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The Discourse and Investigation Regarding the Advancement of Prefabricated Concrete Building Technology

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Abstract: With the advancement of construction industrialization, there is an increasing utilization of precast concrete in construction projects to expedite the pace of construction and ensure the structural integrity. Prefabricated Construction is one of the modern construction techniques where some components of a structure or an entire structure are manufactured in a controlled environment and then installed on the construction site. This paper aims to provide a comprehensive discussion on the research, advancement, and utilization of construction technology for prefabricated concrete structures. Initially, it presents an overview of the background and associated concepts related to prefabricated concrete buildings. Subsequently, it examines the global advancements made in its development while emphasizing its benefits and practical applications in engineering projects. Lastly, it delves into enhancement techniques for prefabricated concrete constructions across three key stages: production, construction and installation, as well as subsequent maintenance. This paper finds that prefabricated concrete structures are increasingly being embraced as the primary focus for the future advancement of the construction sector, offering not only shorter construction timelines but also enhanced environmental sustainability by mitigating pollution associated with traditional building methods and elevating project quality.

Keywords: prefabricated concrete structure, performance analysis, development situation, improvement approach.

1. Introduction

The prefabricated concrete structure constitutes a pivotal component of residential industrialization, offering superior resource utilization compared to the cast-in-place concrete construction method. This alternative approach not only shortens the construction period but also yields greater economic benefits by reducing material and energy consumption. Consequently, it possesses significant developmental potential in China as well as globally[1].

The design and construction process of prefabricated concrete buildings typically involves the utilization of precast columns, beams, floors, stairs, and external wall panels. In practice, the most commonly employed approach is to assemble these one-dimensional components into a frame structure system with rigid joint connections. The performance of this system is essentially equivalent to that of cast-in-place structures in terms of seismic resistance, design methodology, and applicable

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height[2]. Prefabricated buildings originated in Europe and have been widely adopted globally, particularly for post-war reconstruction and residential construction projects[3].

The development of prefabricated buildings is no longer solely focused on quality and cost performance, but rather places greater emphasis on cost reduction, environmental impact mitigation, and the advancement of resource-recycling buildings. To promote the sustainable growth of prefabricated concrete buildings, it is imperative to shift from a singular pursuit of energy efficiency and environmental friendliness towards a more intricate design approach that caters to individual needs[4]. Furthermore, there should be an enhanced focus on establishing comprehensive standards for prefabricated building construction. Additionally, the application value of Building Information Modeling(BIM) and Artificial intelligence(AI) technology holds significant potential in optimizing the entire life cycle of prefabricated buildings[5].

This paper provides an objective analysis of the advantages and disadvantages of prefabricated concrete in practical applications, as well as its potential areas for improvement, through a comprehensive case study and extensive literature review. Additionally, it presents a concise overview of the domestic and international development of this technology. In summary, prefabricated concrete buildings have a strong position in the construction sector and offer promising growth opportunities through technological advancements and standardized systems to meet modern architectural design requirements.

2. Prefabricated concrete building development overview

Prefabricated concrete buildings have the characteristics of high factory pre-system, controllable prefabrication environment, significantly reduced construction period and high technical installation level requirements, which can effectively improve the construction efficiency and quality, make the building design more effectively adapt to the actual needs, and be less affected by the construction environment. But at the same time, there are high costs and high precision requirements of technical problems[6-7].

2.1. Advantages of Prefabricated Concrete Buildings

2.1.1. Standards for quality of structural components

The quality of precast concrete structures is ensured by precast concrete plants through the formulation of precise production specifications.

Prefabricated concrete structures offer improved efficiency, and enhanced project quality, and address limitations of on-site casting through factory production. This method allows for precise control over manufacturing processes, minimizes potential issues, eliminates weather-related constraints, enables parallel workflows, reduces labor requirements, and shortens project timelines [7].

2.1.2. Short construction period and high efficiency

The drawbacks of cast-in-place structures are addressed through factory processing and on-site assembly, leading to enhanced production efficiency and engineering quality. Additionally, this construction method significantly reduces the construction cycle, minimizes expenditure costs, and improves overall construction quality and efficiency.

Since the building parts can be maintained in the factory, the degree of seasonal impact is small, and normal construction can be carried out throughout the year, thus ensuring the safety and reliability of the construction process[8].

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2.1.3. Minimal impact on the environment

Prefabricated concrete buildings can effectively improve the building quality, extend the life of residential buildings, and realize energy saving and material saving in the whole life cycle of residential buildings[7].

Additionally, this approach to construction not only focuses on sustainability but also prioritizes the efficient use of resources. By incorporating eco-friendly materials and energy-saving technologies, it minimizes waste production and reduces carbon emissions. Moreover, this sustainable construction method promotes a healthier living environment by utilizing natural ventilation systems and maximizing natural light penetration. It also considers the long-term impact on the surrounding ecosystem by implementing measures to protect biodiversity and preserve green spaces.

Overall, this approach offers a holistic solution that balances environmental responsibility with practical benefits such as cost savings and improved quality of life for residents.

2.2. The development status at home and abroad

In recent years, precast concrete structure as an efficient construction technology has attracted wide attention and research in the country. Internationally, developed regions such as Europe and the United States have been exploring these systems since the 17th century, aiming to improve construction efficiency, reduce costs, and reduce environmental impact[9]. In Europe and other countries, there is a greater emphasis on environmental protection and energy efficiency[10].

The development of prefabricated concrete buildings in Germany has a rich historical background and extensive technical expertise. Germany boasts a comprehensive and well-established standard specification system for prefabricated buildings, which sets forth stringent technical performance requirements encompassing structural safety, fire resistance, environmental sustainability, and non-toxicity[11]. These standards not only ensure the quality and safety of prefabricated buildings but also foster continuous technological innovation and advancement.

Japan and South Korea have learned from the experience of Europe and the United States, combined with their own actual conditions and needs in the prefabricated structure, volume of seismic resistance and isolation design has made breakthrough progress[12].

In China, research has focused on combining traditional construction methods with modern technologies to achieve standardized design of precast concrete structures and promote the development of modular industrial production[7]. Due to construction site and environmental constraints, prefabricated buildings are very common in Hong Kong and Taiwan, and most high-rise residential buildings use stacked floors, prefabricated stairs and prefabricated exterior walls [10,12].

The penetration rate of prefabricated buildings in some countries is shown in Figure 1:

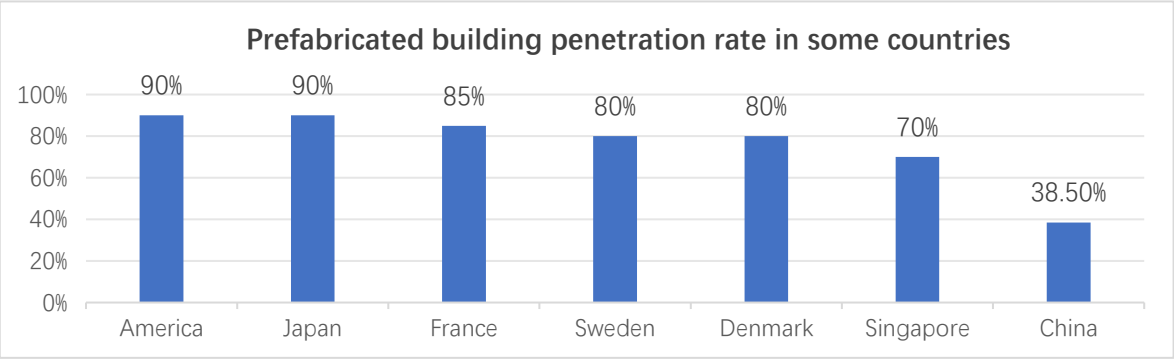

Figure 1: Prefabricated building penetration rate in some countries(Prospective Industry Research Institute)

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2.3. Common problems in prefabricated concrete buildings

Although prefabricated concrete construction has broad development prospects in the world, it still faces some challenges, including cost control, technical difficulties, and a lack of professionals. Solving these problems requires the joint efforts of the government, enterprises and research institutions[13].

Firstly, in the actual construction of prefabricated concrete structures, there often exist disparities between the idealized assumptions made during the design phase and the realities encountered during construction. Designers operate under ideal conditions when formulating their plans, often overlooking various intricate circumstances that may arise on-site, such as technological limitations, environmental constraints, and material performance discrepancies. Consequently, this frequently gives rise to a discrepancy between design intent and actual implementation[10].

Secondly, prefabricated components rely on factory production; however, due to the extensive scale of production, lengthy assembly lines, and intricate interconnections among various stages, factories often encounter challenges in maintaining consistently high standards of quality control throughout each stage[14]. Consequently, this frequently results in performance variations across different batches of components. Additionally, during transportation and storage processes, prefabricated components are susceptible to environmental factors that can significantly impact their performance.

The presence of numerous construction links in prefabricated concrete structures indicates a strong level of professionalism. However, due to the lack of specialized skills and inadequate training, construction personnel often struggle to effectively address technical issues during construction operations, thereby increasing safety risks in the process.

Although prefabricated concrete structures can reduce certain environmental impacts in the production and construction process compared to traditional construction methods, waste disposal and energy consumption in the production process of prefabricated components may have negative impacts on the environment and need to be properly dealt with[14].

3. Improvement and optimization of prefabricated concrete construction technology

How to ensure the sustainable development of prefabricated concrete buildings can be done by taking the following measures:

3.1. Construction component production stage

Enhance the research and development initiatives for prefabricated concrete structures, focusing on improving structural integrity through innovative curing techniques or the utilization of high-performance materials[14]. Additionally, refine the production operational procedures and standardization system for prefabricated components by implementing a hybrid inspection approach that integrates both human expertise and machine assistance to significantly elevate the quality assurance rate of prefabricated components prior to their departure from the manufacturing facility.

Additionally, another avenue worth exploring is the utilization of high-performance materials in prefabricated concrete structures. This involves investigating advanced materials such as fiber-reinforced polymers (FRPs), ultra-high-performance concrete (UHPC), or self-healing materials that possess superior mechanical properties compared to traditional construction materials. Incorporating these high-performance materials into prefabrication processes can lead to stronger and more resilient structures capable of withstanding extreme loads or environmental conditions.

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3.2. Construction and installation stage

The transportation of prefabricated components necessitates the implementation of protective measures. Depending on the factory's location, a judicious selection between maritime and terrestrial transport should be made to minimize component damage during transit.

Furthermore, employing Building Information Modeling (BIM) technology facilitates the creation of parametric models, enabling on-site simulations and virtual analyses that significantly enhance design efficiency while reducing error rates[15]. The use of Building Information Modeling (BIM) software can facilitate efficient design coordination between architects, engineers, and manufacturers while ensuring accurate fabrication specifications are met.

The design and construction of prefabricated structures represent a highly integrated engineering endeavor; thus, it is imperative to strengthen the professional training of operational personnel to elevate construction technology standards[12].

Moreover, collaboration among academia, industry professionals, and government agencies should be encouraged to foster a multidisciplinary approach towards advancing prefabricated concrete technology.

4. Conclusion

This paper presents an objective analysis of the advantages and disadvantages of prefabricated concrete buildings, followed by proposed strategies to enhance the prefabricated building system in light of various factors that impact its development. Prefabricated concrete building is a major change in the history of construction technology, and its promotion and development is the inevitable trend of the future development of the construction industry, which brings the opportunity for innovation and development for the construction industry.

Drawing on successful experiences from countries worldwide, such as policy support and BIM technology integration, this study aims to improve construction efficiency while ensuring quality and safety standards are met, ultimately promoting sustainable development within the construction industry. The paper exhibits certain limitations in terms of the diversity of case analysis and data, and falls short in providing a comprehensive discussion of its economic value and significance.

As related technologies continue to progress and innovate, it is expected that prefabricated concrete buildings will play an increasingly important role in shaping the future of construction. It is expected that in the future, the global innovation in prefabricated concrete technology and construction methods will continue.

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