Quantifying the Green Efficiency of the Construction Industry in China

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ABSTRACT

China's construction industry has long been in the extensive development mode of "high pollution and high energy consumption." As the ecological civilization strategy deepens in China, improving the energy and environmental efficiency of the construction industry is vital for the sector's green transition. To define and quantify the "Green Efficiency" of the construction industry, this study integrated greenhouse gas (GHG), air pollutant emissions, and energy consumption into the efficiency evaluation framework, which was established using data envelopment analysis (DEA) and Malmquist models to measure China's provincial green efficiency from 2010 to 2015. The results show that due to the low level of technological development, the green efficiency of the construction industry in central China is generally low, but the central provinces rank higher in the national green efficiency system when compared with conventional (excluding green considerations) efficiency system. The enhancement of green efficiency in the northeast and central provinces is slow. At last, this study also shed light on directions for the green development of China's construction industry.

INTRODUCTION

China has been the biggest carbon emitter since 2005, with carbon emission per capita being 40% higher than the world's average (WB 2010). In 2017, China accounted for 23.2% of the global energy consumption (BP 2018). As a pillar industry in China, the construction industry consumed 40–50% of the country's total energy (Chang et al. 2011). However, the potential of carbon emission mitigation of China's building sector is predicted to increase to as high as 74% of its current emissions (CABEE 2017) by 2050. Thus, improving the environmental efficiency of the construction industry is vital for China to achieve emission reduction targets and sustainable development. The development of an evaluation framework of "green efficiency" is vital for the construction industry's sustainable transition.

Furthermore, the development of China's provincial construction industry is unbalanced. In 2016, three provinces with the most economic output of the construction industry contributed to 32.36% of the domestic construction industry's total output, while the bottom three provinces accounted for only 0.43% (NBSC 2017). According to the regional development theory, economy is developed with the mechanism of mutual restriction and promotion. Comparing and analyzing the green efficiency of the provincial construction industry contributes to more robust and specific policy making in China.

Some scholars have included environmental factors such as energy and carbon emission into the efficiency evaluation system of the construction industry. Ge et al. (2010) analyzed the ecological efficiency of China's provincial construction industry with a data envelopment analysis (DEA) model based on material inputs. Jia et al. (2014) studied the circular economy efficiency of China's provincial construction industry based on the DEA model that measured waste reuse and emissions, and found that China's overall efficiency and Scale Efficiency (SE) were constantly improving, while the Pure Technical Efficiency (PTE) was backward. Feng and Wang (2015) analyzed the energy efficiency and influencing factors of China's construction industry from 2004 to 2011 based on the Slack Based Model (SBM) and Tobit Model, respectively, and found that technological innovation and the proportion of clean energy consumption were development bottlenecks.

However, the majority of existing studies only considered single environmental elements without constructing a comprehensive index that contains energy consumption, GHG and air pollutant emissions at the same time. Moreover, most studies mainly compare interprovincial efficiency differences without considering each province's efficiency variations over time. Therefore, in this study, we defined a comprehensive index of "green efficiency" with comprehensive consideration of environmental impact of the construction industry. Furthermore, we calculated the conventional efficiency (defined in this paper as the efficiency without energy and environmental considerations) and green efficiency of the construction industry in 30 provinces in mainland China from 2010 to 2015 (due to the absence of data, Tibet was not considered) using the DEA and Malmquist models.

MODEL DEVELOPMENT

Definition of green efficiency: Efficiency evaluates the rationality of factor (such as resources, labor and capital) allocation and the level of production management. In this study we defined the green efficiency of the construction industry as the proportion of its total factor input and output in economic and ecological aspects, which is the synthesis of economic and ecological efficiency (Zhang et al. 2018).

Model selection: According to the criteria of whether specific production function is needed, efficiency evaluation models of the construction industry can be divided into two types, the parametric method and the non-parametric method. The former includes Cobb–Douglas production function and stochastic frontier analysis (SFA), while the latter includes DEA and Malmquist models. Since construction is such a complex activity with multiple inputs and outputs and is affected by political, economic and natural factors, that there is no long-term stable functional relationship between those various elements. According to these considerations, this study selected the non-parametric method.

The efficiency of the construction industry is affected by its scale. Due to different levels of economic and social development, as well as regional-specific regulations, the construction industry of each province may not operate at the optimal scale and might have different scale benefit levels. Thus, the input-oriented BCC-DEA model is adopted for green efficiency measurement. Additionally, the Malmquist model is employed to compare the variation of construction industry's green efficiency of 30 provinces from 2010 to 2015.

EMPIRICAL ANALYSIS

Index system establishment and data sources: This study selected three input factors and three output factors for the indicator system of conventional efficiency measurement. For the green efficiency index system, additional three input indicators, GHG, air pollutant emissions, and energy consumption, were selected and treated as environmental costs. The number of the inputs and outputs of the efficiency systems meets the requirement of $2N+1<M$ (N is the total

number of input and output factors, M is the number of Decision Making Unit (DMU)) and can guarantee the accuracy of the efficiency estimation (Zhang and Liu 2011). Table 1 summarizes the indicator systems of efficiency measurement.

Table 1. Indicator Systems of Efficiency Measurement.

System	Category	Symbol	Indicator
Non-green efficiency	Input	X_1	Total assets of construction enterprises
		X_2	Number of employees in the construction industry
		X_3	Power of self-owned construction equipment of construction enterprises
	Output	Y_1	Construction industry's added value
		Y_2	Total profits and taxes of construction enterprises
		Y_3	Construction area of buildings
Green efficiency	Input	X_1	Total assets of construction enterprises
		X_2	Number of employees in the construction industry
		X_3	Power of self-owned construction equipment of construction enterprises
		X_4	Energy consumption in the construction industry
		X_5	GHG emission of the construction industry
		X_6	SO_2 emission of the construction industry
		X_7	NO_2 emission of the construction industry
	Output	Y_1	Construction industry's added value
		Y_2	Total profits and taxes of construction enterprises
		Y_3	Construction area of buildings

The data of X_1, X_2, X_3 and Y_1, Y_2, Y_3 were obtained from China Statistical Yearbook and China Construction Industry Statistical Yearbook from 2011 to 2016. The data of X_4 and X_5 were derived from China Emission Accounts and Datasets (CEADs 2016). The data of X_6 and X_7 were calculated based on emission coefficients of AP-42, which was released by the U.S. Environmental Protection Agency (USEPA 1995).

Interprovincial efficiency analysis based on DEA: Using the Data Envelopment Analysis (Computer) Program (DEAP) Version 2.1 soft tool, the conventional and green efficiency of the construction industry from 30 provinces were estimated, as well as the variation in each province's ranking based on the two efficiency evaluation systems (see Figure 1).

Note: The efficiency value in (a) and (b) are 2010 to 2015 on average. (a) The provincial conventional efficiency. (b) The provincial green efficiency. (c) The variation in conventional and green efficiency rankings, calculated as green efficiency ranking minus conventional efficiency ranking.

It can be seen that both the conventional efficiency and the green efficiency of China's construction industry show specific regional patterns. Specifically, the two kinds of efficiency gradually decrease from the east to the middle and west regions, whereas the efficiency difference between the northern and southern provinces is not obvious. When compared with the conventional efficiency, the green efficiency ranking in the northwest and eastern coastal region raises, while the ranking of the central provinces (such as Hunan, Henan, Hebei and Shanxi) decreases. This might be because of the rapid social and economic development as well as the strong ecological and environmental awareness and strict government regulations in the southeast coastal region. In the western region, the market size for buildings and infrastructure and production scale of the construction industry are comparatively small, which help in avoiding the extensive development mode that solely pursues profits and industry development speed.

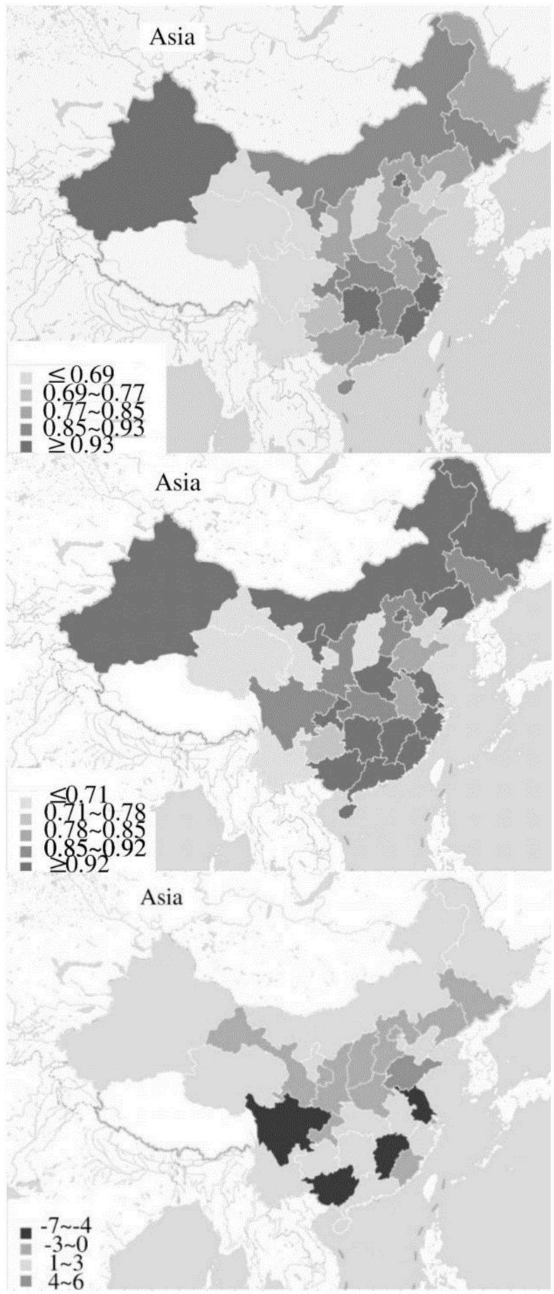

Figure 1. A comparison of the conventional efficiency and green efficiency of the construction industry in 30 provinces from 2010 to 2015 (a, b and c).

Figure 2 presents the green efficiency of the construction industry in 30 provinces (2010 to 2015 on average) in the ascending order. It can be seen that the national average value is 0.895; seven provinces are in the green production frontier, while another ten provinces are lower than the average level, of which Yunnan is at the bottom with a value of 0.644. Thus, there is still a large gap in the green development of the construction industry in different regions.

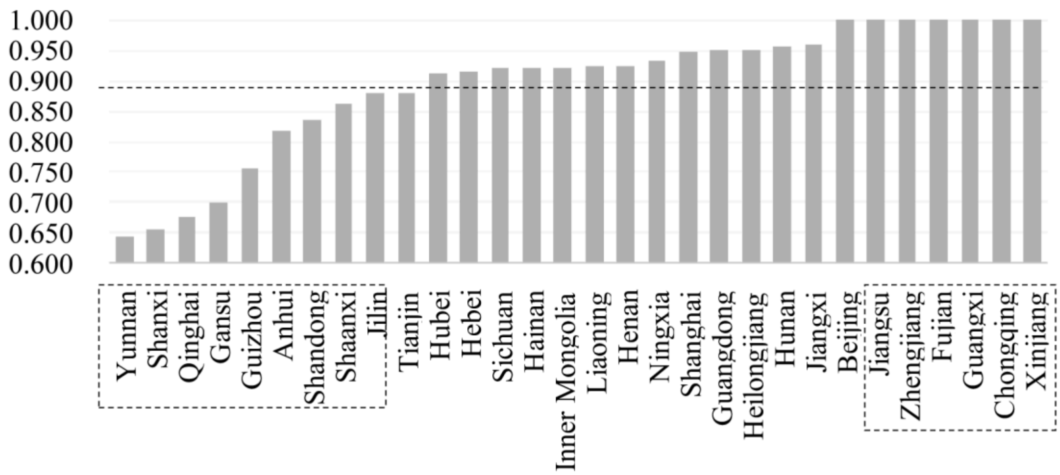

Figure 2. The average green efficiency of the construction industry in 30 provinces from 2010 to 2015.

To further identify the main influencing factors of green efficiency, the provinces whose green efficiency is lower than the national average value are selected, and their efficiency indicators are analyzed. Green Efficiency (GE) represents a comprehensive efficiency determined by multiple factors (such as carbon emission, energy consumption, labor, and other ecological and economic factors) (see Figure 3).

Pure technical efficiency (PTE) and scale efficiency (SE) respectively represents the efficiency only affected by green technology and management factors and by scale factors. As is shown above, the national average PTE was 0.925, which is higher than 90% of the selected provinces. The national average SE is 0.967, which is higher than the value of 40% of the selected province. PTE is the main factor resulting in the low GE of the lagged behind provinces.

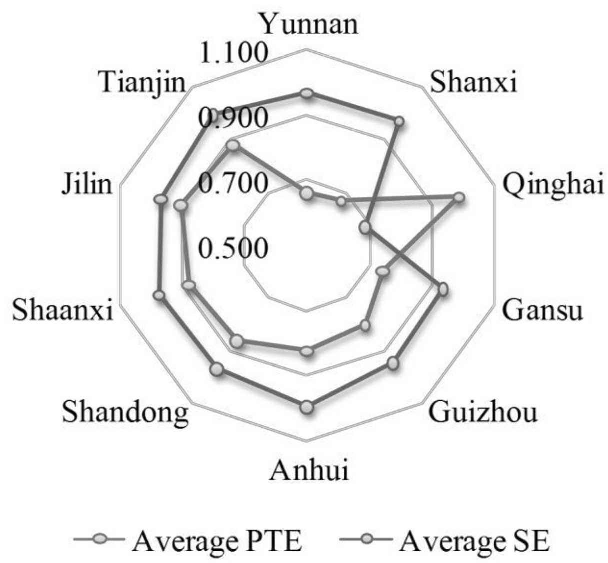

Figure 3. Pure technical efficiency (PTE) and scale efficiency (SE) of the construction industry of the selected provinces in China.

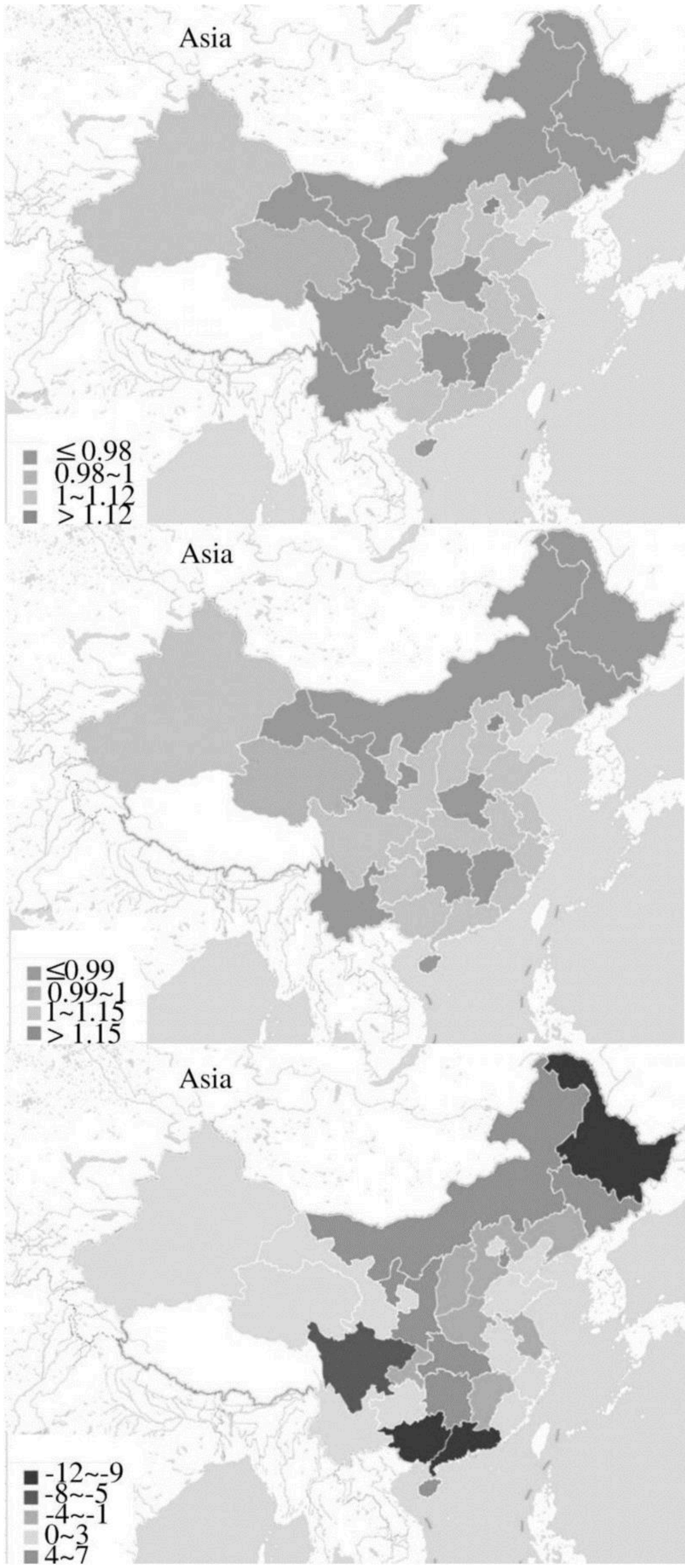

Figure 4. A comparison of the conventional and green TFPCH of the construction industry in 30 provinces from 2010 to 2015 (a, b and c).

Dynamic efficiency analysis based on Malmquist model: The Total Factor Productivity Change (TFPCH) represents the speed of efficiency improvement. The condition, $\mathrm{TFPCH} > 1$, indicates an improvement in the DMU efficiency. The TFPCH of the conventional and green efficiency systems are shown in Figure 4 (a) and (b), respectively, where significant regional differences are present in the improvement speed of both conventional and green efficiency. Figure 4(c) reflects the ranking variations of the 30 provinces in the two evaluation systems. It can be seen that after integrating ecological indicators into efficiency measurement, the ranking of some provinces (such as Sichuan, Guangxi, Jiangxi and Jiangsu) declined, indicating that the development of the construction industry in these provinces is less ecologically oriented.

Figure 4 note: The TFPCH in (a) and (b) are 2010 to 2015 on average. (a) The conventional TFPCH of the construction industry in 30 provinces. (b) The green TFPCH of the construction industry in 30 provinces. (c) The variation in conventional and green TFPCH rankings, which is calculated as green TFPCH ranking minus conventional TFPCH ranking).

In approximately one-third of the 30 provinces, the annual average TFPCH is lower than 1, meaning that their overall efficiency level is declining. To identify the major causes, this study selected the provinces whose TFPCH is lower than 1 and further analyzed their dynamic efficiency indicators. The TFPCH can be decomposed into Technological Progress Index (TECHCH) and Technological Efficiency Change Index (EFFCH), see Equation (1). TECHCH refers to the advancement of the construction industry's efficiency; EFFCH denotes the DMU's efficiency improvement compared with the industry without considering the scale effect. Furthermore, EFFCH can be further decomposed into PTE Variation Index (PECH) and SE Variation Index (SECH), which respectively represents the DMU's technological efficiency progress excluding scale effect and returns to scale.

$$\mathrm{TFPCH=TECHCH*EFFCH=TECHCH*PECH*SECH} \tag{1}$$

It can be seen from Figure 5 that for the provinces with low TFPCH, their EFFCH is generally the lowest in all efficiency indexes, followed by PECH, indicating that technical factors are responsible for the low green efficiency of the construction industry in China. The SECH of all the selected provinces is less than 1, implying decreasing returns to scale, especially for Hainan province. These provinces should examine whether their construction industry's scale is oversized.

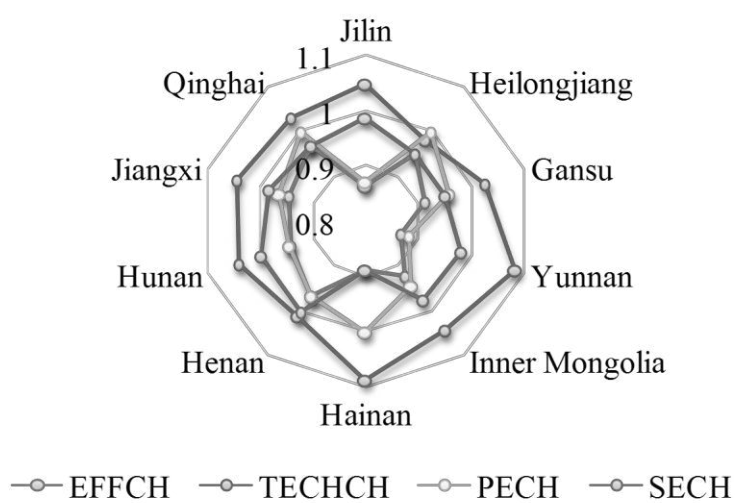

Figure 5. Dynamic efficiency indexes of the low-TFPCH provinces.

CONCLUSION AND SUGGESTIONS

Faced with the huge climate change and energy challenges, the green transition of China's construction industry is necessary more than ever. To fill the gap in the existing studies about comprehensive measurement of the construction industry's green development, this paper defined and quantified China's provincial green efficiency of the construction industry from 2010 to 2015 using DEA and Malmquist models.

This study came up with following conclusions and policy suggestions:

Integrating energy and environmental factors into the efficiency measurement framework of the construction industry. Both economic and ecological impacts associated with building construction should be equally emphasized. This will help to scientifically guide the green transition of the construction industry. Specifically, northwest provinces should maintain the greenness of their construction industry, but improve the sector's economic performance; the construction industry of the northeast and southeast coastal provinces should follow an economically and ecologically oriented development pathway.

Technology is mainly responsible for the low green efficiency in some provinces of China. Domestic construction industry should be regarded by the authorities as a whole to avoid local protectionism. Relevant policies should be made to support the technological advancement of the construction industry. Besides, knowledge sharing and management experience transfer should be encouraged.

Scale effect is a main factor influencing the green efficiency growth of China's construction industry. For the construction industry of northeast and northwest areas and the Hainan Province, the decreasing returns to scale is obvious. Thus, enterprises should avoid blindly pursuing larger production scale and emphasize a balance between scale and efficiency. Policies should be made to promote the transparency and sharing of construction market information, strengthen cooperation, and cultivate fair competitions among construction enterprises. It is important for construction enterprises to upgrade their production structure and switch to delicacy management mode to maximize the returns to scale.

ACKNOWLEDGMENTS

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REFERENCES

BP. (2018). "Statistical review 2018: China's energy market in 2017." <https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-china-insights.pdf>(Sep. 21, 2018).

China Emission Accounts and Datasets (CEADs). (2016). "China Emission Accounts and Datasets." <http://www.ceads.net>(Sep. 21st, 2018).

Chang, Y., Ries, R. and Wang, Y.W. (2011). "The quantification of the embodied impacts of construction projects on energy, environment, and society based on I-O LCA." *Energy Policy*, 39(10), 6321-6330.

Feng, B. and Wang, X.Q. (2015). "Empirical research on energy economic efficiency and energy environmental efficiency of China's construction industry-based on the SBM-Tobit two-stage model." *Journal of Beijing Institute of Technology (Social Sciences Edition)*, 17(1), 14-22. (in Chinese).

Ge, Z.B., Zhang, J.B., Li, D.Z. and Zhang, X. (2010). "Eco-efficiency evaluation of construction industry in China: a data envelopment analysis approach." *Journal of Qingdao Technological University*, 31(5), 95-100. (in Chinese).

Jia, G.Z., Liu, S.G. and Meng, K.Y. (2014). "Evaluation research on recycle economy efficiency of construction industry based on an improved DEA model." *Management Review*, 26(4), 14-21. (in Chinese).

China Association of Building Energy Efficiency (CABEE). (2017). *Report of construction energy consumption in China*, Shanghai, China. (in Chinese).

U.S. Environmental Protection Agency (USEPA). (1995). "AP 42: Compilation of air pollutant emission factors." <http://www.epa.gov/ttnchie1/ap42>(Sep. 22nd, 2018).

World Bank (WB). (2010). "Total greenhouse gas emissions (kt of CO_2 equivalent)." <https://data.worldbank.org.cn/indicator/EN.ATM.GHGT.KT.CE>(Sep. 22nd, 2018).

Zhang, J.X., Chang, Y., Wang, C.B. and Zhang, L.X. (2018). "The green efficiency of industrial sectors in China: a comparative analysis based on sectoral and supply-chain quantifications." *Resources, Conservation and Recycling*, 132, 269-277.

Zhang, Z.H. and Liu, R.J. (2011). "Empirical research on construction efficiency assessment based on data envelopment analysis." *Journal of Engineering Management*, 25(3), 252-255. (in Chinese).

An Engineering Consumption Differences Calculation Model for Prefabricated and Conventional Buildings in China

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ABSTRACT

In recent years, in order to change the rough construction method, prefabricated buildings have been vigorously developed in China. To rationally evaluate the sustainability of this new construction technology, it is necessary to study the differences in consumption between prefabricated and conventional buildings. This paper uses a comparative analysis method to develop a detailed engineering consumption differences calculation model from the three aspects of labor, material, and machinery based on a design atlas and criteria, and a construction quota document. Then, multiple case studies of 10 real-life prefabricated buildings are conducted. From the results the following conclusions can be drawn: the labor consumption of the prefabricated building project is significantly decreased; as for materials, the consumption of concrete, steel formwork, and iron parts is increased, and the consumption of wood formwork, masonry block, and mortar is decreased; as for machinery, the consumption of tower cranes, mortar mixers is increased, and the consumption of steel processing machinery, woodworking machinery, and trucks is decreased.

INTRODUCTION

Prefabricated building has enormous advantages compared with traditional building (Cao et al. 2015), such as saving labor, improving construction efficiency and improving engineering quality (Xu 2018).It has become an opportunity for the transformation and upgrading of the current extensive construction industry in China. However, the development of prefabricated buildings in China is currently in a transitional stage.

Therefore, issues of measuring the resource consumption of prefabricated buildings and identifying the factors that cause excessive cost in China have become the focus of recent research. Li et al. (2013) conducted a case study on a residential building in Shenyang City, and calculated the assembly drawings as a cast-in-place drawing to calculate the construction resource consumption and compared it with the actual data to obtain the resource consumption difference. From the perspective of engineering cost management, Chen et al. (2018) directly measured the incremental cost of a project by considering the impact of prefabricated component design capacity factors on component production consumption. By analyzing the cost of actual engineering projects, Li et al. (2014) proposed measures to solve the cost problem through a combination of a management model and technological innovation. Sun et al. (2018) proposed that under the EPC model, the quantification of resource consumption can realize the overall management and control of the building design to the construction stage to optimize resource allocation. Xie et al. (2018) conducted a case study on an actual prefabricated building and