

# Efficiency of Chinese Prefabricated Building Industry

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China is a world leader in capital construction. In the construction field, the shift toward prefabricated construction has become an important path for industrial transformation. China's prefabricated building industry has a moderate micro-level efficiency. This means that it is necessary to further rationalize industrial planning; strengthen technological innovation; and improve standardization, mechanization, and automation levels. At the macro level, China's prefabricated buildings have a low industrial efficiency and remain at the initial stage of industrial development. A series of problems, such as small industrial scale and unsound policies, are restricting the industry's rapid and efficient development.

data envelopment analysis (DEA)

industry sustainable development

overall technical efficiency

## 1. Introduction

As an important material production sector in the Chinese national economy, the building industry is closely related to the economic development of the country as a whole and the improvement of people's lives (in 2016, the General Office of the State Council issued the "Guiding Opinions of the General Office of the State Council on Vigorously Developing Prefabricated Buildings". The growth stage and rapid expansion of the Chinese prefabricated building industry started soon after. The "Guiding Opinions of the General Office of the State Council on Promoting the Sustainable and Sound Development of the Building Industry" and the "Several Opinions on Accelerating the Development of New-type Building Industrialization", which were both issued in 2017, emphasize that the country should improve the professional knowledge and technical level of professional technicians in the application field of building industrialization, train talents in accordance with the development of new-type building industrialization and constantly perfect relevant technical systems: these changes, it suggests, will ensure the future development of the prefabricated building industry.). In addition to rapidly developing, the building industry is influencing national economic growth in an increasingly significant way. However, China's building industry is facing a series of problems, including labor shortages, severe pollution, poor technical systems, inadequate technological innovation and poor international competitiveness <sup>[1][2][3]</sup>. These problems are caused by the traditional construction method applied by the construction industry in the construction process, which scatters building material and generates a large amount of dust, resulting in environmental pollution. The accelerated pace of the country's rural revitalization strategy and the increase in employment opportunities for villagers has increased the problem of aging construction workers, and the number of new young construction workers has dropped significantly, resulting in a labor shortage in the country's industry. The overall technical content of the country's

construction industry is low, and it is still labor-intensive, rather than technology-intensive [4]. The formation of a high-quality development system framework and apparent improvements in the industrialization, digitalization, and intelligence levels of buildings have contributed to the rapid development of the prefabricated building industry and the effective alleviation of many problems that affect the current stage. The emergence of prefabricated buildings is driven by technological innovation in construction work. In relying on the industrial production of high-quality prefabricated units, most cast-in-place work in traditional building construction is now being completed at factories, before prefabricated units are assembled onsite by mechanized construction [5]. This helps to achieve sustainable development by integrating the completely industrial chain, increasing productivity and reducing labor demand and energy consumption [6][7]. This defines productivity according to a prefabricated component factory and construction productivity.

Increased urbanization in the country created further demand for new buildings. A booming market and favorable policies caused the prefabricated building industry to rapidly expand. In 2016 alone, the market size of China's prefabricated building industry achieved year-on-year growth of 392%, and the cumulative area of new prefabricated buildings increased by 57%. Technological upgrading, management model improvement, and structural optimization all helped to improve enterprises' total factor productivity [8].

In 2016, new prefabricated buildings accounted for about 5% of the total area of new buildings in China. However, in the period 2017–2020, this proportion surged from 6.5% to 20.5 percent, and the market size expanded rapidly from 283.9 to 1227.7 billion yuan. However, when compared to the penetration of prefabricated buildings in developed countries (90% in the US and Japan, and 85% in France), the penetration rate of prefabricated buildings in China has the potential to increase significantly [9] (by 2020, the cumulative area of new prefabricated buildings in China had reached 630 million m<sup>2</sup>—with an annual growth of 50%, prefabricated buildings accounted for about 20.5% of the total area of new buildings [10]. The number of enterprises related to prefabricated buildings (hereafter referred to as “related enterprises”) has also rapidly increased.).

By 2020, the number of related enterprises in China had exceeded 14,000. However, the costs of prefabricated buildings were still higher than those of traditional cast-in-place buildings, mainly because of the low-capacity utilization rate of prefabricated component factories, single business patterns, and the scattered industrial distribution of related enterprises [10]. This ran counter to the original intention of the prefabricated building industry, namely to achieve higher cost effectiveness and production efficiency by rationally transforming the industry chain [11] (statistical data suggest that when the prefabrication rate reached 60%, the costs of prefabricated buildings (in comparison to traditional buildings) increased by 33.8%. This large gap in costs greatly undermined the subjective motivation to develop prefabricated buildings and seriously impacted industrial efficiency.).

Although China's prefabricated construction industry has developed rapidly in recent years, this has been driven by policy, and the associated (high) costs have seriously hindered the development of the industry. Researchers have not engaged with this to a sufficient extent and so, in order to achieve the efficient and sustainable development of China's prefabricated construction industry, it is necessary for this to analyze the current situation, clarify the stage

of industrial development and explore factors that have limited the development of the industry. This will then provide a theoretical basis for the development of the country's prefabricated construction industry.

## 2. Prefabricated Building Industry

### 2.1. Prefabricated Building Industry in China

Prefabricated buildings are based on the industrial production of prefabricated components as the core and a construction production technology that connects prefabricated components together on site after production. It is a modern construction technology that replaces traditional cast-in-place construction, which has attracted widespread attention in many countries in recent years <sup>[12]</sup>.

A study in the U.K. showed that time, cost, quality, and productivity are the main factors that drive developers to adopt prefabricated construction <sup>[13]</sup>. Blismas et al. <sup>[14]</sup> investigated the building market of Australia from the perspective of sustainable development and found that the development of the prefabricated building industry is mainly driven by increased productivity and reduced labor demand. Zhai et al. <sup>[7]</sup> suggested that the advantages of prefabricated buildings, such as reduced construction waste and building energy consumption, have driven the development of the prefabricated building industry in China. Prefabricated construction is a mode of construction that is recommended on the basis of the fact that it saves energy, materials, water, and land resources and protects the environment. It reduces more than 40% of the carbon emissions throughout its full lifecycle, and this is one of the reasons why the "Notice by the State Council of the Action Plan for Carbon Dioxide Peaking Before 2030" proposes vigorously developing prefabricated buildings. In relying on the labor supply-side reform of the traditional building industry, the prefabricated building industry not only solved the problem of labor shortages, but also increased labor productivity by combining the industrial production of prefabricated members with mechanized installation and construction. The prefabricated building industry has developed rapidly in China because of its advantages including economic benefits, environmental benefits and social benefits. In seeking to create a favorable development environment for the prefabricated building industry, the Chinese government has issued many relevant policies. The "Opinions on Promoting the Green Development of Urban and Rural Construction" issued by the General Office of the State Council of the People's Republic of China clearly pointed out that China should vigorously develop prefabricated buildings, focus on promoting the construction of steel structure prefabricated houses, continuously improve the standardization level of components, promote the formation of a complete industrial chain and promote the coordinated development of intelligent construction and construction industrialization. Additionally, the State Council of the People's Republic of China issued the "Carbon Peak Travel Plan before 2030" clearly emphasized the need to promote green low-carbon building materials and green construction methods, accelerate the industrialization of new buildings, vigorously develop prefabricated buildings, promote steel structure housing and the recycling of building materials, along with the need to strengthen green design and green construction management. Moreover, the prefabricated building industry is a technology-oriented industry that has achieved technological innovation on the basis of the traditional construction industry in almost all aspects of the industry chain, including design, construction, and installation. In recent years, the "Guiding Opinions on Accelerating the Cultivation of Building Workforces in the New Era", which were jointly issued by 12

departments, including the Ministry of Housing and Urban-Rural Development, have accelerated the improvement of a sound vocational training system, promoted the transformation and upgrades of the building industry, and provided talent support for the prefabricated building industry.

In the past few years, the production scale of prefabricated building enterprises in China has rapidly expanded [15]. Large-scale production has reduced product costs and boosted market competitiveness. However, an expanded production scale means higher costs of technological upgrading and, as a consequence, slower technological updating. As the country imposes increasingly higher requirements on prefabricated building technology systems, the capacity that does not satisfy market demands will be eliminated, which not only causes economic losses for enterprises but will also result in wasted resources and obstructed industrial development [16]. Moreover, as with the manufacturing industry, it has a stronger industry chain integration capability and requires considerable human (related technicians) and material (related equipment) early-stage inputs. When compared to the traditional construction industry, the prefabricated component production industry is a new industry in the prefabricated construction industry chain that must act cautiously in relation to cost control during transformation and upgrading, as this will help to avoid losses caused by excess capacity [17].

In addition, China has issued many policy incentives to promote the development of the prefabricated construction industry. For example, Beijing introduced the “Plan of Competitive Bidding for High-Standard Commercial Housing Construction” into the link of land auction. According to this plan, when the premium rate of land exceeds 15%, the ownership of land development will be determined by evaluating building construction schemes, livable technology applications, and management models provided by bidders. This plan enhances enterprises’ subjective motivation to develop prefabricated building technologies. The notable reduction in the premium rate of land from the previous 50% saves considerable capital for enterprises [18][19]. However, most existing policy subsidies are direct economic subsidies, such as the reduction in or exemption of construction fees and the exemption of charges for building waste disposal. However, enterprises seek to obtain policy subsidies by frequently choosing primary prefabricated members that only meet the lowest requirements for the prefabrication rate (such as prefabricated laminated plates). They adopt cast-in-place construction for the main structures, which is not conducive to the development of the country’s prefabricated building industry. In attending to this phenomenon, the country has gradually perfected relevant governmental subsidy strategies.

## 2.2. Research Gaps

Studies of China’s prefabricated industry show two limitations:

(1) Due to the rapid development of the prefabricated construction industry in China, the scale of related enterprises has expanded rapidly. However, the rapid expansion of enterprise scale will waste resources and affect the industry’s sustainable development. In order to realize the sustainable development of China’s prefabricated construction industry, it is therefore necessary to study whether the existing scale of different enterprises in the prefabricated construction industry chain can meet the industry’s needs.

(2)The Chinese government and relevant departments have issued many policies that provide prefabricated construction enterprises with clear incentives to promote the development of the prefabricated construction industry. However, researchers need to establish whether these incentives are effective.

## 3. Industry Efficiency

According to the traditional industrial organization theory that prevailed in the Western world at the early stage of industrial development, an industry is a collection of enterprises that produce similar products or provide similar services. With the development of economics, an increasing number of scholars, including Charnes and Cooper, introduced econometrics and statistics to the measurement of industrial efficiency, with the aim of analyzing the factors that influence industrial development and offering targeted suggestions on how to promote industrial development [20]. Farrell [21] decomposed efficiency into overall technical efficiency and allocative efficiency, which, respectively, reflect the maximum output of an enterprise under a given input level and the ability of the enterprise to use the optimal input proportion under given technical and price levels. Depending on the specific fields involved, efficiency has been classified into overall technical efficiency and institutional efficiency, static and dynamic efficiency, as well as pure overall technical efficiency and scale efficiency. Overall technical efficiency reflects the comprehensive resource allocation and technical level of decision-making units. On the basis of an output perspective, overall technical efficiency can be defined as the possibility that an industry increases its output under a given production capacity and technical level [22][23]. Pure technical efficiency refers to the efficiency created by institutional and managerial levels. It represents the production efficiency of an enterprise affected by factors such as management and technology. A pure technical efficiency of 1 indicates that the use of input resources is efficient under the current technical level [24]. Scale efficiency refers to the difference between the existing scale and the optimal scale under given institutional and managerial levels. It is the production efficiency of an enterprise that is affected by scale and reflects the gap between the actual scale and the optimal scale. Factors such as imperfect competition and financial constraints may cause decision-making units to operate at a suboptimal scale. In this case, scale efficiency reflects the effect of optimal resource allocation on output units and serves as an important index for analyzing the optimal production scale [25][26]. Total factor productivity is the efficiency of production activities in a given period. It is a productivity index used to measure the total output per unit of total input, which is used to analyze the industry's dynamic efficiency [27].

Given that enterprises (instead of industries) are behaving as subjects, overall technical efficiency is calculated from statistical data on enterprises. However, macro development trends and policy orientation also exert a huge influence on the overall technical efficiency of enterprises. Therefore, comprehensive analysis of industrial efficiency from the micro and macro levels can better identify the status of industrial development.

### 3.1. Micro-Level Industry Efficiency

A lot of research on micro-level industrial efficiency has mainly been focused on: enterprise scale; enterprise operation efficiency; and enterprise production efficiency [28][29][30][31].

Micro-level industrial efficiency is usually analyzed from the perspective of economic benefits. Due to the different attributes of industries, there are differences in the influencing factors of industrial efficiency at the micro level. When selecting input-output indicators at the micro-level, although the decision-making unit (DMU) can use any resource as an indicator, the correlation between the selected indicator and the industry affects the accuracy of industrial efficiency analysis [28]. The prefabricated building industry chain includes consulting industry (design), manufacturing industry (prefabricated component production), logistics industry (component transportation), and construction industry (construction). Therefore, it is necessary to comprehensively select the input and output indicators according to the attributes of each link of the prefabricated construction industry chain to improve the effectiveness of the efficiency analysis of the prefabricated construction industry at the micro level.

## 3.2. Macro-Level Industry Efficiency

The research on industrial efficiency at the macro level mainly focuses on: regional industrial efficiency differences; new technology application level; input scale control capability; resource utilization; and environmental benefits [32][33][34][35][36].

In analyzing industrial efficiency at the macro level, based on the principle of reflecting the overall input and output of the industry as much as possible, indicators that have a great impact on industrial efficiency are selected [33]. In order to analyze the differences in regional industrial development, the industrial development level is usually divided into regions according to the different levels of regional development driven by the economic development plan. However, policies have dominated the development of China's prefabricated construction industry, and the level of industrial development is usually evaluated by assembly rate and prefabrication rate, which leads to the fact that the efficiency of prefabricated construction industry in different regions is not necessarily directly related to the economic development of the region [32]. In addition, the prefabricated construction industry is the product of the transformation and upgrading of the traditional construction industry, which is a knowledge-intensive industry [5]. Compared with the traditional construction industry, the required employees are industrial workers with high technical level, which results in significantly fewer employees [4]. Therefore, the number of employees cannot accurately measure the impact of investment scale control ability on the efficiency of the prefabricated construction industry. When analyzing the efficiency of the prefabricated building industry, it is necessary to pay attention to the impact of policy, economy and technology on the industry [36].

## 3.3. Research Gaps

There are three main limitations of the studies of China's prefabricated industry.

(1) Existing research focuses on the micro level or macro level when analyzing industrial efficiency, and rarely conducts a comprehensive analysis of industrial efficiency at the micro and macro levels. Enterprises (instead of industries) behave as subjects, and so macro development trends and policy orientations will have a huge influence on enterprises' overall technical efficiency. When analyzing industrial efficiency, it is therefore

necessary to comprehensively analyze micro-level and macro-level industrial efficiency, as this will improve the comprehensiveness of research and the accuracy of evaluation.

- (2) Scholars have extensively researched the efficiency of the construction industry, but the prefabricated construction industry is a new type of industry that transforms and enhances the traditional construction industry through technological innovation. At present, few researchers have addressed industrial efficiency. In order to identify the development level of China's prefabricated construction industry, it will be instructive to refer to the efficiency analysis method of traditional construction industry. It can then be combined with an assessment of micro and macro level characteristics and used to analyze the efficiency of China's prefabricated construction industry.
- (3) Current research on the efficiency of China's prefabricated building industry focuses on three levels (policy, the economy and technology). However, the data sources of input and output indicators, such as the development of the prefabricated construction industry chain, are subjective. The use of qualitative indicators of this kind may result in inaccurate measures of industrial efficiency.

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