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Evaluation and Optimization of Sustainable Development Level of Construction Industrialization: Case Beijing-Tianjin-Hebei Region

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Abstract: In order to promote the sustainable development of architectural industrialization, it is necessary to evaluate its development level, identify the development status and key restricting factors, and achieve the effect of "promoting the development by evaluation". However, the existing studies are mostly limited to the scope of provinces and cities, and there are few studies on the construction industrialization of an economic circle as a whole. Therefore, this paper locates the research within the scope of the region, constructs the evaluation model of the sustainable development level of the regional construction industrialization, and selects the Beijing-Tianjin-Hebei region as a case study. The research shows that the sustainable development level of construction industrialization in the Beijing-Tianjin-Hebei region is in the middle level, which needs to be improved from the aspects of economic support, technological innovation, and management. This paper provides a reasonable reference for how to evaluate and better promote the sustainable development of regional construction industrialization.

Keywords: construction industrialization; sustainable development; gray comprehensive evaluation model; optimization path

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1. Introduction

With the continuous reduction of available resources, environmental pollution becomes more and more prominent, which restricts the sustainable development of human society seriously. In order to build a "resource-saving" and "environment-friendly" society and promote the sustainable development of the construction industry, the traditional construction industry with "low efficiency, high energy consumption and high pollution" will gradually develop towards the direction of sustainable construction industrialization.

Construction industrialization is the future development direction of the construction industry. By forming a complete industrial chain in development, design, production, and construction through production methods such as standardized design, factory production, assembly construction, integrated decoration, and information management, the purpose is to realize the industrialization, intensification, and socialization of building construction in the whole life cycle; to improve the production quality and efficiency; and to achieve the purpose of resource conservation and environment protection.

Developing construction industrialization is a fundamental way to realize the transformation of construction from extensive mode to intensive mode, an inevitable choice for

the sustainable development of the construction industry, and the future direction of the construction industry development. In order to promote the sustainable development of Chinese construction industry industrialization and show the leading role of the pilot area, the State Council issued the "Guidance on Vigorously Developing Assembled Construction" on 27 September 2016 [1], which established the Beijing-Tianjin-Hebei region as the crucial areas to promote assembled construction. Since 2017, the overall frequency of issuing the policies related to construction industrialization in the Beijing-Tianjin-Hebei region has gone up, with the number of policies released in 2017 being seven and ten in 2020, which is a significant increase in intensity. In addition, the synergistic development of the Beijing-Tianjin-Hebei region has further deepened, with Beijing having officially released three synergistic standards of the Beijing-Tianjin-Hebei region and Hebei having released five synergistic standards (four of them are related to construction industrialization) of the Beijing-Tianjin-Hebei region as of 30 April 2021. However, at present the sustainable development of construction industrialization in the Beijing-Tianjin-Hebei region now presents the following constraint characteristics: development lacks balance in regions, the complete regional development plan for construction industrialization is not established, and the quality of the labor force cannot meet the demand of industrialization development.

Many scholars have affirmed the positive role of construction industrialization [2,3], which is to solve the bottleneck and unsustainable development factors in the development process of the construction industry through the factory production of components, construction technology innovation, information management, and the coordination of the whole industry chain and the control of the whole life cycle [4]. Construction industrialization is an effective way to promote the development of the construction industry, which can effectively improve resource utilization rate, reduce construction waste discharge, and improve construction efficiency. [5] These advantages have been proven by practice to some extent.

The United States has strong technological innovation ability and no housing shortage, so the development of the industrialization of American architecture pays more attention to the diversification and personalized needs of architecture [6]. The construction industrialization of Japan is characterized by the mass production of architecture, through the standardized design and factory production [7]. France began to adopt assembly construction in the late 19th century, and gradually formed an industrialized construction system of "design-construction" integration in the 1960s [8]. The development level of construction industrialization is affected by many factors, such as technology, economy, sustainability, enterprise development and development environment which all play a significant role [9]. The development of Chinese construction industrialization is promoted by the macro development and the government, as well as a self-driven process [10]. However, those policy interventions ignore the dynamic influence of stakeholders and technologies, which significantly influence the efficient management of construction industrialization [11]. That is to say, the policy factor plays a dominant role, while the management factor and market factors are also significant [12].

To address the issue of sustainable development evaluation, most scholars establish evaluation index systems to reflect the development level of construction industrialization from different dimensions. To comprehensively evaluate the development level, the following three evaluation index systems are mainly used to assess the sustainable development level of construction industrialization through a three-level index system including target level, criterion level, and indicator level [13]; to construct an evaluation system through designing multi-level indicators from high-level to low-level [14]; and to evaluate the index system of the construction industry built based on input and output theories [15]. Specifically, for construction industrialization, most studies rely on the aspects of influencing factors. The commonly used methods include Analytic Hierarchy Process [9], Entropy Value Method [16], Principal Component Analysis [17], etc. In order to overcome the defects of various evaluation methods, during the actual evaluation process, some scholars did

combination studies of methods based on different theories and constructed a combination evaluation model [18].

Huang, W.J. [19] uses factor analysis and comprehensive evaluation to characterize the construction enterprise development index system. Based their investigation on the theory of green economy, Liu, F. [20] analyzed the factors affecting the economic transformation of construction enterprises, proposed the objectives and principles of the economic transformation of construction industry, and established the original evaluation index system on the basis of analyzing the development status of the economic transformation of construction enterprises. Gallo, P. [21] selected 21 qualitative parameters to compare and evaluate their sustainability performance, and proposed a set of strategies and methods to enhance prefabrication sustainability. Li, Long [22] pointed out that Chinese construction industrialization paid attention to environmental and social sustainability, but the obstacles to economic sustainability had not been solved well.

In the past, most of the research on construction industrialization focused on the system technology level, performance evaluation, decision-making strategies and policy making, and most of the research was limited to the scope of provinces and cities. There were few studies on the construction industry industrialization with an economic circle as a whole, which could not evaluate the sustainable development level of regional construction industry industrialization. Therefore, it is of great significance to study and establish a scientific and reasonable evaluation method for sustainable development level of construction industrialization. In order to bridge this gap, this paper puts forward an evaluation paradigm of sustainable development of regional construction industry industrialization, aiming to identify the defects in economy, society, technological innovation, and environmental resources, in order to better promote the sustainable development of regional construction industrialization. The research objectives include: (1) determining the index system for evaluating the level of sustainable development of regional construction industrialization; (2) proposing the grey comprehensive evaluation method of regional building industrialization; (3) selecting Beijing-Tianjin-Hebei region to the empirical analysis, to analyze its advantage disadvantage, which can provide reference for other regions.

2. Methods

2.1. Index System Screening

The process of index system screening is shown in Figure 1.

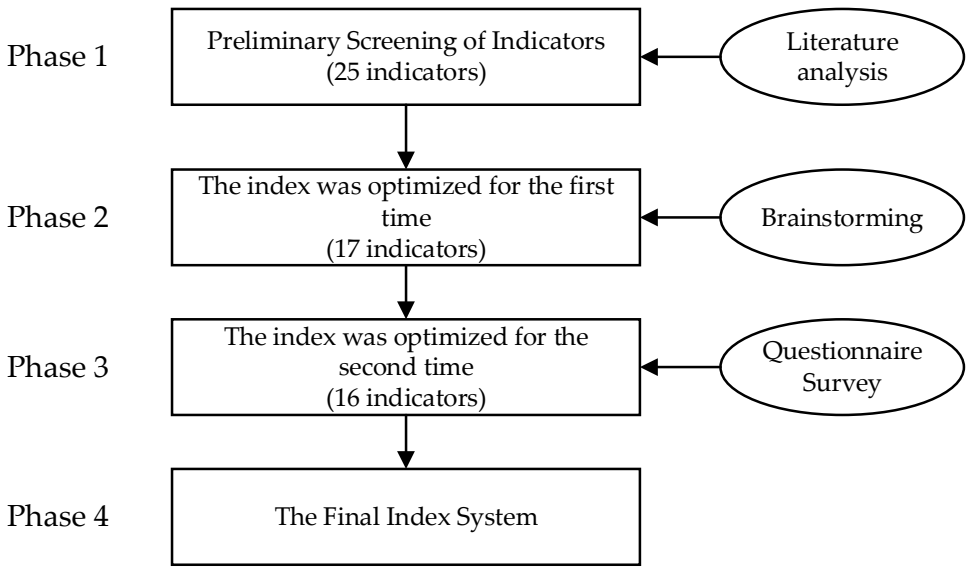

Figure 1. The process of index system screening.

2.1.1. Preliminary Screening of Indicators

The preliminary indicators were screened by the literature analysis. In order to establish a comprehensive evaluation index system, it is significant to consider the development level from different views. This paper refers to the evaluation index systems of the industrial building, prefabricated building, and construction industrialization. A number of representative papers were selected from the retrieved results, and the indicators with high frequency were counted. The initial screening results are shown in Table 1.

Table 1. Preliminary screening indicators.

	Preliminary Screening Indicators
1	Compulsory policy [23]
2	Subsidy policy [24]
3	Technology standard [25]
4	The degree of government support [26]
5	The scientific level of industry chain structure [27]
6	the level of construction organization management and scientific management [28]
7	The capacity of industry workers [29]
8	Market share level of industrialized enterprises [30]
9	Construction assembly level [31]
10	Degree in information management [32]
11	Factory level of production of components and accessories [33]
12	Degree of design standardization [34]
13	The technical proficiency of industry workers [35]
14	Industry cluster level [36]
15	Level of regional economy contribution [9]
16	The investment level in scientific research [37]
17	Cost-effectiveness level [38]
18	Resource utilization rate [39]
19	Level of consumer awareness [40]
20	Degree of consumer satisfaction [41]
21	Degree of scale efficiency [42]
22	Provision level of land market [43]
23	The quality-price ratio of construction product [44]
24	Level of green and energy-saving [45]
25	The degree to which resources are optimized and allocated [46]

2.1.2. Index Optimization 1

The preliminary selected indicators are obtained through the literature research, but their applicability and rationality need to be verified. To avoid the problems of "meaning duplicate term", "category asymmetry", and "ambiguity" in the main indicators, this paper adopts the brainstorming method to optimize the indicators for the first time.

The process of index optimization for the first time was as follows. A brainstorming team composed of 3 experts in the field of construction industrialization and 6 project research members sent information about the purpose and main indexes of the brainstorming to the 9 experts by email. After 1 h and 55 min of discussion, the optimization results are shown in Table 2.

Table 2. The index of the first optimization.

	Preliminary Screening Indicators	The Index of the First Optimization
1	Compulsory policy	The degree of government support for construction industrialization
2	Subsidy policy	
3	Technology standard	
4	The degree of government support	
5	The scientific level of industry chain structure	√
6	the level of construction organization management and scientific management	√
7	The capacity of industry workers	√
8	Market share level of industrialized enterprises	√
		+ Industry collaboration level
9	Construction assembly level	√
10	Degree in information management	√
11	Factory level of production of components and accessories	√
12	Degree of design standardization	√
		+ construction parts and set up product certification system
13	The technical proficiency of industry workers	×
14	Industry cluster level	×
15	Level of regional economy contribution	√
16	The investment level in scientific research	√
17	Cost-effectiveness level	√
18	Resource utilization rate	×
19	Level of consumer awareness	×
20	Degree of consumer satisfaction	×
21	Degree of scale efficiency	×
22	Provision level of land market	√
23	The quality-price ratio of construction product	×
24	Level of green and energy-saving	√
25	The degree to which resources are optimized and allocated	√

(√ means indicators that meet requirements, × means indicators to be deleted, and + means indicators to be added).

(1) Meaning duplicate term

① Indexes 1 to 4 belong to "meaning duplicate term" and can be replaced by "The degree of government support for construction industrialization".

② "The capacity of industry workers" is similar to "The technical proficiency of industry workers", so the latter is deleted.

③ "The degree to which resources are optimized and allocated" is similar to "Resource utilization rate", so the latter is deleted.

(2) Inappropriate items

"Level of consumer awareness", "Degree of consumer satisfaction", and "The quality-price ratio of construction product" are inappropriate indicators, so they are deleted.

(3) Other indicators to be deleted

"Industry cluster level" covers too much scope and "Degree of scale efficiency" is ambiguous, so they are deleted

(4) Indicators to be added

"Industry collaboration level" and "construction parts and set up product certification system" are added to the index system.

2.1.3. Index Optimization 2

In order to ensure the practicality and scientificity of the evaluation index system, this paper adopts the method of the questionnaire survey to analyze the indexes and delete the inappropriate indexes, so as to establish a complete and scientific evaluation index system for the development level of construction industrialization to ensure the authenticity of the evaluation results.

(1) Questionnaire design and distribution

The questionnaire was designed in the form of the Likert scale, and the importance of each index was divided into five levels, with scores ranging from 1 to 5 indicating "very unimportant", "less important", "important", "relatively important", and "very important", respectively.

The effective rate of the questionnaire was 80%. Reliability analysis was performed on the 16 valid questionnaires, with the results indicating high reliability (Cronbach's $\alpha = 0.834$). Shen et al. noted that the threshold value of Cronbach's α for a reliable questionnaire is 0.70.

(2) Second index optimization

Concentration degree (J) and fluctuation degree (Q) were calculated according to the questionnaire results. J reflected the average value of the importance degree of indicators. Q reflects the consistency of experts' opinions on the importance of indicators.

$$J = \frac{x_1 + x_2 + \cdots + x_m}{m};\ Q = \sqrt{\frac{\sum_1^m (x_i - J)^2}{m}} \quad (1)$$

where x_{ij} is the importance rating of expert i to indicator j, m is the number of experts, and n is the number of indicators.

The calculation results of index Q and J are processed according to the following:

$J \leq 2.5$ and $Q \leq 1$, the index is omitted; $J > 2.5$ and $Q \leq 1$, the index is left; $J \leq 2.5$ and $Q > 1$, the index is determined by analysis; $J > 2.5$ and $Q > 1$ need to be determined according to the expert investigation results.

After the second optimization, "Provision level of land market" was deleted and 16 indicators were retained, the optimization results are shown in Table 3.

Table 3. The index of the second optimization.

The Index of the First Optimization	J	Q	The Index of the Second Optimization
The degree of government support for construction industrialization	4.1	0.539	√
The scientific level of industry chain structure	3.9	0.436	√
the level of construction organization management and scientific management	3.55	0.589	√
The capacity of industry workers	4	0.837	√
Market share level of industrialized enterprises	3.8	0.678	√
Industry collaboration level	3.75	0.766	√

Table 3. *Cont.*

The Index of the First Optimization	J	Q	The Index of the Second Optimization
Construction assembly level	3.7	0.458	√
Degree in information management	3.65	0.572	√
Factory level of production of components and accessories	3.65	0.572	√
Degree of design standardization	3.6	0.663	√
+ construction parts and set up product certification system	2.4	1.020	√
Level of regional economy contribution	4.25	0.622	√
The investment level in scientific research	3.65	0.792	√
Cost-effectiveness level	3.8	0.678	√
Provision level of land market	2.2	0.510	×
Level of green and energy-saving	2.58	0.726	√
The degree to which resources are optimized and allocated	3	0.447	√

(√ means indicators that meet requirements, × means indicators to be deleted, and + means indicators to be added.).

2.1.4. The Final Index System

The 16 indicators include four categories: Economy, Society, Technology Innovation, and Environmental Resources. The final index system divided according to the four categories is shown in Table 4.

Table 4. Results of index system construction.

Target Layer	Criterion Layer	Indicator Layer
Sustainable Development of Construction Industrialization U	Economy U_1	Cost-benefit U_{11}
		Regional economic contribution U_{12}
		Spending on science and technology U_{13}
	Society U_2	Quality of industrial practitioner U_{21}
		Market share of industrial enterprises U_{22}
		Scientization of industrial chain structure U_{23}
		Scientization of construction organization and management U_{24}
		Industrial synergy U_{25} Support of government for construction
		industrialization U_{26}
	Technological Innovation U_3	Degree of information management U_{31}
		Degree of design standardization U_{32}
		Industrialization of components, fittings and parts U_{33}
		Construction assembly U_{34}
		Building parts and components product certification system U_{35}
	Environmental Resources U_4	Degree of optimal resource allocation U_{41}
		Green energy saving U_{42}

2.2. Determine Index Weight and Index Scoring Levels

The process of determining index weight and index scoring levels is shown in Figure 2.

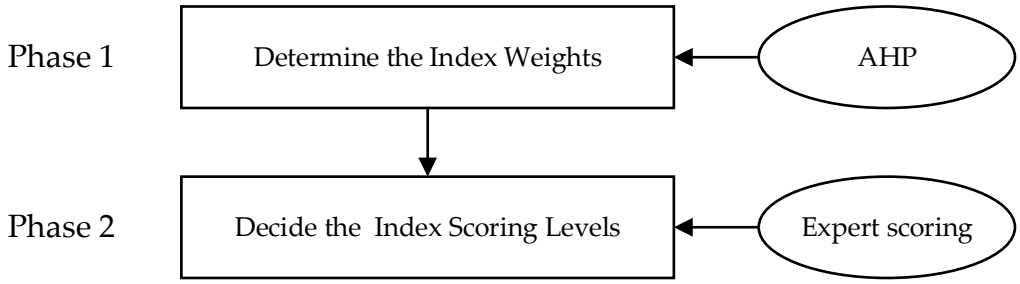

Figure 2. The process of determining index weight and index scoring levels.

2.2.1. Determine the Index Weights

The Analytic Hierarchy Process (AHP) is used to determine the index weight, construct a judgment matrix, and then select experts of different levels to propose one to nine layers of scaling methods using Sauty. These methods are compared in pairs to compare the relative importance between indicators and an indicator with that of the next layer. We constructed weight judgment matrix $A = (a_{ij})_{n \times n}$ for different levels, then applied yaahp (yaahp is an analytic hierarchy process auxiliary software) to determine indicator weights, sort, and conduct consistency tests. We determined the weight set of the first-level indicators of comprehensive evaluation U_i as $W = (W_1, W_2, W_3, W_4)$ and the second-level indicators as $W_i = (W_{i1}, W_{i2}, \ldots, W_{ili})$.

In this paper, five experts are invited, including two experts in the field of construction industrialization from North China University of Technology, one staff member from the Center for Science, Technology and Industrial Development of the Ministry of Housing and Urban-Rural Development, and two senior practitioners in the field of construction industrialization. The weights W and W_i of indicators in each layer are obtained and expressed as (W_i) and (W_{ili}).

2.2.2. Decide the Index Scoring Levels

The 16 indicators contained in Table 5 are divided into qualitative and quantitative indicators. On the basis of consulting expert opinions, each indicator is divided into five levels [1,2), [2,3), [3,4), [4,5), [5,∞). In the evaluation process, each expert scores according to their own experience. The final results are shown in Table 5.

2.3. Gray Comprehensive Evaluation

The grey comprehensive evaluation method is constructed based on the mathematical principle of grey clustering, and grey clustering is a method that aggregates indicators or observation objects into several definable categories according to the grey correlation matrix or the grey whitening weight function. A cluster can be regarded as a collection of observation objects belonging to the same category. Grey clustering can be divided into grey correlation clustering and grey whitening weight function clustering.

The grey relational clustering analysis method can simply get the relative size or superiority of several research objects with the same attributes, so as to select the better ones, but cannot determine the level of research objects. Whitenization weight function clustering is mainly used to check whether the evaluation object belongs to different levels set in advance, so as to obtain the final comprehensive evaluation value of the evaluation object and the evaluation level, so as to understand the current status of the research object better and solve the problem specifically. In this paper, the grey comprehensive evaluation method based on the Whitenization weight function is more suitable because the correlation between indicators is not clear.

Table 5. Index weight and index Scoring Levels.

Target Layer	Criterion Layer (Weight W_i)	Indicator Layer (Weight W_{iIi})	Indicator Evaluation Standard Score				
			V_1	V_2	V_3	V_4	V_5
			[1,2)	[2,3)	[3,4)	[4,5)	[5,∞)
Sustainable Development of Construction Industrialization U	Economy U_1 (0.3303)	Cost-benefit U_{11} (0.3299)	Far below	Slightly far below	Similarly	Sightly above	Far above
		Regional economic contribution U_{12} (0.4938)	0~10%	10~20%	20~30%	30~50%	>50%
		Spending on science and technology U_{13} (0.2072)	Very low	Relatively low	medium	Slightly above	Very high
	Society U_2 (0.1594)	Quality of industrial practitioner U_{21} (0.1092)	0~20%	20~40%	40~60%	60~80%	80~100%
			Completely unskilled	Less skilled	Generally skilled	Skilled	Master
		Market share of industrial enterprises U_{22} (0.0721)	0~10%	10~30%	30~50%	50~70%	70~100%
		Scientization of industrial chain structure U_{23} (0.2866)	Uncompleted	Less complete	medium	More complete	Totally complete
		Scientization of construction organization and management U_{24} (0.1553)	Completely incompatible	Less compatible	medium	More compatible	Fully compatible
		Industrial synergy U_{25} (0.2556)	Completely unrelated	Less related	medium	More related	Complete synergy
		Support of government for construction industrialization U_{26} (0.1212)	Completely unadaptable	Less adaptable	medium	More adaptable	Fully adaptable

Table 5. *Cont.*

Target Layer	Criterion Layer (Weight W_i)	Indicator Layer (Weight W_{ili})	Indicator Evaluation Standard Score				
			V_1	V_2	V_3	V_4	V_5
			[1,2)	[2,3)	[3,4)	[4,5)	[5,∞)
	Technological Innovation U_3 (0.2128)	Degree of information management U_{31} (0.3681)	0~5%	5~20%	20~50%	50~70%	70~100%
			Poor results	Less poor results	Average results	Better results	Put into application
		Degree of design standardization U_{32} (0.1094)	Very low	Relatively low	medium	Slightly high	Very high
		Industrialization of components, fittings and parts U_{33} (0.2121)	0~1	1~2	2~3	3~4	4~5
			0~20%	20~40%	40~60%	60~80%	80~100%
		Construction assembly U_{34} (0.201)	Very low	Relatively low	medium	Slightly high	Very high
		Building parts and components product certification system U_{35} (0.1094)	Very low	Relatively low	medium	Slightly high	Very high
	Environmental Resources U_4 (0.2975)	Degree of optimal resource allocation U_{41} (0.3975)	Almost no change	Very little change	Few changes	More changes	Much more changes
		Green energy saving U_{42} (0.6025)	Almost no change	Very little change	Few changes	More changes	Much more changes

2.3.1. Determine Evaluation Sample Matrix

Expert scoring is used to determine the evaluation sample matrix. According to the rating scale set above, m experts in the relevant fields are invited to grade indicators and fill in the scoring table. Let the serial number of experts be k, then $k = 1, 2, \ldots, m$; let the score of expert k on U_{ij} be b_{ijk}, then the evaluation sample matrix B can be obtained as follows.

$$B = \begin{bmatrix} b_{111} & b_{112} & \ldots & b_{11n} \\ b_{121} & b_{122} & \ldots & b_{12n} \\ b_{131} & b_{132} & \ldots & b_{13n} \\ b_{211} & b_{212} & \ldots & b_{21n} \\ b_{221} & b_{222} & \ldots & b_{22n} \\ b_{231} & b_{232} & \ldots & b_{23n} \\ b_{241} & b_{242} & \ldots & b_{24n} \\ b_{251} & b_{252} & \ldots & b_{25n} \\ b_{261} & b_{262} & \ldots & b_{26n} \\ b_{311} & b_{312} & \ldots & b_{31n} \\ b_{321} & b_{322} & \ldots & b_{32n} \\ b_{331} & b_{332} & \ldots & b_{33n} \\ b_{341} & b_{342} & \ldots & b_{34n} \\ b351 & b352 & \ldots & b35n \\ b411 & b412 & \ldots & b41\mathrm{n} \\ b421 & b422 & \ldots & b42\mathrm{n} \end{bmatrix} \quad (2)$$

2.3.2. Determine the Evaluation Gray Clustering

Experts' evaluation of the indicators for construction industrialization is based on their knowledge of the object, and what they get is only a whitened value of the gray number. To accurately reflect the development state of the indicator, it is necessary to determine the grade of evaluation gray clustering; set the ordinal number e of the evaluation gray clustering, $e = 1, 2, \ldots, 5$; then set five levels: high, higher, medium, relatively low and low. The whitenization weight function is given as follows.

(1) The first gray cluster is "high level", $e = 1$, gray number is $\otimes_1 \in (5, \infty)$, and its whitenization weight function is expressed as Equation (3).

$$f_1(b_{ijk}) = \begin{cases} \frac{b_{ijk}}{5}, & b_{ijk} \in [0, 5] \\ 1, & b_{ijk} \in [5, \infty] \\ 0, & b_{ijk} \in [-\infty, 0] \end{cases} \quad (3)$$

(2) The second gray cluster is "higher level", $e = 2$, gray number is $\otimes_2 \in [0, 4, 8]$, and its whitenization weight function is expressed as Equation (4).

$$f_2(b_{ijk}) = \begin{cases} \frac{b_{ijk}}{4}, & b_{ijk} \in [0, 4] \\ 2 - \frac{1}{4} b_{ijk}, & b_{ijk} \in [4, 8] \\ 0, & b_{ijk} \notin [0, 8] \end{cases} \quad (4)$$

(3) The third gray cluster is "medium level", $e = 3$, gray number is $\otimes_2 \in [0, 3, 6]$, and its whitenization weight function is expressed as Equation (5).

$$f_3(b_{ijk}) = \begin{cases} \frac{b_{ijk}}{3}, & b_{ijk} \in [0, 3] \\ 2 - \frac{1}{3} b_{ijk}, & b_{ijk} \in [3, 6] \\ 0, & b_{ijk} \notin [0, 6] \end{cases} \quad (5)$$

(4) The fourth gray cluster is "relatively low level", $e = 4$, gray number is $\otimes_2 \in [0, 2, 4]$, and its whitenization weight function is expressed as Equation (6).

$$f_4(b_{ijk}) = \begin{cases} \frac{b_{ijk}}{2}, & b_{ijk} \in [0, 2] \\ 2 - \frac{1}{2} b_{ijk}, & b_{ijk} \in [2, 4] \\ 0, & b_{ijk} \notin [0, 4] \end{cases} \tag{6}$$

(5) The fifth gray cluster is "low level", $e = 5$, gray number is $\otimes_2 \in [0, 1, 2]$, and its whitenization weight function is expressed as Equation (7).

$$f_4(b_{ijk}) = \begin{cases} 1, & b_{ijk} \in [0, 1] \\ 2 - b_{ijk}, & b_{ijk} \in [1, 2] \\ 0, & b_{ijk} \notin [0, 2] \end{cases} \tag{7}$$

2.3.3. Calculate Gray Evaluation Coefficients and Weight Matrix

For all the evaluation indicators U_{ij}, we let the gray evaluation coefficient of the e Grey clustering be $M_{ije,}$ then all coefficient of all gray clusters be $M_{ij,}$ the gray evaluation weight of U_{ij} about the e gray cluster be recorded as $r_{ije,}$ and the gray evaluation weight vector of U_{ij} to each gray cluster be r_{ij}, so that the gray evaluation weight matrix R_i of the subordinate indicators U_{ij} of U_i for all gray clusters is obtained.

Equations are shown as follows:

$$M_{ije} = \sum_{k=1}^{m} f_e(b_{ijk}) \tag{8}$$

$$M_{ij} = \sum_{e=1}^{5} M_{ije} \tag{9}$$

$$r_{ije} = \frac{M_{ije}}{M_{ij}} \tag{10}$$

$$r_{ij} = (r_{ij1}, r_{ij2}, r_{ij3}, r_{ij4}, r_{ij5}) \tag{11}$$

$$R_i = [r_{i1} \quad r_{i2} \quad \cdots \quad r_{ij}]^T \tag{12}$$

2.3.4. Comprehensive Evaluation

Firstly, a comprehensive evaluation of U_{ij} is done. The set result is B_i, and the calculation formula is Equation (13), based on which the gray evaluation weight matrix R of U_i for each evaluation gray cluster can be obtained, as Equation (14). According to the maximum membership degree principle, the development of each U_i layer indicator is determined.

$$B_i = W_i \times R_i \tag{13}$$

$$R = [B_1 \quad B_2 \quad \cdots \quad B_j]^T \tag{14}$$

According to Equation (15), the comprehensive evaluation of the sustainable development U of construction industrialization is calculated, and the sustainable development of regional construction industrialization is obtained in light of maximum subordination.

$$B = W \times R \tag{15}$$

3. Case Study

3.1. Study Region

The Beijing-Tianjin-Hebei region (Figure 3) contains Beijing, Tianjin, and 11 prefecture-level cities in Hebei Province, including Baoding, Langfang, Tangshan, Shijiazhuang, Handan, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Xingtai, Hengshui, Dingzhou and Xinji, as well as 2 provincial cities that are directly under the control of Hebei Province. Beijing, Tianjin, Baoding, and Langfang are functional core areas in central areas. In the dual context of the transition stage of high-quality development in the construction industry and the accelerated implementation of regional coordinated development strategy, it is worthwhile to discuss the evaluation of the sustainable development level of regional construction industrialization.

Figure 3. Study Region.

As the vital promotion area of China's construction industrialization development, the development level of the Beijing-Tianjin-Hebei region can be viewed as a reference for other key promotion areas. Therefore, the research on the development level of construction industrialization in the Beijing-Tianjin-Hebei region is of great significance. Combining with the current situation of the development of construction industrialization in the Beijing-Tianjin-Hebei region, a set of evaluation systems in line with the characteristics of the Beijing-Tianjin-Hebei region will be established and the development level of the Beijing-Tianjin-Hebei region is evaluated, which is in expectation of finding the weak process of development, formulating targeted promotion measures, providing a reference for the evaluation of the development level of construction industrialization in other regions, and offering a basis for the policy formulation of sustainable development of construction industrialization in the Beijing-Tianjin-Hebei region in the future.

3.2. Grey Comprehensive Evaluation

Some people were consulted through the questionnaires, including 2 members of the Center for Science, Technology and Industrial Development of the Ministry of Housing and Urban-Rural Development, 2 professors studying construction industrialization in the Beijing-Tianjin-Hebei region, 2 experts who have been studying construction industrialization for a long time, 1 researcher of China Architecture Design Institute, and 2 researchers of China Academy of Building Research.

1. Experts Score to Determine Sample Matrix B

$$B = \begin{bmatrix} 2 & 3 & 2 & 1 & 2 & 2 & 2 & 3 & 2 \\ 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 \\ 3 & 4 & 4 & 3 & 4 & 3 & 3 & 3 & 3 \\ 2 & 2 & 1 & 1 & 2 & 2 & 2 & 1 & 1 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\ 2 & 2 & 3 & 1 & 2 & 3 & 2 & 3 & 2 \\ 2 & 2 & 2 & 1 & 3 & 2 & 2 & 3 & 2 \\ 2 & 3 & 2 & 2 & 3 & 3 & 3 & 3 & 3 \\ 4 & 4 & 3 & 5 & 4 & 4 & 3 & 4 & 4 \\ 3 & 4 & 3 & 3 & 4 & 4 & 4 & 5 & 3 \\ 2 & 3 & 2 & 2 & 3 & 3 & 2 & 2 & 2 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\ 4 & 3 & 4 & 3 & 3 & 4 & 4 & 3 & 3 \\ 2 & 3 & 2 & 1 & 1 & 2 & 2 & 2 & 2 \\ 3 & 2 & 4 & 3 & 4 & 4 & 3 & 3 & 3 \\ 3 & 4 & 3 & 4 & 3 & 3 & 4 & 3 & 3 \end{bmatrix}$$

2. Calculate Gray Weight Matrix R

According to Equations (8)–(12), the gray evaluation weight matrix R_i of the subordinate indicators U_{ij} of U_i for all gray clusters is obtained.

$$R_1 = \begin{bmatrix} 0.163 & 0.203 & 0.271 & 0.321 & 0.043 \\ 0.156 & 0.195 & 0.260 & 0.390 & 0 \\ 0.245 & 0.306 & 0.327 & 0.122 & 0 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0.127 & 0.159 & 0.212 & 0.319 & 0.182 \\ 0.211 & 0.263 & 0.351 & 0.175 & 0 \\ 0.169 & 0.211 & 0.282 & 0.296 & 0.042 \\ 0.163 & 0.203 & 0.271 & 0.321 & 0.430 \\ 0.194 & 0.242 & 0.323 & 0.242 & 0 \\ 0.310 & 0.365 & 0.280 & 0.044 & 0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.283 & 0.332 & 0.300 & 0.086 & 0 \\ 0.175 & 0.219 & 0.292 & 0.313 & 0 \\ 0.211 & 0.263 & 0.351 & 0.175 & 0 \\ 0.257 & 0.321 & 0.317 & 0.104 & 0 \\ 0.149 & 0.186 & 0.248 & 0.329 & 0.880 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.240 & 0.299 & 0.317 & 0.145 & 0 \\ 0.245 & 0.306 & 0.327 & 0.122 & 0 \end{bmatrix}$$

3. Comprehensive Evaluation

According to Equation (13), evaluate U_{ij} and obtain the result B_i, then the gray evaluation weight matrix R of U_i for each evaluation gray cluster is further obtained.

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{bmatrix} = \begin{bmatrix} 0.182 & 0.227 & 0.286 & 0.324 & 0.014 \\ 0.190 & 0.234 & 0.249 & 0.288 & 0.097 \\ 0.236 & 0.287 & 0.307 & 0.160 & 0.096 \\ 0.243 & 0.303 & 0.323 & 0.131 & 0 \end{bmatrix}$$

Given the principle of maximum subordination, it can be found that, in the aspect of economy, society, technology innovation, and resource environment, the development of the Beijing-Tianjin-Hebei region is relatively low, relatively low, medium, and medium, respectively.

According to Equation (15), calculate the comprehensive evaluation of the sustainable development U of construction industrialization:

$$B = W \times R = [0.213 \quad 0.263 \quad 0.302 \quad 0.220 \quad 0.041]$$

Therefore, according to the maximum membership degree principle, the development of construction industrialization in the Beijing-Tianjin-Hebei region is calculated to be at a medium level.

4. Results and Discussion

By the evaluation results, the highest membership value of the construction industrialization development in the Beijing-Tianjin-Hebei region is at medium level, reaching 0.302. It can be concluded that the development of construction industrialization in the Beijing-Tianjin-Hebei region is medium, indicating that the construction industrialization has been increasingly improved. However, there is still a need to continuously improve and renew current problems in economic support, technological innovation, and management. These practices above conform to the current development state of construction industrialization in the Beijing-Tianjin-Hebei region. The specific analysis is as follows.

4.1. Analysis of the Level of Development of the Economic Dimension

The membership degree of the economic index development level is 0.324, so the sustainable development of construction industrialization economy is still at a lower level. In the evaluation of the sustainable development level of construction industrialization economy, the contribution level of the regional economy accounts for the largest weight, and it is the biggest index affecting sustainable development of construction industrialization among economic indexes.

In the early stage of market development, large incremental costs lead to a slow growth rate. Therefore, the government needs to implement incentive policies including financial support, tax reform, and preferential land policies to guide market development and expand the regional industrialization market. It is necessary to reduce incremental costs from scale benefits and industrial clusters to increase the economic benefits, expand the proportion of constructed new buildings in this region, give priority to developing assembled buildings from government investment projects, and promote the development of the whole industrial chain from demand. To build a construction industrialization park in the Beijing-Tianjin-Hebei region, industry-leading enterprises should be developed in assembly design, parts production, construction and operation, in addition, enterprises should be encouraged to transform from building materials production to parts production, from traditional construction to assembly construction, and play a supportive role in market entities.

4.2. Analysis of the Level of Development of the Social Dimension

The highest membership degree is the social index of the development level in construction industrialization, reaching 0.288, so the sustainable development of construction industrialization society is at a low level.

In the development of construction industrialization in the Beijing-Tianjin-Hebei region, each region has its unique advantages. Beijing and Tianjin have strong economic strength and technical support, while Hebei has rich land resources and the developed manufacturing industry. Therefore, it is necessary to promote the synergistic development, respect discrepancies, take into account the local conditions, highlight advantages in each region to realize the development trend of low input and high output through sharing talents and other resources, co-build industrial parks and bases, and further promote the integrated construction industrialization development in Beijing-Tianjin-Hebei region. In addition, sustainable development is based on the scientific development of the overall industrial chain in the whole region through cooperation, resource sharing, and coordinated development of enterprises in each node. The horizontal scientific integration requires enterprises with the same function to realize cluster expansion, while the vertical requires the core enterprises in the whole industrial chain to participate in the development actively, play a positive role in promoting the healthy development of each link, and maintain the sustainable development of the whole industrialization jointly.

4.3. Analysis of the Level of Development of Technological Innovation Level

The index of technological innovation has the highest membership degree of construction industrialization development level, which is 0.307. The sustainable development of technological innovation of construction industrialization is in the middle-level stage. In the evaluation of technology innovation level in building industrial development level, the information management is the most important factor affecting the technological innovation. The influence on the performance of the minimum is the product certification system of construction industrialization, while the certification system is an important part of the construction of social credit system and the best evidence to guarantee product quality. The development of a certification system helps to improve the quality of products of construction industrialization and make the industry achieve sustainable development faster and better.

To implement the integrated development of the Beijing-Tianjin-Hebei region, it is necessary to realize the standardization of design links, the generalization of production parts, and the serialization of decoration links. The standardized system of each link requires research, development, and improvement to ensure that the development of regional construction industrialization follows a unified standard. In the early process, the government could take the lead in implementing standards such as standardized staircases and composite floor slabs to raise standardization in the process of construction industrialization continuously. Encourage correlative enterprises in Beijing, Tianjin and Hebei to carry out technical research and development, increase factory production efficiency and technical innovation of on-site assembly equipment, develop new construction materials, improve the quality of products continuously, and provide technical support for the rapid development of construction industrialization.

4.4. Analysis of the Level of Development of the Environmental Resource Dimension

The degree of subordination to the development level of the construction industrialization is 0.323, so the sustainable development of the environment and resources of the construction industrialization is at the medium level. Developers ought to pay attention to environmental protection, generalize and use green building materials, design and develop structural components for assembled construction such as assembled insulation and energy-saving building panels, steel-framed energy-saving wall panels, and lightweight and high-strength energy-saving composite panels, etc. They ought to transform and develop green building materials production enterprises, increase supply quantity, and

improve quality of green building materials, as well as enhance specialized standards of production and increase the proportion of green building materials used in assembled buildings. On the other hand, they ought to eliminate the use of materials forcibly that do not meet the requirements of energy conservation and environmental protection in relevant regulations; however, they ought to take advantage of incentive policies to encourage enterprises to increase the use of energy-saving and environmentally friendly building materials spontaneously.

5. Conclusions

In the past, the research on sustainable development of construction industrialization was mainly focused on the provincial and municipal level, and there were few evaluations on a certain economic circle. Aiming at this research gap, this paper puts forward an evaluation method for sustainable development of regional construction industrialization. According to the characteristics of regional construction industrialization, this paper determines 16 indicators from the four levels of economy, society, technological innovation and environmental resources, uses the analytic hierarchy process to determine the weight value of each evaluation index, establishes the grey comprehensive evaluation model, and obtains the comprehensive evaluation value and evaluation grade of each evaluation index. This paper chooses The Beijing-Tianjin-Hebei region as a case study, and the results show that the Beijing-Tianjin-Hebei region construction industrialization sustainable development is at a medium level and that the sustainable development of economy and society is at a low level, while the sustainable development of technological innovation and environmental resources is at a medium level. To promote the sustainable development of construction industrialization, this paper puts forward the corresponding suggestions from four aspects according to the evaluation results. The suggestions could help to promote the sustainable development of the Beijing-Tianjin-Hebei region construction industrialization, at the same time provide a reference for the level evaluation of sustainable development in construction industry of other regions, and promote the government to adjust measures to local conditions, formulate feasible policies and measures.

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