabricated buildings perform well in energy saving and emission reduction. By applying efficient insulation materials, energy-saving doors and windows, and renewable energy systems such as solar photovoltaic power generation and ground source heat pumps, buildings' energy consumption can be significantly reduced. Additionally, intelligent energy management systems can monitor and regulate buildings' energy use in real-time, improving energy efficiency and reducing carbon emissions.

3.2.5 Lifecycle Management

Green prefabricated buildings emphasize the environmental benefits throughout the building's lifecycle. Every stage, from design, construction, operation to demolition, focuses on efficient resource utilization and minimal environmental impact. The application of lifecycle management technologies, such as Lifecycle Assessment (LCA) and intelligent operation management systems, ensures that buildings maintain efficient and environmentally friendly operation throughout their lifecycle.

4. Practical Paths of Green Prefabricated Buildings

4.1 Selection and Application of Green Building Materials

The selection and application of building materials are crucial factors in the development of green prefabricated buildings. Green building materials must not only possess environmental performance but also exhibit excellent physical and chemical properties to ensure the safety and durability of buildings. The following principles guide the selection and application of green building materials:

Renewable Materials: Renewable materials such as bamboo and wood have good environmental performance and carbon sequestration capabilities. These materials can absorb carbon dioxide during their growth, reducing greenhouse gas emissions. Additionally, they have long lifespans and strong renewability, effectively reducing resource consumption.

Recycled Materials: Recycled materials like recycled concrete and steel reduce resource waste and environmental pollution through the recycling and reuse of construction waste. For example, recycled concrete not only possesses good strength and durability but also significantly reduces carbon emissions during production.

Low-Carbon Materials: Low-carbon materials such as low-carbon cement and eco-friendly insulation materials exhibit low carbon footprints during production and use. Low-carbon cement reduces energy consumption and carbon dioxide emissions by optimizing production processes. Eco-friendly insulation materials like polyurethane foam and rock wool offer excellent insulation, fire resistance, and durability.^[4]

Eco-Friendly Coatings: The application of eco-friendly coatings like low volatile organic compounds (VOC) and water-based paints helps reduce harmful gas emissions, improve indoor air quality, and ensure the environmental and safety standards of buildings.

4.2 Green Construction Technologies and Processes

Green construction technologies and processes play a crucial role in the practice of prefabricated buildings. Through the innovation and optimization of construction technologies, efficient, safe, and environmentally friendly construction processes can be achieved. The main aspects include:

Prefabrication Technology: Prefabrication technology is the core of prefabricated buildings. By producing prefabricated components in factories and assembling them on-site, construction efficiency is

improved, and construction waste and noise are significantly reduced. For instance, prefabricated concrete wall panels, floor slabs, and beams can be standardized and produced in factories to ensure high quality and precision.

Modular Construction: Modular construction involves the standardization of design and modular production, breaking down buildings into standardized modules for factory prefabrication and on-site assembly. Modular construction shortens the construction period, enhances building flexibility and adaptability, and is suitable for various building types and scales.

Intelligent Construction Equipment: The application of intelligent construction equipment such as automated lifting systems, drone inspections, and robotic construction improves the safety and efficiency of the construction process. Drones can monitor construction sites in real-time to ensure quality, while robotic construction can perform high-precision operations in complex and hazardous environments, reducing the risks associated with manual labor.

Energy-Efficient Construction Technology: Energy-efficient construction technologies, such as the use of low-energy equipment and temporary solar power systems, help reduce energy consumption and carbon emissions during construction. By optimizing construction processes and equipment configurations, energy conservation and emission reduction can be achieved, enhancing the environmental benefits of construction.^[5]

4.3 Adaptability of Prefabricated Buildings to Different Climatic Conditions

The adaptability of prefabricated buildings to different climatic conditions is crucial for achieving green environmental protection. Measures need to be taken during design and construction to ensure the comfort and energy efficiency of buildings in various climates:

Adaptability in Cold Climates: In cold climates, prefabricated buildings need to focus on insulation and thermal performance. Using high-efficiency insulation materials such as polyurethane foam and rock wool can enhance the insulation of exterior walls, roofs, and floors. Additionally, equipping buildings with high-performance energy-efficient windows and doors reduces heat loss. Combining this with ground source heat pump systems, which utilize stable underground temperatures, provides efficient heating and cooling.

Adaptability in Hot Climates: In hot climates, prefabricated buildings need to emphasize cooling and ventilation design. Measures such as using shading panels, reflective materials, and green roofs reduce solar radiation's heat load on buildings. Natural ventilation designs and intelligent ventilation systems can effectively lower indoor temperatures and improve living comfort. Additionally, using solar photovoltaic systems provides clean energy and reduces reliance on traditional power sources.

Adaptability in Rainy Climates: In rainy climates, prefabricated buildings need to focus on waterproofing and drainage design. Using high-quality waterproof materials such as waterproof membranes and coatings ensures the building structure's seal and durability. Designing efficient drainage systems, such as roof drainage channels and rainwater harvesting systems, prevents water accumulation from damaging buildings and allows for rainwater reuse, enhancing water resource utilization efficiency.

4.4 Management and Maintenance of Green Prefabricated Buildings

The management and maintenance of green prefabricated buildings are key to ensuring their efficient and environmentally friendly operation throughout their lifecycle. Scientific management and maintenance measures can extend building lifespans and improve performance:

Lifecycle Management: The lifecycle management of green prefabricated buildings covers the entire process from design, construction, operation to demolition. Lifecycle assessment (LCA) technology analyzes the environmental impact and resource consumption of buildings throughout their lifecycle, optimizing design and construction plans to reduce environmental load.

Intelligent Management and Maintenance Systems: The application of intelligent management and maintenance systems achieves smart monitoring and maintenance of buildings. Using Internet of Things (IoT) technology, intelligent monitoring systems can be established to monitor energy consumption, environmental quality, and equipment operation in real-time, identifying and addressing issues promptly. Intelligent maintenance systems use monitoring data to develop scientific maintenance plans, optimizing resource allocation and improving maintenance efficiency.

Green Operation and Maintenance Strategies: Green operation and maintenance strategies include energy conservation, resource reuse, and environmental protection. High-efficiency energy-saving equipment and technologies reduce energy consumption and carbon emissions. Implementing resource reuse strategies, such as rainwater harvesting and waste recycling, increases resource utilization efficiency. Environmental protection measures, such as greening and beautification and noise control, improve environmental quality and user comfort.^[6]

Education and Training: Training management and maintenance personnel in green building technologies and management knowledge improves their professional skills and competence, ensuring the management and maintenance level of green prefabricated buildings. Establishing user education systems raises users' environmental awareness and energy-saving behaviors, promoting the widespread application of green building concepts.

5. Conclusion

The integration of green building concepts with prefabricated buildings can effectively enhance the environmental performance of buildings, achieving efficient resource utilization and minimal environmental impact. Supported by policies and technological innovations, prefabricated buildings have made significant progress domestically and internationally, demonstrating promising market applications for green prefabricated buildings.

Future research directions include further deepening the innovation of green technologies in prefabricated buildings, developing more efficient and eco-friendly building materials and construction processes, strengthening the management of green buildings throughout their lifecycle, promoting the application of intelligent management and maintenance systems, and fostering international cooperation and exchange to learn from global experiences in green and prefabricated buildings, driving sustainable development in the industry.

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