Research on Sustainability and Economic Efficiency of Structural Design under the Concept of Green Building

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Abstract: In the context of global advocacy of sustainable development, the transformation of the construction industry to green has become an inevitable trend. This article focuses on the sustainability and economy of structural design under the concept of green building. Through theoretical analysis, the concept of green building and related theoretical basis of structural design are sorted out, and the sustainable elements such as structural system selection, material selection, durability design, and the embodiment of economic elements in design scheme, construction, operation and maintenance stages are analyzed. Different structural systems and building materials have different effects on sustainability and economy, and the economic factors in each stage are interrelated. It is suggested that the comprehensive design concept should be established and the balance strategy such as simulation analysis technology should be used. The research shows that the balance between the two needs to be coordinated in many aspects, which is of great significance to promote the development of green buildings and achieve a win-win situation of environmental, economic and social benefits.

1. Introduction

With the increasingly severe global environmental problems and the aggravation of resource shortage, sustainable development has become an important theme of social development today [1]. In the field of architecture, the concept of green building came into being and quickly became the inevitable trend of industry development [2]. Green building is committed to saving resources, protecting the environment and reducing pollution to the maximum extent in the whole life cycle of the building, and providing people with healthy and applicable use space [3]. As a key link in architectural design, structural design plays an important role in achieving the goal of green building. Under the concept of green building, structural design should not only meet the safety and functional requirements of buildings, but also pay attention to the balance between sustainability and economy [4]. Sustainable structural design is helpful to reduce the negative impact of buildings on the environment and improve the efficiency of resource utilization. The economy ensures that while achieving the green goal, the construction cost is controlled and the economic benefit is maximized.

Many international studies have been carried out on the sustainability and economy of green building structural design. Some countries started early in this field and have formed a relatively perfect theoretical system and practical experience. Some developed countries have promoted the wide application of sustainable structural design by formulating strict green building standards and norms [5]. With the vigorous promotion of green buildings, China has also made remarkable progress in theoretical research and engineering practice. However, there are still some shortcomings in the current research.

Under this background, it is of great practical significance to study the sustainability and economy of structural design under the concept of green building. On the one hand, it is helpful to improve the theory of green building structure design and provide designers with more scientific and comprehensive design basis; On the other hand, it can promote the construction industry to develop in a greener and more economical direction, and realize a win-win situation of

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environmental benefits, economic benefits and social benefits. The purpose of this article is to deeply discuss the related issues of sustainability and economy in the structural design of green buildings through theoretical analysis and other methods, and put forward practical balance strategies to contribute to the sustainable development of green buildings.

2. Green building concept and related theories of structural design

The concept of green building takes the idea of sustainable development as the core, emphasizing the harmonious symbiosis between architecture and natural environment. It runs through the whole life cycle of building site selection, design, construction, operation and demolition, involving energy utilization, environmental protection, resource conservation and indoor environmental quality [6-7]. Its goal is to reduce the damage of construction activities to the ecological environment, improve the utilization efficiency of energy and resources, and create a healthy, comfortable and environmentally friendly space environment for users. As the skeleton support of architecture, structural design is based on a series of scientific theories. Mechanics principle is the cornerstone of structural design, including statics, material mechanics and structural mechanics. With the help of these mechanical knowledge, designers can accurately analyze the internal force and deformation of the structure under various loads to ensure the safety and stability of the structure [8]. Material characteristics are also important factors to be considered in structural design. Different building materials have different properties, such as strength, elastic modulus and durability. Reasonable selection of materials is very important to the structural performance and the overall effect of the building.

Under the concept of green building, there is a close theoretical relationship between the sustainability of structural design and economy. Sustainability focuses on long-term environmental benefits and rational utilization of resources, while economy focuses on short-term and long-term cost control [9]. In the long run, sustainable structural design may increase some investment in the early stage, but by reducing energy consumption and prolonging the service life of buildings, it can save a lot of costs and achieve economic goals in the construction operation stage. This balanced relationship requires designers to comprehensively consider various factors in the design process and seek the optimal combination of sustainability and economy in order to maximize the comprehensive benefits of green buildings.

3. Sustainable elements of green building structural design

In the structural design of green buildings, sustainability factors cover many key aspects and play a decisive role in the long-term development and environmental friendliness of buildings. The first is the choice of structural system. There are significant differences in resource consumption and environmental impact among different structural systems. Taking frame structure, shear wall structure and frame-shear wall structure as examples (see Table 1), the spatial layout of frame structure is flexible, the construction speed is relatively fast, but the lateral stiffness is weak, so it may be needed to consume more materials to ensure stability in high-rise buildings; Shear wall structure has high lateral stiffness and good seismic performance, but its space division is relatively limited, and the amount of wall materials is more; Frame-shear wall structure combines the advantages of both, but the complexity of design and construction has increased. Structural designers should weigh the advantages and disadvantages of each structural system and choose the most sustainable scheme according to the functional requirements, height and site conditions of the building.

Table 1 Comparison of Characteristics of Common Structural Systems

Structural System	Spatial Flexibility	Lateral Stiffness	Construction Speed	Material Consumption
Frame Structure	High	Moderate	Relatively Fast	Relatively High (for high-rise

				stability)
Shear Wall Structure	Low	High	Moderate	High
Frame-Shear Wall Structure	Relatively High	Relatively High	Relatively Slow	Moderate

Secondly, the selection of building materials is very important. Renewable materials, such as wood, have good ecological performance, can absorb carbon dioxide in the growth process, and the processing energy consumption is low. However, large-scale use needs to pay attention to the sustainable management of forest resources. Low energy consumption materials, such as aerated concrete blocks, have good thermal insulation performance and low energy consumption in the production process, which can effectively reduce energy consumption in the construction stage. In addition, the use of local materials can reduce carbon emissions during transportation and improve the stability of material supply. Furthermore, structural durability design is an important guarantee for sustainability. Reasonable durability design can prolong the service life of buildings, reduce the demolition and reconstruction caused by premature structural damage, and thus reduce the repeated consumption of resources. This involves the protective measures of structural members, such as the anti-corrosion treatment of steel bars in concrete structures and the waterproof design of maintenance structures outside buildings. Futhermore, considering the maintainability and repairability of the structure in the design stage is also helpful to prolong the service life of the structure and realize the sustainable development of the building. Through the comprehensive consideration and optimization design of the above sustainable elements, the sustainable development goal can be better realized in the structural design of green buildings.

4. Economic elements of green building structure design

The economic elements of green building structural design run through all stages of construction projects and have a key impact on the overall cost control. In the stage of design scheme, the choice of structural form plays a decisive role in the project cost. For example, the selection of foundation form needs to comprehensively consider geological conditions, building loads and other factors. Taking common independent foundations, raft foundations and pile foundations as examples (see Table 2), independent foundations are suitable for situations with good soil quality and small load, with relatively simple construction technology and low cost; Raft foundation has good integrity and can bear large loads, but the amount of concrete and steel bars is large and the cost is high. Pile foundation is often used in soft foundation. By transferring the load to the deep solid soil layer, its cost is not only affected by the pile type, but also closely related to the pile length. The economic differences of different foundation forms in different scenarios are obvious, and designers need to analyze them accurately and select the models reasonably.

Table 2 Economic Comparison of Different Foundation Types

Foundation Type	Applicable Conditions	Main Material Consumption (per m^2)	Unit Cost (RMB/m^2)
Isolated Foundation	Good soil, light load	Concrete: 0.3-0.5m^3, Rebar: 20-30kg	300-500
Raft Foundation	Low bearing capacity, heavy load	Concrete: 0.8-1.2m^3, Rebar: 40-60kg	800-1200
Pile Foundation	Soft soil conditions	Concrete: varies by pile type/length, Rebar: varies	1000-2000 (adjustable based on pile type & length)

In the process of construction, structural design also profoundly affects the economy. Complicated structural design may increase the difficulty of construction, thus increasing labor costs and construction equipment rental expenses, and may also extend the construction period. For example, special-shaped structures or long-span structures have unique advantages in architectural modeling and space use, but they require high construction technology, and formwork engineering and steel binding are more complicated. It is estimated that the labor cost of the structure with greater construction difficulty may increase by 20%-30% compared with the conventional structure. Futhermore, the extension of the construction period means the increase of management costs, such as venue rental fees and occupation cost.

5. Balance strategy and development trend of sustainability and economy

At the level of design philosophy, it is needed to establish a comprehensive consideration concept. Designers need to abandon the previous design approach that only focuses on a single indicator and place equal importance on sustainability and economic indicators. In the design of green building structures, the selection of materials is crucial for sustainability and economy. Table 3 compares the full life cycle assessment of common traditional concrete and new aerated concrete blocks.

Table 3 Life Cycle Assessment Comparison: Traditional Concrete vs. AAC Blocks

Assessment Item	Traditional Concrete	AAC Blocks
Initial Procurement Cost (RMB/m²)	120	100
Construction & Installation Cost (RMB/m²)	30	25
Energy Consumption Cost (RMB/year·m²)	12	8
Maintenance Cost (RMB/5 years·m²)	25	10
Service Life (years)	50	60
Environmental Impact Score (1-10, 10=best)	4	7

Traditional concrete is widely used, with high strength and good durability, but its production process has high energy consumption and large carbon emissions. Aerated concrete block is a new type of environmental protection wall material, which has the advantages of light weight, good thermal insulation and sound insulation, and can be cut and formed with woodworking tools. From the technical point of view, the use of advanced simulation analysis technology can help balance the relationship between the two. Through building performance simulation software, energy consumption, lighting, ventilation and other performance indexes of buildings under different structural design schemes can be predicted, and the optimal scheme can be selected by combining cost budget analysis. For example, in the structural system optimization, with the help of finite element analysis software, the mechanical properties and economy of different structural arrangements are analyzed, and the material consumption and construction difficulty are reduced on the premise of meeting the safety and functional requirements.

As far as the development trend is concerned, the structural design of green buildings will pay more and more attention to intelligence and integration. Intelligent structural monitoring system can track the state of building structure in real time, warn potential problems in advance, reduce maintenance costs and safety risks, prolong the service life of buildings and enhance sustainability. The integrated design emphasizes the coordination of architecture, structure, equipment and other disciplines to reduce the waste of resources and cost increase caused by poor connection of all links. The continuous emergence of new materials and technologies also provides more possibilities for balancing sustainability and economy. For example, high-performance composite materials have excellent mechanical properties and environmental protection characteristics. Although the initial cost is high, in the long run, good economic benefits can be achieved by reducing maintenance and energy consumption costs.

6. Conclusions

This study focuses on the sustainability and economy of structural design under the concept of green building. In terms of sustainability, structural system, selection of building materials and durability design are very important to reduce the impact of the building environment and improve the efficiency of resource utilization. Different structural systems have their own advantages and disadvantages, for example, the space of frame structure is flexible, but the stability of high-rise buildings needs more materials; Renewable and low-energy materials can reduce energy consumption and environmental damage; Reasonable durability design can prolong building life and reduce repeated consumption of resources. Economic factors run through the stages of design, construction and operation and maintenance. The choice of foundation form and structural system in the design scheme directly affects the cost; Complex design in construction stage increases cost and construction period; In the operation and maintenance stage, reasonable design can reduce maintenance and energy consumption costs. However, there are often contradictions between sustainability and economy, and high sustainability measures may be accompanied by high initial costs. For this reason, to achieve the balance between the two, we need to establish the concept of comprehensive consideration and optimize the design by means of simulation analysis and other technical means. Although the adoption of new materials and technologies may increase the initial investment, it can achieve good economic benefits in the long run. In the future, intelligence and integration are the development direction, which can help to better balance the relationship between them.

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