CONCLUSIONS

Through path analysis to significant validation of various assumptions, we can get to know collaborative innovation of construction industrialization has a close relationship with Government Intervention, Intermediaries intervention, Enterprises Collaborative, Complementary resources, Trust and Effective communication, that's to say the hypothesis H1 ~ H6 is practicable.

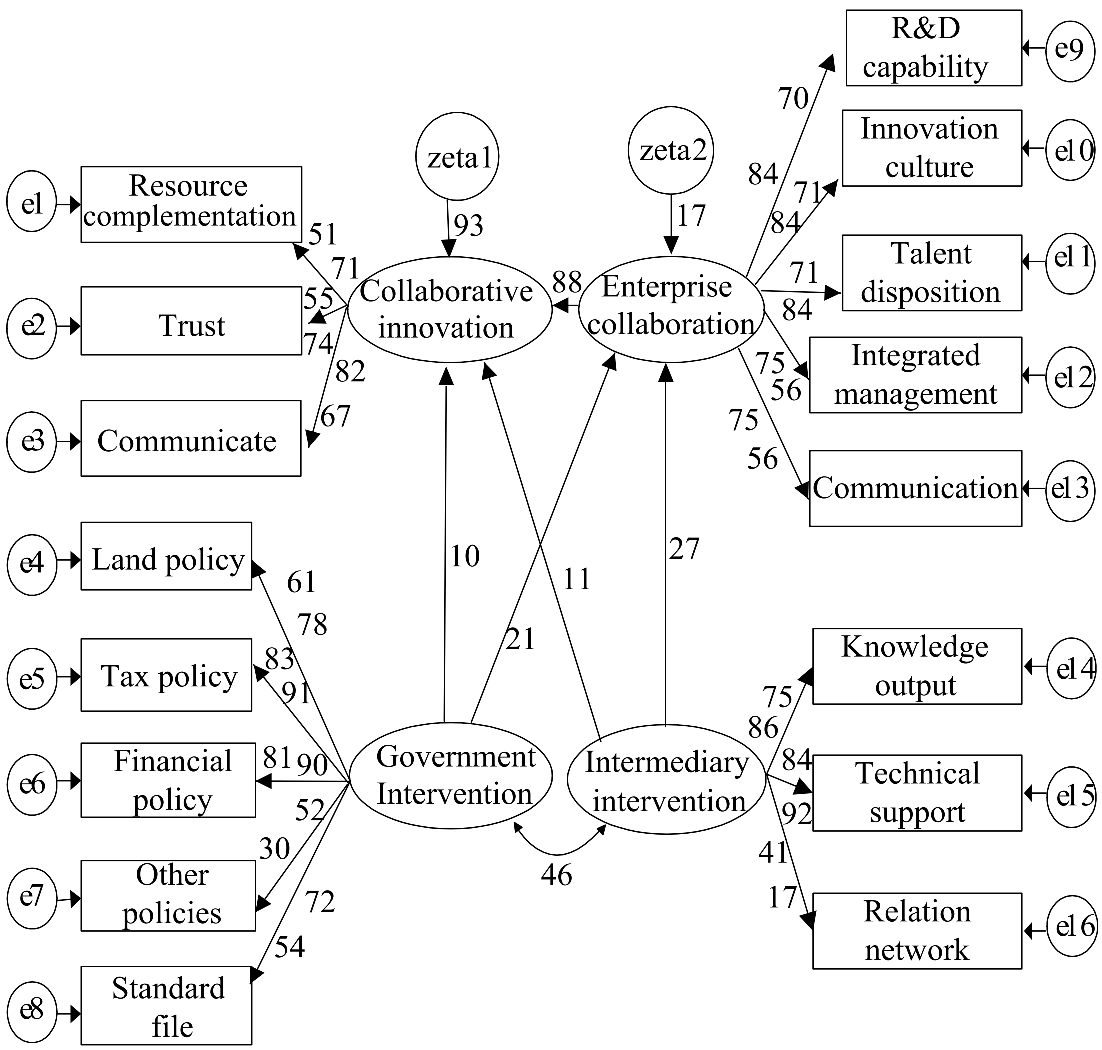

Figure 3.Construction industrialization collaborative innovation influencing factors structural equation model diagram.

Table 2.Evaluation Indexes and Results.

Index	Standardsof model adaptation degree Model adaptation
GFI>0.9	0.924
AGFI>0.9	0.904
PGFI>0.5	0.665

Through the study of this paper, we know:

(1) Government Intervention (p=0.099) has a weakly effect on the collaborative innovation of construction industrialization, which is relevant to little driving of Incentive policy on the actual process. On the other hand, with the development of the construction industrialization and the scale effect formed, Government intervention should be appropriately reduced and autonomous regulation by the market.

Table 3.Path Coefficient and Hypothesis Test Results.

Assumptive variables	Path Coefficients	P Value	Test Results
H1	0.711	<0.05 (***)	Significant
H2	0.744	<0.05 (***)	Significant
H3	0.817	<0.05 (***)	Significant
H4	0.099	<0.05 (0.012)	Weakly Significant
H5	0.105	<0.05 (0.009)	Weakly Significant
H6	0.877	<0.05 (***)	Significant

(2) The result of effect on the Intermediaries for collaborative innovation (p=0.105) shows that Intermediaries have weakly effect on enterprise technology innovation ability, so Construction industry need further perfect scientific research institutions function, open intermediary market and build resource sharing platform.

(3) Enterprises collaborative innovation has a significant effect (p=0.877), which shows that Enterprises is the biggest influence factor for collaborative innovation of construction industrialization among the participants. Enterprises collaborative pay more attention to the professional collaborative, technology integration, the application of BIM information and integrated management, which committed to through technological progress and innovation management mode to make enterprise difference competition and reach the collaborative innovation within the enterprise and between enterprises.

(4) Internal Elements have a significant impact on collaborative innovation of construction industrialization. Trust (p=0.744) of collaborative innovation of construction industrialization is between organizations. Trust is not only the basis to build partnership but also the necessary condition to achieve good benefit. Establishing good trust relationship among different stakeholders is conducive to lower transaction costs and can reduce the risk of uncertainty factors and the opportunism. Effective communication (p=0.817) can timely eliminate the misunderstanding and interest conflict within stakeholders' cooperation, can dissolve the speculation, misunderstanding and contradiction in the process of cooperation and ensure the information accessibility. Complementary resources (p=0.711) are a cross-border integration to achieve innovation. In collaborative innovation mechanism, each participant is required for their lack of external resources to obtain higher economic benefits and social benefits.

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Evaluation of Industrialized Construction Capability of Construction Enterprises Based on AHP-Entropy Method

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Abstract

Construction industrialization is an essential way to promote the sustainable development of the construction industry, while the industrialized construction capability of construction enterprises is the key to realize construction industrialization. In this paper, the evaluation index system of the construction capacity is established from the perspective of construction enterprises themselves, and the indicators are classified by means of factor analysis method firstly. Then, the subjective AHP weights and the objective weights by entropy are calculated respectively. At last, the combined weight of each indicator is obtained according to the principle of minimum identification information meanwhile the importance degree of the industrialized construction capacity indicators of construction enterprises can be got. Through the analysis of relevant data of China's construction enterprises from 1991 to 2008, the crucial indicators affecting the capacity of industrialized construction are identified, which can provide decision-making supports for the construction enterprises to enhance their industrialized construction capacity.

INTRODUCTION

At present, China's construction industry is on the road of scale expansion and transformation upgrading, the construction industrialization is an inevitable trend of development of the construction industry. The government made great efforts on the construction industrialization, and the State Council put forward the request of "develop new construction methods and vigorously promote the assembly of constructions". In order to promote the development of assembly-construction in an all-round way, Shenzhen City issued three notifications continuously stressing the improvement of the industrialized capacity of the construction enterprises in January 2017.

In the context of construction industrialization, industrialized construction capacity is a main factor in the survival and competitiveness of construction enterprises and also an important guarantee for industrialization. However, the level of industrialized construction in China's construction enterprises varies greatly, and the existing construction level of construction enterprises is insufficient to evaluate the development requirements of the construction industry. Therefore, the evaluation of industrialized construction capacity of construction enterprises has a practical significance.

Foreign researches for the construction industrialization is relatively mature (Arditi and Mochtar 2000; Bing and Chen 2010; Jaillon and Poon 2008; Jaillon and Poon 2009), but we can only learn from the research methods while the content is not fully adapted to China's national conditions. There are relatively few theoretical studies on the industrialized construction capacity of construction enterprises in China, which mainly focus on the industrialized development model of construction enterprises (Yang and Li 2012), making comprehensive evaluation of the industrialized construction capacity for construction enterprises by mathematical statistics (Chen 2011), subjective weight method (Zheng 2014; Zhang 2016), lean value chain theory (Chen et al. 2013), and studying the development level of the construction industrialization with a sustainable perspective (Yang 2012) and so on. At present, the emphasis on construction industrialization has reached a certain height, but it is not enough to study the industrialized construction capability of construction enterprises. So the evaluation of industrialized construction capacity of construction enterprises has a theoretical significance.

This paper takes the industrialized construction ability of construction enterprises as the research object, analyzes the influencing factors of the industrialized construction ability of the construction enterprises and identifies the key indexes that affect the industrial construction capacity, combining with the existing evaluation index system of industrial construction capability, and then provided decision support for construction enterprises to enhance the industrialized construction capacity.

MODEL ESTABLISHMENT

Factor analysis grading index system. Because multiple variables reflect some information about the research problem at varying degrees, there is a certain correlation between the indicators, and statistical data may overlap in a certain extent. Factor analysis is mainly to achieve dimensionality and classify the indicators. So firstly, factor analysis is used to classify the index system to simplify the process of AHP and improve the calculation accuracy.

Calculation of the subjective weights by AHP. AHP was proposed by professor T L Saaty in the 1970s, and its specific algorithm steps are shown as follows:

Step 1: Establish the hierarchical structure model;

Step 2: Construct the judgment matrix A, and a_{ij} means the ratio of the relative weight between the indicator i and j.

$$A = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_1} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

Step 3: Calculate the weights using the arithmetic average method (Deng et al. 2012).

$$\overline{W_{\mathrm{i}}} = \sum_{j=1}^{n} \overline{a_{ij}} (i = 1, 2, \ldots, n) \quad (2)$$

Step 4: Consistency check. When $CR < 0.1$, the consistency of judgment matrix is regarded to be acceptable.

Calculation of the objective weights by entropy method. The concept of entropy was created by Clausius in 1850, which was a measurement of disorder degree of the system. Information entropy describes the discrete degree of some index data. The bigger the discrete degree is, the greater the influence of the indicator on evaluation results is, and the bigger the index weight is (Malekian and Azarnivand 2016).

Calculation steps of determining weights by entropy method:

Step 1: Normalize the original data. Set the matrix of original data with m schemes and n evaluation indexes being $A = (a_{ij})_{m \times n}$ and normalize it in the light of the column to $R = (r_{ij})_{m \times n}$. r_{ij} in the normalized matrix denotes the contribution of the i scheme under the indicator j.

Step 2: Define entropy. In the evaluation problem with m schemes and n indicators, the entropy of the indicator j is the Equation (3):

$$h_j = -k \sum_{i}^{m} f_{ij} \ln f_{ij} \quad (3)$$

h_j indicates the total contribution of all samples to indicator a_j.In the Equation (3), $f_{ij} = r_{ij} / \sum_{j=1}^{m} r_{ij}$,and the constant $k = 1/\ln m$; when $f_{ij} = 0$, set $f_{ij} \ln f_{ij} = 0$.

Step 3: Calculate the entropy weights. The entropy weight of the indicator j can be solved by the Equation (4):

$$w_j = d_j / \sum_{j=1}^{n} d_j (0 \le w_j \le 1, \sum_{1}^{n} w_j = 1) \quad (4)$$

When $d_j = 0$, the indicator j whose weight is zero, can be deleted.

Determination of the combined weights. Suppose the subjective weights vector by AHP is w_1, the subjective weights vector calculated by the entropy method is w_2, and the combined weights vector is w. According to the minimum identification information principle (Yuan et al. 2013; Zhu 2001), the combined weights can be calculated by the Equation (5):

$$w(i) = \frac{\left[w_1(i) w_2(i)\right]^{0.5}}{\sum_{i=1}^{m} \left[w_1(i) w_2(i)\right]^{0.5}} \quad (5)$$

Making use of the combined weights to identify the key indicators of influencing industrial construction capacity and calculate the composite index of construction capacity development level in different years.

MODEL SOLVING

The data in this paper are derived from the existing literature Chen (2011), and they are all verified in the China Statistical Yearbook, China Statistical Yearbook on Construction, China Labor Statistical Yearbook, and Science and Technology of China Yearbook. The original data are shown in Table 1.

The index system draws lessons from the industrialized construction capability index system of Japanese construction enterprises, and adjusts the index system according to the actual situation in our country, and then obtains the initial index system on the basis of the feasibility of getting the actual data. Using factor analysis method to merge the relevant indicators and then to achieve the evaluation.

Firstly, the KMO and the Bartlett's Test of Sphericity are used to determine whether the sample data are suitable for factor analysis. The results are shown in Table 2.

The data in Table 1 shows that the result of KMO is 0.764 and the statistical significance of the Bartlett's Test of Sphericity is 0.000, which satisfy the significant level of 0.001. So the measurement problem is suitable for factor analysis. The rotated component matrix is shown in Table 3 below.

According to the results of factor analysis, three components are extracted which explain 96.4% of the total information. The number of professional personnel, per capita enterprise profits, per capita enterprise income, per capita enterprise asset, labor productivity and per capita number of patents are used to indicate the basic support condition. And the per capita mechanical equipment value at the end of year, technical equipment rate, per capita fixed asset and proportion of professional personnel are to demonstrate the personnel technical equipment condition, while the R&D investment condition is represented by per capita research funding. And then the index system can be adjusted, as shown in Figure 1.

According to the formula of AHP, the consistency indicator which satisfies the consistency test can be solved by using Matlab programming. The subjective weights vector calculated by AHP is:

$$w_1 = (0.0279,\ 0.0190,\ 0.0148,\ 0.0096,\ 0.0556,\ 0.0368,\ 0.0718,\ 0.2702,\ 0.0528,\ 0.1442,\ 0.2973)$$

In accordance with the Equation (3) and (4), the objective weights vector calculated by entropy method using Matlab programming is:

$$w_2 = (0.1531,\ 0.0209,\ 0.0858,\ 0.1079,\ 0.0874,\ 0.0351,\ 0.1228,\ 0.1069,\ 0.1050,\ 0.0995,\ 0.0756)$$

The combined weights using the principle of minimum identification information can be solved as follows:

$$w_i = (0.0754, 0.0230, 0.0411, 0.0371, 0.0804, 0.0415, 0.1083, 0.1961, 0.0859, 0.1382, 0.1730)$$

Table 1.The Value of Industrialized Construction Capacity Index.

Year	PCMEVEY	TER	PCFA	NPP	PPP	PCEP	PCEI	PCEA	LP	PCNP	PCRF
1991	2719	2572	0	61	0	397	0	0	14741	0.0021	30.94
1992	4260	2719	0	63	0	585	0	0	18238	0.0021	46.54
1993	3446	4105	0	66	0	502	0	33915	24214	0.0029	67.67
1994	4264	3446	0.43	68	0.63	495	36591	37379	32184	0.0043	59.98
1995	4154	4264	0.42	71	0.59	515	35758	44854	38679	0.0029	73.01
1996	4729	4154	0.47	53	0.89	523	39897	43560	39033	0.0021	60.85
1997	5127	4729	1.15	54	2.13	578	45262	50406	43428	0.0021	51.04
1998	5756	5127	1.26	55	2.29	766	50232	58475	48255	0.0025	54.13
1999	6304	5756	1.42	56	2.54	963	57699	65067	53328	0.0034	50.75
2000	7136	6304	1.61	35	4.59	1395	69051	7300	59585	0.005	43.8
2001	9675	7136	1.9	56	3.4	1650	79035	80390	67275	0.005	28.09
2002	9957	9675	1.84	57	3.24	2153	91279	90817	76171	0.0051	26.99
2003	9297	9957	1.94	60	3.23	2877	112358	97511	86666	0.0055	28.9
2004	9273	9297	1.87	64	2.93	3358	145895	114245	101939	0.0073	25.73
2005	9109	9273	1.92	63	3.04	4145	139516	116617	117317	0.007	21.69
2006	9208	9109	1.91	91	2.1	4982	157688	125110	131800	0.0074	22.99
2007	9915	9208	2.01	91	2.21	6642	183220	137311	148101	0.0086	30.57
2008	9915	9915	2.01	92	2.18	6642	183220	155996	161805	0.0106	26.44

Table 2.KMO statistics and Bartlett's Test of Sphericity.

KMO		0.764
Bartlett's Test of Sphericity	*Approx. Chi-Square*	369.069
	df	55
	Sig	0.000

Table 3.Rotated Component Matrix.

Indicators	Components		
	1	2	3
Per Capita Mechanical Equipment Value at The End of Year (PCMEVEY)	0.482	0.762	0.380
Technical Equipment Rate (TER)	0.553	0.727	0.330
Per Capita Fixed Asset (PCFA)	0.394	0.864	0.279
Number of Professional Personnel (NPP)	0.946	-0.256	0.084
Proportion of Professional Personnel (PPP)	-0.061	0.967	0.203
Per Capita Enterprise Profits (PCEP)	0.850	0.361	0.335
Per Capita Enterprise Income (PCEI)	0.749	0.583	0.280
Per Capita Enterprise Assets (PCEA)	0.805	0.505	0.176
Labor Productivity (LP)	0.802	0.513	0.274
Per Capita Number of Patents (PCNP)	0.783	0.458	0.310
Per Capita Research Funding (PCRF)	-0.317	-0.410	-0.853

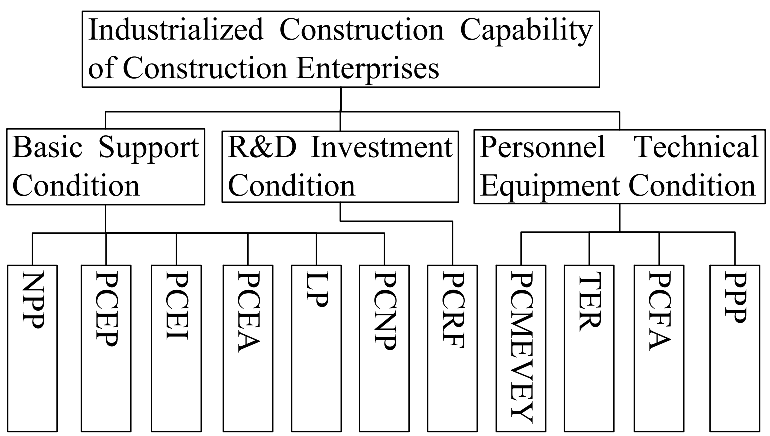

Figure 1.Industrialized construction capability index system of construction enterprises.

It is easy to see that the top three indicators are the technical equipment rate, per capita research funding and the proportion of professional personnel. Therefore, those construction enterprises in the process of promoting the construction industrialization should focus on the implementation and management of these indicators. By the value of each index and its combined weight, we can get the development level of industrial construction capacity of China's construction enterprises from 1991 to 2008, as shown in Figure 2.

It can be seen from the Figure 2, the construction capacity of construction enterprises in China shows an upward trend as a whole, but still at a low level. In 1996, the Ministry of Construction began to pilot the modernization of residential constructions nationwide. Therefore, after the brief decline in 1996, it began to show an upward trend again from 1997. In 2006, the former Ministry of Construction issued the "National Housing Industrialization Base Trial Scheme", which indicated China's residential construction industrialization began to enter a period of comprehensive progress. So, the level of industrial construction capacity continues to rise after 2006.

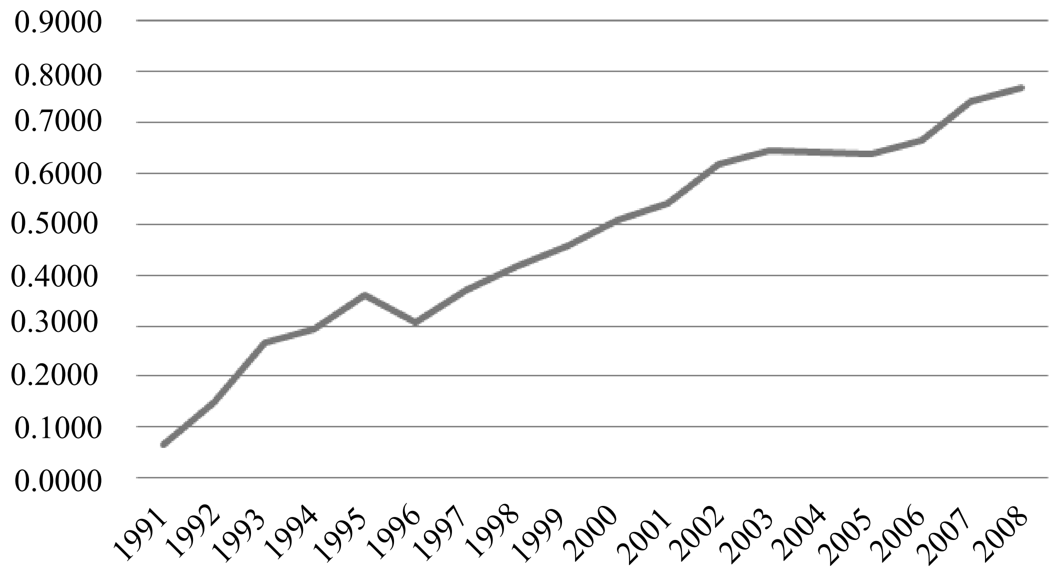

Figure 2.Industrialized construction capability development level of construction enterprises in China from 1991 to 2008.

CONCLUSIONS

Based on the calculation of the combined weight of each index, the key indicators of the industrial construction capacity of the construction enterprises are obtained in this paper, and the development level of industrial construction capability of China's construction enterprises from 1991 to 2008 are analyzed, which has a certain practical significance. However, construction ability of construction enterprises is a comprehensive performance of all aspects of the enterprise. The index system of this paper only evaluates from the aspects of construction and ignores the influence of the external environment on the industrial construction capability. Moreover, focusing on the application of research methods and ideas without testing the accuracy of the data needs to be further improved.

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