Analysis on coordinated development of prefabricated construction industry, regional economy and ecological environment
——taking Beijing-Tianjin-Hebei region as an example

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Abstract: Taking eleven prefecture-level cities including Beijing, Tianjin and Hebei as research objects, this paper established an evaluation system for coordinated development of the prefabricated construction industry, regional economy and the environment. Additionally, the weighting TOPSIS method was adopted to assess the overall development level of three major systems in this region and the evolving relation of coupled coordination for three systems in provinces and cities of Beijing-Tianjin-Hebei region was analyzed from time and space dimensions based on the coupled coordination model. The results show that prefabricated construction industry and regional economies in Beijing-Tianjin-Hebei region have relative relevance, but there is no significant conflict between economic development and ecological environment. From time, it is found that coupled coordination degree of three major systems keeps stable and rises with fluctuation and the main restriction factors of coupling development in each province and city are different.

1. Introduction
In recent years, each province or city in China has proposed the supporting policies of architectural industrialization continuously, thus promoting the development of the prefabricated construction industry in the aspects of investment promotion, fiscal levy, land transfer and market promotion [1]. However, the development of prefabricated construction in China is unbalanced at present and the development in regions and economy as well as environment restrict mutually. Despite bringing huge economic and social interests, the development of regional economy and prefabricated construction might damage the natural environment. If environmental deterioration exceeds its bearing capacity, the cost of economic activity will be increased and long-term development of prefabricated construction will be restricted. Therefore, how to coordinate the relationship among regional economy, ecological environment protection and the development of prefabricated construction is great significance to promote the national regional harmonious development.

The relationship among prefabricated construction industry, regional economy, ecological environment could be regarded as the open huge system with wide content, complex structure and coupling features. Deeply understanding the interaction mechanism of these three parties is the first problem to be solved in the coordinated development of prefabricated construction industry, regional economy, ecological environment (as shown in Figure 1). The regional economy is the basic guarantee of prefabricated construction industry and ecological environment. Compared with traditional
construction methods, the production mode of prefabricated construction is the important connection to coordinate regional economy and ecological environment due to its high economic benefit, energy saving and environmental protection. Ecological environment is the material basis of economy activity and the important guarantee of the continuous development of prefabricated construction.

![Figure 1 Fabricated building industry - Regional economy - ecological environment mutual coupling model](image)

Presently, most of the existing literature at home and abroad is based on the analysis of the pairwise relationship between regional economy, ecological environment or prefabricated construction and the systematic researches on the organic unity of the three parties are few. Lombera et al. [2] established the comprehensive value model (MIVES) of industrialized construction with sustainable assessment. Lu and Bonamente et al. [3-4] quantified the carbon and energy footprints in construction departments and verified that prefabricated agricultural building could reduce material consumption by up to 78% compared with traditional concrete structures. Abdouli et al. [5] studied the influence of economic growth and energy consumption on environment degradation in 17 countries of the Middle East and North Africa and proved the existence of Environmental Kuznets Curve (EKC). Aşıcı [6] verified the positive correlation between economic income and natural pressure. Lee et al. [7] proved the reverse U relation between China's economic growth and environmental quality as well as N-shaped relation between income and pollution. Wu et al. [8] made an empirical study on the temporal and spatial distribution of regional economic growth as well as environmental coupling and coordinated development in 31 provinces and cities in China. Dai et al. [9] studied the coupling and coordinated development situation of construction industry and regional economic growth in China and found that most of the provinces were in the primary coordination or the marginal coordination stage. Qi et al. [10] analyzed the coordinated development of construction industry and resource setting in Liaoning province by introducing coordination model. Fan et al.[11] analyzed the promoting effect of industrialized building on energy consumption, material discharge and economy development of construction industry based on the Decoupling theory.

However, the existing literature focuses more on a single city or province instead of macro-scale cross-provincial comparison and coordinated analysis of large watersheds. As the capital economy circle and key area of prefabricated construction planned by China, Beijing-Tianjin-Hebei region faces with the large challenge of the coordinated development in prefabricated construction industry, regional economy and ecological environment. Based on relevant researches, this paper took eleven prefecture-level cities including Beijing, Tianjin and Baoding, Langfang, Shijiazhuang, Tangshan, Handan, Qinhuangdao, Chengde, Baoding, Cangzhou, Xingtai, Hengshui in Hebei province as research objects, established evaluation index system of coupled coordination among prefabricated construction industry, regional economy and ecological environment and analyzed the coupling coordination relationship of three major systems from time and space based on the weighing TOPSIS and coupling coordination model.

2. Background of research area, index system and data sources

2.1 Background of research area Beijing-Tianjin-Hebei region
The Beijing-Tianjin-Hebei region has eleven prefecture-level cities, including Beijing city, Tianjin city and Baoding, Langfang, Shijiazhuang, Tangshan, Handan, Qinhuangdao, Zhangjiakou, Chengde, Baoding, Cangzhou, Xingtai, Hengshui in Hebei province. As the important developing area of prefabricated construction, Beijing-Tianjin-Hebei region becomes the leading area in the development
of prefabricated construction in China. In addition, the influence degree and protection intensity of ecological environment in each province and city are different due to the large differences of economic scale and industrial structure. However, behind the rapid development of regional economy and prefabricated construction, the serious environmental hazards exist. It is of great significance to quantify and analyze the coupled coordination relationship of the provinces and cities in Beijing-Tianjin-Hebei region by scientific methods, thus realizing the sustainable development in regions.

2.2 Index system

To highlight the important coordination and connectivity role of prefabricated construction development in regional economy and environment, three subsystems of regional economy, ecological environment and prefabricated construction are studied at the same level. At the same time, the important parts of economy activities in the process of prefabricated construction is taken into consideration and the membership relationship as well as weights of three factors are focused in the analysis. Based on the relevant researches [15-22], this paper focused on three cores, including regional economy, ecological environment and prefabricated construction and made the analysis from six dimensions, including total economic scale, economic structure characteristics, present situation of pollution scale, environmental structure characteristics, prefabricated construction scope, development structure. Moreover, after selecting 26 unidirectional indexes and considering the availability of indicator data, the evaluation system of coupled coordination of prefabricated construction industry, regional economy, ecological environment was established (as shown in Table 1). Among them, the contrary indicators include number of registered unemployed persons in cities and towns, waste water discharge, exhaust gas emission, production of industrial solid waste and ambient noise decibels.

2.3 Data sources

Three types of original data information were collected in this paper, including

(1) 2012-2016: China Statistical Yearbook and regional economic statistical yearbook of 11 prefecture-level cities in Hebei province.

(2) Development Report on National Prefabricated Construction, China’s Housing Industry Development Report, National Prefabricated Building Survey, Statistical Table on Basic Situation of Prefabricated Construction and Research Report on the 13th Five-Year Development of Prefabricated Buildings in Hebei Province.

(3) Related policies of Prefabricated Construction in Beijing-Tianjin-Hebei region from 2012 to 2016.

3. Research methods

(1) Modified entropy method

The original Entropy was the physical quantity to characterize the disorder of the system in thermodynamic and it was widely used after being borrowed by system science. Based on the evaluation index weight coefficients obtained by analytic hierarchy process (AHP), this paper adopted entropy technology to modify the weight, thus making the weight more in line with the real situation [23]. The weights of each index were calculated, which were shown in Table 1.

| Primary indicators               | Secondary indicators         | Three-level indicator                              | unit       | Indicator attribute | Entropy weight | Correction weight |
|---------------------------------|------------------------------|----------------------------------------------------|------------|---------------------|----------------|------------------|
| Prefabricated construction      | Scale of development         | Gross output value of the construction industry    | billion    | positive            | 0.1275         | 0.1288           |
| industry                        |                              | Added value of the construction industry           | billion    | positive            | 0.0611         | 0.0555           |
|                                 |                              | Building completion area                           | M2         | positive            | 0.0606         | 0.0653           |
| Category                  | Metric                                                                 | Unit          | Evaluation Value | Z-Score 1 | Z-Score 2 |
|---------------------------|------------------------------------------------------------------------|---------------|------------------|-----------|-----------|
| Development structure     | Construction industry fixed assets investment                         | ten thousand yuan | positive        | 0.1149   | 0.1125   |
|                           | Number of employees in the construction industry                       | individual    | positive         | 0.1181   | 0.0990   |
|                           | Prefabricated buildings account for the proportion of Newly built buildings | %             | positive         | 0.1020   | 0.1260   |
|                           | New construction area of prefabricated buildings                        | M2            | positive         | 0.1410   | 0.1405   |
|                           | Number of industrial bases                                             | %             | positive         | 0.1502   | 0.1451   |
|                           | GDP                                                                     | Billion       | positive         | 0.136    | 0.1330   |
|                           | Per capita GDP                                                          | yuan          | positive         | 0.084    | 0.0970   |
|                           | Tertiary industry output value                                          | billion       | positive         | 0.105    | 0.0925   |
| Regional economy          | Regional fiscal revenue                                                 | ten thousand yuan | positive        | 0.185    | 0.1275   |
|                           | Total retail sales of consumer goods                                     | billion       | positive         | 0.215    | 0.1725   |
|                           | Household consumption level                                             | yuan/person   | positive         | 0.075    | 0.1025   |
|                           | Disposable income of urban residents                                    | yuan          | positive         | 0.095    | 0.1225   |
| Economic structure        | Tertiary industry ratio                                                 | %             | positive         | 0.017    | 0.0585   |
|                           | Urban registered unemployment                                           | Ten thousand people | negative     | 0.088    | 0.094    |
|                           | Industrial wastewater discharge                                         | Ton           | negative         | 0.2074   | 0.1887   |
|                           | Industrial exhaust emissions                                            | M3            | negative         | 0.1368   | 0.1434   |
|                           | Industrial solid waste                                                  | Ton           | negative         | 0.1397   | 0.1399   |
| Ecological environment    | Industrial pollution control investment                                 | ten thousand yuan | positive        | 0.1319   | 0.1210   |
|                           | Per capita public green area                                            | M2            | positive         | 0.0943   | 0.0872   |
|                           | Environmental noise decibel                                             | decibel       | negative         | 0.0649   | 0.0675   |
|                           | Green coverage rate in built-up areas                                   | %             | positive         | 0.0962   | 0.1131   |
|                           | Ambient air quality rate                                                | %             | positive         | 0.1288   | 0.1394   |

(2) Weighting TOPSIS method and coupled coordination model
As the commonly used multi-attribute decision making method in system engineering, the principle of TOPSIS is that the relative distance between the evaluation value vector and the positive and negative ideal solution is chosen by the measurement alternative. This method is widely used in tourism industry,
ecological environment and other domains [24]. Originating from physics, coupling refers to the phenomenon that two or more than two systems or forms of motion influence each other via all kinds of interactions. And the coupling degree is used to measure the extent of interaction between systems or elements while coordination refers to the relationship of coordination and virtuous circle between systems or elements [25]. This paper used weighting TOPSIS method to calculate the comprehensive evaluation index of three major systems, including prefabricated construction industry, regional economy and ecological environment in Beijing-Tianjin-Hebei region. Via introducing coupled coordination model, the coupling degree and coordination development degree of three systems were calculated.

4. Analysis of research results

4.1 Development analysis of prefabricated construction industry, regional economy and ecological environment

After obtaining weight coefficients of each index in three major systems in the provinces and cities of Beijing-Tianjin-Hebei region based on modified entropy method, the similarity degree of three systems was calculated via using weighting TOPSIS method, which could be the evaluation value of each system (as shown in Figure 2-Figure 4). From Figure 2 and Figure 4, it is known that the prefabricated construction industry and regional economy in the provinces and cities of Beijing-Tianjin-Hebei region have strong similarity. The variation trend of Beijing, Tangshan and Tianjin (in the first four provinces and cities) is the same. In the past five years, Shijiazhuang, Tangshan and Handan were in the top six in the regional economic development and they ranked fifth, second and sixth respectively in the prefabricated construction industry in 2016. Hengshui and Xingtai were at the bottom of the economic development from 2012 to 2016, and they were in the bottom four in the development of the prefabricated construction industry.

By analysis above, it reveals that there is a strong correlation between regional economy and prefabricated construction industry. The economy development supports and promotes the development of prefabricated construction industry. In terms of dynamic comparison between economic development and prefabricated construction industry, the curve of the former is gradually and steadily increasing, while curve of the latter is more volatile. The macro-economic structure and varied range of economy development is more stable. The macroeconomic differences in Beijing-Tianjin-Hebei region would exist for a long time and it is difficult to change effectively in a short period. As the resource support and environment-dependent industry, prefabricated construction industry has more flexibility in development under the condition of making full use of policy guidance and supporting services, which is great of significance to balance the development differences between regions and promote the coordinated development of the whole region. In the area with better economy development, cultivating industrialization base as well as technology research and development center could lay a good foundation for the development of prefabricated construction industry while the rapid development of prefabricated construction industry could drive the economic development and ensure the high-speed and smooth development of economy, both of which promote the coordinated development of each other.
From Figure 3 and Figure 4, it is found that the evaluation value of ecological environment in Beijing-Tianjin-Hebei region is mainly increasing gradually with the supplementing changing modes including fluctuation decline as well as first dropping and then increasing. Compared with economy and prefabricated construction, the variable characteristics of regional ecological environment system in the provinces and cities of Beijing-Tianjin-Hebei region have some differences. The areas with high ecological environment evaluation value include Beijing, Qinhuangdao, Chengde, Hengshui and Cangzhou, among which only Beijing has better economy development, while the other four areas have slow economy development. Despite low ecological environment evaluation value, Tangshan and Shijiazhuang have better economic development, which shows that there is no significant correlation between the economy development and ecological environment in Beijing-Tianjin-Hebei region. However, certain conflicts between economy development and ecological protection in this area exist. When developing regional economy and prefabricated construction industry, the ecological environment could be optimized by advocating ecological civilization, circular economy, sustainable development and other methods.

Based on the coupled coordination model, the comprehensive evaluation indexes of three system were calculated, thus reflecting the differences of comprehensive development of prefabricated construction industry, regional economy and ecological environment (as shown in Figure 5). According to the variation tendency of comprehensive evaluation index in provinces and cities of Beijing-Tianjin-Hebei region in 2012-2016, those provinces and cities could be divided into three types. The first type (0.65~0.85) includes Beijing city, which always places in the first position of the comprehensive evaluation index of three major systems. The second type (0.3~0.65) includes Tianjin, Zhangjiakou, Qinhuangdao and Handan. Among those, the comprehensive evaluation indexes of Handan increase and then decrease while the comprehensive development level of Tangshan is fluctuating and rising due to its advantages of economy development and prefabricated construction industry. The other eight provinces and cities belong to the third type (0.1~0.3), which has a trend of falling with fluctuation and
then rising. Therefore, except Beijing, the comprehensive development level of coupled coordination among prefabricated construction industry, regional economy and ecological environment in most of areas is poor.

4.2 Time-space analysis of coupled coordination of prefabricated construction industry, regional economy and ecological environment

The evaluation values of each subsystem in prefabricated construction industry, regional economy and ecological environment in Beijing-Tianjin-Hebei region were put into the formula of coupling degree and coupled coordination index, thus obtaining the coupled coordination indexes of three major systems (seen in Table 2). From the time evolution, it is seen that in 2012-2016, the coupled coordination degree of regional economy, ecological environment and prefabricated construction industry in Beijing-Tianjin-Hebei region mainly keeps maintain stability and rising volatility, which is developed in the direction of benign coordination. However, some individual provinces and cities have the slow and relatively downward trend in the development. The coupled coordination degrees of Handan, Tangshan, Xingtai, Cangzhou and Tianjin are always in the fixed interval, which shows that the relations of the coordinated development of three major systems in those provinces and cities are stable. Langfang and Hengshui rise from mild maladjustment to the verge of maladjustment; Qinhuangdao rises from the verge of misalignment to barely coordination; Beijing rises from ultimate coordination to good coordination. Zhangjiakou, whose coupled coordination degree is lowest, is always in the slight misalignment and it is expected to reach the verge of misalignment in 2017 due to its rapid growth. From 2012 to 2016, the coupled coordination degree of Chengde decreases, which is transferred from the verge of misalignment to slight misalignment. Therefore, Chengde should adopt comprehensive measures to improve the coordination development of regional economy, ecological environment and prefabricated construction industry and prevent regional socioeconomic system from becoming unbalanced and deteriorated.

Table 2 Time-variation of coupled construction industry-regional economy-ecological environment coupling coordination degree

| Province   | 2012   | 2013   | 2014   | 2015   | 2016   |
|------------|--------|--------|--------|--------|--------|
| Shijiazhuang| 0.4096 | 0.4064 | 0.4228 | 0.4316 | 0.4665 |
| Baoding    | 0.3890 | 0.4161 | 0.4133 | 0.4380 | 0.4831 |
| Handan     | 0.4170 | 0.4328 | 0.4558 | 0.4789 | 0.4699 |
| Tangshan   | 0.4168 | 0.4209 | 0.4298 | 0.4409 | 0.4636 |
| Qinhuangdao| 0.4256 | 0.4442 | 0.4733 | 0.4976 | 0.5149 |
| Xingtai    | 0.3395 | 0.3359 | 0.3404 | 0.3328 | 0.3358 |
| Chengde    | 0.4020 | 0.4001 | 0.4009 | 0.3908 | 0.3767 |
| Langfang   | 0.3984 | 0.3924 | 0.3867 | 0.4152 | 0.4311 |
| Zhangjiakou| 0.2834 | 0.3068 | 0.3402 | 0.3714 | 0.3931 |
| Cangzhou   | 0.4070 | 0.4155 | 0.4247 | 0.4178 | 0.4325 |
| Hengshui   | 0.3144 | 0.3365 | 0.3606 | 0.3943 | 0.4135 |
| Beijing    | 0.7093 | 0.7383 | 0.7737 | 0.8062 | 0.8474 |
| Tianjin    | 0.5100 | 0.5067 | 0.5122 | 0.5462 | 0.5778 |

To compare the coupled coordination development of three major systems in Beijing-Tianjin-Hebei region horizontally, this paper calculated the average values of coupled coordination indexes of prefabricated construction industry, regional economy and ecological environment in Beijing-Tianjin-Hebei region from year 2012 to year 2016 (as shown in Table 3). From space, it is seen that the distribution of coupled coordination degree of three major systems in Beijing-Tianjin-Hebei region is similar to that of comprehensive evaluation index of the main system, in which most areas are within the range between the verge of maladjustment and slight maladjustment. However, from the evaluation values of the subsystems of Beijing-Tianjin-Hebei region, it is found that the main factors influencing the coupled coordination development are different. Baoding, Handan and Qinhuangdao belong to the economy development retarded type, while Tangshan, Beijing and Tianjin belong to the ecological...
environment retarded type and other provinces and cities belong to prefabricated construction retarded type. In Hebei province, only Baoding, Handan, Tangshan, Qinhuangdao belong to non-prefabricated construction retarded type, which not only shows that those cities are the pilot cities of modernization construction industry, but also reflects that the development of prefabricated construction has been in a leading position in recent years. Belonging to the ecological environment retarded type, the deficiency of natural ecological environment becomes the leading factor to restrict the coordination development in Beijing and Tianjin. Therefore, when rapidly developing economy and prefabricated construction industry, the protection of ecological environment should be poured attention to.

Table 3 Analysis of the development of the coupled construction industry-regional economy-ecological environment coupling coordination degree

| Province       | Prefabricated building evaluation value | Regional economic evaluation | Ecological environment evaluation value | Comprehensiv e evaluation value | Coupling | Comprehensive evaluation value | Coordination type | Main constraints                          |
|----------------|----------------------------------------|-----------------------------|----------------------------------------|---------------------------------|---------|---------------------------------|------------------|------------------------------------------|
| Shijiazhuang   | 0.2811                                 | 0.3174                      | 0.3095                                 | 0.3026                          | 0.6710  | 0.4505                          | the verge of dys | Assembled building lag                    |
| Baoding        | 0.3128                                 | 0.1761                      | 0.3698                                 | 0.2862                          | 0.6574  | 0.4511                          | the verge of dys | Economic development lag                  |
| Handan         | 0.2952                                 | 0.2568                      | 0.4324                                 | 0.3281                          | 0.6893  | 0.4754                          | the verge of dys | Economic development lag                  |
| Tangshan       | 0.4216                                 | 0.2715                      | 0.2370                                 | 0.3100                          | 0.6766  | 0.4579                          | the verge of dys | Ecological environment lag                |
| Qinhuangdao    | 0.2733                                 | 0.1949                      | 0.5836                                 | 0.3506                          | 0.7043  | 0.4966                          | the verge of dys | Economic development lag                  |
| Xingtai        | 0.1021                                 | 0.1782                      | 0.3833                                 | 0.2212                          | 0.6046  | 0.3657                          | Mild disorder   | Assembled building lag                    |
| Chengde        | 0.0860                                 | 0.2166                      | 0.5441                                 | 0.2822                          | 0.6558  | 0.4302                          | the verge of dys | Assembled building lag                    |
| Langfang       | 0.1798                                 | 0.2650                      | 0.3917                                 | 0.2789                          | 0.6531  | 0.4267                          | the verge of dys | Assembled building lag                    |
| Zhangjiakou    | 0.0837                                 | 0.1850                      | 0.3755                                 | 0.2147                          | 0.5967  | 0.3573                          | Mild disorder   | Assembled building lag                    |
| Cangzhou       | 0.1567                                 | 0.2246                      | 0.5009                                 | 0.2941                          | 0.6649  | 0.4422                          | the verge of dys | Assembled building lag                    |
| Hengshui       | 0.0880                                 | 0.1694                      | 0.4578                                 | 0.2384                          | 0.6185  | 0.3835                          | Mild disorder   | Assembled building lag                    |
| Beijing        | 0.7958                                 | 0.8283                      | 0.5941                                 | 0.7394                          | 0.9034  | 0.8169                          | Advanced coordination | Ecological environment lag              |
| Tianjin        | 0.3916                                 | 0.4869                      | 0.3775                                 | 0.4187                          | 0.7476  | 0.5593                          | Reluctant coordination | Ecological environment lag              |

5. Conclusions and discussions
First, there is a high level of correlation between regional economy and prefabricated construction industry in Beijing-Tianjin-Hebei region. Among these eleven provinces and cities, Beijing, Tianjin and Tangshan rank the first three places in regional economy and prefabricated construction industry, whose changing trends are the same. Compared with the regional macro economy, prefabricated construction industry has more flexibility and competitiveness under the condition of making full use of policy guidance and supporting facilities. However, ecological environment is mainly steadily rising or it is decreasing first and then rising. There is no obvious conflict between environmental protection and economic development. When developing regional economy and prefabricated construction industry, the ecological environment could be improved via advocating ecological civilization and developing circular economy.

Second, in terms of time, the coupled coordination degrees of three major systems in Beijing-Tianjin-Hebei region mainly maintained stability and wavelike rise from year 2012 to year 2016. However, there was a small decline in exceptional province or region, which was required to pay attention to the ecological protection. Moreover, the main factors restricting the coordination development in provinces and cities are different. Beijing, Tianjin and Tangshan belong to ecological environment retarded type, while Baoding, Handan and Qinhuangdao belong to economy development retarded type and the rest
provinces and cities belong to prefabricated construction industry retarded type with backward economy development.

Last, this paper quantified and analyzed the coupled coordination relationship and development laws of the prefabricated construction industry, regional economy and ecological environment based on modified entropy method, weighting TOPSIS method and coupled coordination model, which breaks through the limitation of taking a single province or city as the analysis unit and the pairwise coupling relationship as the research content in the existing literature.

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