

Article

Evolution of the Construction Industry in China from the Perspectives of the Driving and Driven Ability

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Abstract: The construction industry has been developing in recent years, facilitating economic development in China. However, the industry's development has been confronted by a series of challenges. Exploring the characteristics of the influences of power and the association structure and their level of correlation in the construction industry is important to improve the understanding of the status and development of laws, to optimize industrial structure, and to improve the efficiency of the construction industry—factors that are fundamental to the realization of an optimized, upgraded construction industry. Therefore, the total consumption coefficient and the total distribution coefficient were calculated to reveal the influencing power of the construction industry. Based on the total consumption coefficient and the total distribution coefficient, the driven coefficient and driving coefficient are used to reflect the general effect on the entire industry network. The driven and driving networks were constructed using the total consumption coefficient and the total distribution coefficient to reveal the critical positions of the networks. The results show that the construction industry has significant driven and driving effects on other industries, which facilitate the improvement of the entire economic industry. However, an obvious gap exists between the driven ability and the driving ability as measured by the complex network. The point degree, betweenness degree, and subgroup cohesive characteristics show that the effect of the driven ability is much greater than that of the driving ability for the construction industry in 30 provinces. The findings provide information for policymaking related to the sustainable development of the construction industry in China.

Keywords: construction industry; influence power; association structure; driven ability; driving ability

1. Introduction

The construction industry has contributed considerably to China's economic development and the urbanization process. The gross output of the construction industry in China has increased from USD \$0.21765 trillion to USD \$2.902 trillion dollars, up by 1160% (China Statistical Yearbooks). However, the construction industry is still a traditional industry in China, characterized by low efficiency, high pollution, large capital requirements, and an unreasonable structure, hindering its development [1]. With the further deepening of the globalization of China's economy, the optimization and upgrading of industrial structure will be the major problems to be addressed [2–4] by China's construction industry in the future.

The construction industry plays an important role in the national economy, having quickly progressed and developed [5–8]. However, some fundamental changes occurred in the construction industry after the economic reform [7]. The relationship between the construction industry and the economy has been studied, and the results reported are inconsistent [9]. In 1978, the data from 87 countries were analyzed, showing that with the increase in per capita gross domestic product (GDP),

the proportion of construction output increased first, and then decreased at a decreasing rate [10]; the relationship between the two factors was an S-shaped curve [11]. A more accurate study of the relationship between construction output value and GDP per capita was conducted [12,13], and the proportion of construction value relative to GDP showed a cubic curve with the increase in per capita GDP [13]. Zou used co-integration, the Granger causality test, and an error correction model to analyze the long- and short-term effects of the construction industry on economic growth in Sichuan Province [14] and argued that steady development of the construction industry can be adopted to promote the long-term development of the national economy [15]. Jiang analyzed the time series data from 1978 to 2004 and found a co-integration relationship between the construction industry and national economic growth [16]. Some scholars studied the relationships among fixed asset investment, installation investment, and GDP growth [17]. The driving factors that influence the construction industry have been comprehensively studied, including innovation technology, BIM, big data [18–20], economic development, and natural factors [21–27]. The development patterns of the industry, off-site production, and low carbon [28–33] have also been analyzed.

Scholars have comprehensively analyzed the optimization and upgrade of the construction industry. Studies about the construction industry have paid substantial attention to the state-of-the-art status, driving factors, the development pattern, and industrial association. Researchers have been inclined to regard the development of the construction industry as the result of the interactions between construction and external environmental factors. However, studies about influencing power and association structure and their level of correlation in the construction industry are lacking, and those that have been published fail to provide effective recommendations for policymakers. The growth and evolution of any industry is inextricably related to other industries. Exploring the characteristics of influencing power and association structure and their level of correlation in the construction industry is particular significant for understanding the status and development of laws, as well as for optimizing the industrial structure and improving the efficiency of the construction industry, which are fundamental for upgrading to an optimal construction industry.

To comprehensively analyze the characteristics of China's construction industry from the perspective of growth and evolution, the total consumption coefficient and the total distribution coefficient were employed to reveal the influencing power of the construction industry. Based on these two coefficients, the driven coefficient and driving coefficient are used to reflect the general effect of the construction industry on the entire industry network. The driven and driving networks were constructed using the total consumption coefficient and total distribution coefficient to reveal the critical position of the construction industry in the network.

2. Methodology and Data Source

2.1. The Framework of the Methodology

To reveal the characteristics of construction from the perspective of driven and driving ability, the input–output analysis (IOA) and social network analysis (SNA) are employed. The framework of the methodology is shown in Figure 1.

As shown in Figure 1, the framework of the methodology used in this paper mainly includes three steps: (1) The definition of the characteristics of construction industry from the driven and driving perspective. In this paper, the driven and driving characteristics are discussed from two aspects: The characteristics of construction industry relative to other industries and in the entire industrial system. (2) The reflection of the driven and driving characteristics of construction industry. First, the driven and driving coefficients are established according to the total consumption and total distribution coefficient. Second, based on the driven and driving coefficients, the driven social network and driving social network are constructed. (3) The analysis of driven and driving characteristics from two aspects: Relative to other industries and in the entire industrial system. The driven and driving coefficient are used to represent the driven and driving power to other industries. After that, the social network

analysis method is used to reveal the characteristics of construction industry relative to the entire industrial system.

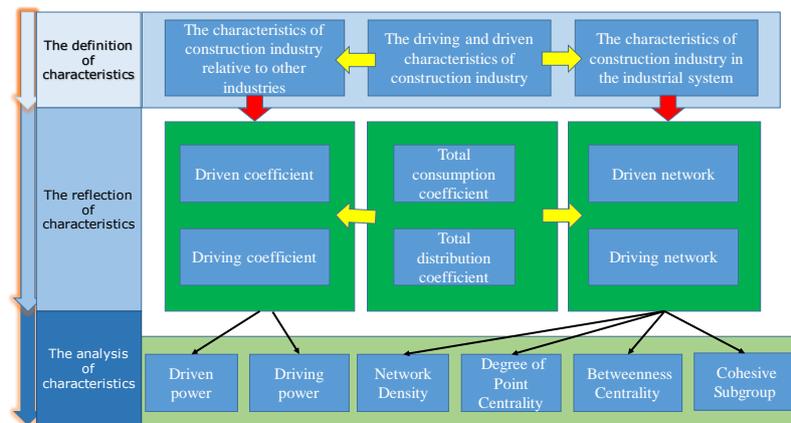


Figure 1. The framework of the methodology.

2.2. Driving Coefficient and Driven Coefficient

The total consumption/distribution coefficient is the amount of production/products of the i th industry consumed/distributed to/by the unit products/production of the industries that have direct and indirect relationships with the i th industry. The total consumption coefficient reflects the industry's backward linkage, which is called the driven ability in this paper. The total distribution coefficient reflects the industry's forward linkage, which is called the driving ability. The total consumption/distribution coefficient of the i th industry is used to explain the driven/driving ability of the i th industry to the specified industry. However, the coefficient cannot reveal the driven/driving ability of the i th industry for the entire industrial system. Therefore, this paper proposes the use of the driven/driving coefficients to measure the industry's driven/driving ability for the entire industrial system. The driven coefficient represents the sum of all other industries' products consumed by the unit production of the i th industry. Similarly, the driving coefficient represents the sum value of all other industries' products resulting from the i th industry's unit production.

2.2.1. Total Consumption Coefficient and Driven Coefficient

The driven coefficient is calculated based on the total consumption coefficient. The total consumption coefficient represents the direct and indirect consumption by the unit output of the producer [1]. It reveals the direct and indirect relationships between industries [34]:

$$B = A + C \quad (1)$$

where B is the total consumption coefficient, A is the direct consumption coefficient, and C is the indirect consumption coefficient. The total consumption coefficient is the sum of A and C [2]:

$$A = [a_{ij}]_{n \times n} \quad (2)$$

$$C = B \times A \quad (3)$$

where a_{ij} is the amount of the i th industry's products consumed by the j th sector's unit production. B can be obtained as follows:

$$B = (I - A)^{-1} - I \quad (4)$$

where I is the same order unit matrix. The driven coefficient F_j can be expressed by Equation (5). The driven coefficient measures the driven ability of the industry on other industries:

$$F_j = \frac{\frac{1}{n} \sum_{i=1}^n b_{ij}}{\frac{1}{n^2} \sum \sum b_{ij}} = \frac{\sum_{i=1}^n b_{ij}}{\frac{1}{n} \sum \sum b_{ij}} \quad (j = 1, 2, 3, \dots, n) \quad (5)$$

where b_{ij} is the total consumption coefficient. The larger the driven coefficient, the greater the driven ability of the industry. F_j may be greater than 1, indicating that the driven ability of j th industry exceeds the average level of the driven ability of all industries.

2.2.2. Total Distribution Coefficient and Driving Coefficient

The driving coefficient is calculated based on the total distribution coefficient. The structure is symmetric between the total distribution coefficient and the total consumption coefficient. Therefore, the calculation method for the total distribution coefficient is similar to that of the total consumption coefficient, with the calculation of columns transformed into the calculation of rows:

$$R = [r_{ij}]_{n \times n} \quad (6)$$

where R is the matrix of direct distribution coefficient and r_{ij} is the direct distribution coefficient, representing the amount of the i th industry's unit products that is distributed to the j th industry's production. The distribution coefficient can be expressed as follows:

$$D = (I - R)^{-1} - I \quad (7)$$

where D is the total distribution coefficient matrix. The driving coefficient F_i can be demonstrated as follows:

$$F_i = \frac{\frac{1}{n} \sum_{j=1}^n d_{ij}}{\frac{1}{n^2} \sum \sum d_{ij}} = \frac{\sum_{j=1}^n d_{ij}}{\frac{1}{n} \sum \sum d_{ij}} \quad (j = 1, 2, 3, \dots, n) \quad (8)$$

where d_{ij} is the total distribution coefficient. The driving coefficient measures the industry's driving ability on other industries. The larger the driving coefficient is the greater driving ability of the i th industry. F_i may be greater than 1, indicating that the driving ability of the i th industry exceeds the average level of the driving ability of all industries.

2.3. Complex Network Analysis

2.3.1. Construct of Complex Network

A complex network of industries in China was constructed using 0–1 matrices that were dichotomized from the total distribution coefficient and total consumption coefficient matrix. The thresholds of the 0–1 matrices used in this paper were the averages of the total distribution coefficient and total consumption coefficient matrix. The value of the total distribution coefficient and total consumption coefficient matrix was 1 when it was greater than the average, indicating an obvious relationship between industries. The value was 0 when it was smaller than the average, indicating no obvious relationship between industries [3].

2.3.2. Density Analysis of the Complex Network

The density of industrial complex network can be used to describe the degree of tightness between nodes in an industrial network. The relationship between nodes is tighter when the network density is

close to 1, representing higher speed and efficiency of information and material flow in the network. The complex network density can be denoted by D , as follows:

$$D = \frac{T}{n(n-1)} \quad (9)$$

where T is the number of edges connecting all nodes and n is the number of all nodes in the network. In this paper, $n = 123$.

2.3.3. Centrality Analysis of the Complex Network

Centrality reflects the importance of industries in the complex network, consisting of the degree centrality and betweenness centrality. Centrality reflects the industrial influence from a quantitative point of view. The degree centrality focuses on directly measuring the number of edges connected to other nodes and consists of out-degree centrality and in-degree centrality. The out-degree centrality of one node is the number of edges extending from the node, and the in-degree centrality is the number of edges entering the node. They represent the producer and consumer in a complex industrial network, respectively. The betweenness centrality is used to measure the node's control between its two adjacent nodes, representing the key-nexus in the industrial complex network. In this paper, the degree centrality and betweenness degree are used to demonstrate the industries' characteristics in complex network. The degree centrality and betweenness centrality are shown in Figure 2.

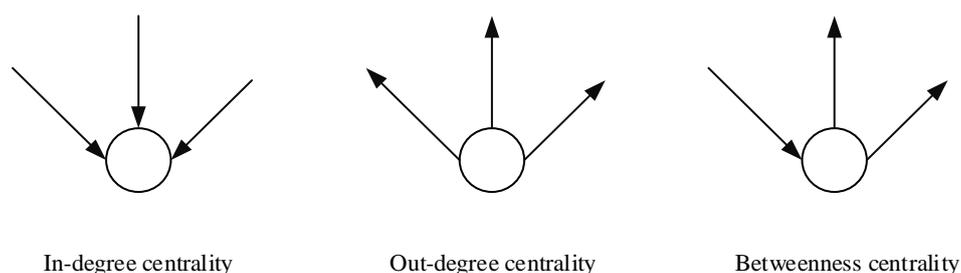


Figure 2. The degree centrality and betweenness centrality in complex network.

2.3.4. Cohesive Subgroup Analysis of Complex Network

Cohesive subgroup analysis is a method of exploring the actual or potential relationships between social actors in a complex network. A cohesive subgroup is a subset of the whole set of actors. The actors in the subset have a relatively strong, direct, close, regular, or positive relationship with each other. The relationships between subsets are looser than those within a subset. Through cohesive subgroup analysis, we can measure the structure of communities formed in a complex network and the equilibrium of the entire network.

2.4. Data Sources

In this study, the multi-region input–output table (multi-IO tables) from the China Emissions Accounts and Datasets (CEAD) in 2012 was used to calculate the total consumption coefficient and total distribution coefficient of China's economic sectors [35]. The CEAD database provides the most up-to-date input–output tables of energy, emissions, and socioeconomic accounting inventories for China. The multi-IO tables have detailed sectoral divisions that contain 30 separate economic sectors in 30 provinces and municipalities. The 2012 version of the multi-IO tables is the latest version. The relevant departments and their codes are shown in the CEAD datasets and Appendix A [35].

3. Results

Through the network structure, China's construction industry has extensive ties with other industries. The position and the degree of connection of the construction industry with other industries

in the industrial structure network are different in different provinces. From the perspective of the driving and driven coefficients and the complex network, I analyzed the influencing power of the construction industry on other industries, as well as the industrial topological structure of China's construction industry in 2012, to determine the evolution of China's construction industry.

3.1. Driving and Driven Coefficients

3.1.1. Total Consumption Coefficient and Driven Coefficient

The total consumption coefficient represents the products and services produced by other industries consumed by the construction industry. This paper only lists the top 10 industries' codes, and the results are shown in Table 1.

Table 1. The top 10 industrial sectors ranked by the total consumption coefficient of the construction industry. For the industrial code, see Appendix A.

Construction Industry Code	Code of Top 26 Industrial Sectors
A24	C14, A13, B14, A30, P13, B25, A26, F13, A25, B26
B24	B14, B13, B26, P13, B25, F13, B28, B5, B15, B30
C24	C14, C13, C4, C12, C15, C25, C2, C22, C11, C30
D24	D14, D13, D30, D22, D2, D12, D11, D4, C14, D27
E24	E14, E13, E30, E22, E12, E2, E28, E4, E5, E25
F24	F14, F13, F12, F25, F11, F30, F26, F15, F16, F4
G24	G13, G12, G14, G11, G22, G30, G25, G28, F14, G26
H24	H13, F13, H25, G13, H14, H30, F14, H26, H11, H12
I24	I24, I14, I13, I28, I26, P13, I30, J13, I25, I12
J24	J14, J13, J12, J15, P13, J18, J28, J22, J30, C14
K24	K14, K13, K30, K12, K22, K26, K18, K25, K15, K29
L24	L13, L14, J12, L22, L30, J26, L25, L12, L15, L18
M24	M14, M13, M25, M30, M22, M12, M26, M15, M11, M18
N24	N14, N13, N12, N22, N30, N25, N26, N18, N4, N5
O24	O13, O12, O14, O11, O9, O15, O22, O25, O16, O18
P24	P13, P14, P12, P5, P22, P25, P26, P2, P4, P30
Q24	Q13, Q14, Q30, Q22, Q28, Q12, Q26, Q29, Q25, Q5
R24	R14, R13, R25, R26, R30, R22, R12, R2, R18, P13
S24	S13, S12, S15, S26, S14, S22, S30, S25, S19, S18
T24	T13, T14, T25, T26, T22, T12, T30, T11, T5, T4
U24	U13, T14, U26, U30, U25, U12, S12, Y14, T9, U22
V24	V13, V14, V22, P13, V25, V12, V15, Y14, V30, C14
W24	W14, W13, W12, W30, W22, W5, W2, W26, W15, W16
X24	X14, X13, X22, X25, X2, X30, X26, X12, X28, Y14
Y24	Y14, Y13, Y24, Y22, Y26, Y30, Y25, Y12, Y2, P13
Z24	Z13, Z14, P13, Z22, Z2, Z25, Z30, Z11, Z12, C14
AA24	AA14, AA13, AA22, AA25, AA26, AA11, P13, AA30, AA18, AA2
AB24	AB14, AB22, AB13, AB2, AB12, AB30, AB11, AB24, AB3, AB4
AC24	AC22, AC25, AC13, AC14, AC26, AC11, AC30, P13, E2, D2
AD24	AD14, AD13, AD11, AD25, AD30, AD26, AD22, AD12, AD5, P13

Table 1 shows that the main products and services consumed by the construction industry are metallurgy, nonmetal products, transport and storage, wholesale and retailing, and other services. The construction industry in Beijing is dependent on the metallurgy industry in Hebei and Tianjin. Nonmetal products are mainly produced in Beijing and Henan. Beijing and Tianjin are the most important providers, as they provide transport and storage as well as wholesale and retail products for the construction industry in Beijing. For construction in Tianjin, the largest providers of materials and services are Tianjin, Henan, and Liaoning. The production activities of Shanghai rely on the supply from Shanghai, Jiangsu, and Henan. The top 10 material and service providers for the construction industries of Hebei, Inner Mongolia, Liaoning, Heilongjiang, Zhejiang, Fujian, Jiangxi, Shandong,

Henan, Hubei, Guangdong, Guangxi, Sichuan Guizhou, Gansu, and Qinghai are all from the provinces themselves. In other words, these provinces have the ability to supply their own fundamental products and services. The metallurgy products consumed by the construction industry in Shanxi are not only from Shanxi but also from Hebei. Similarly, the province of Jiangsu obtains metallurgy products from the province of Liaoning. Wholesale and retailing services from Jiangsu are significant for the construction industry in Anhui. Henan is the provider of nonmetal products for Hunan. The construction industry in Hainan requires a considerable number of products and services from the provinces of Guangdong, Guangxi, Hainan, and Yunnan.

The total consumption coefficient in Table 1 provides a good understanding of the detailed information about the providers and their supply capacity for the products and services consumed by the construction industry in 30 provinces and municipalities. Although the total consumption coefficient can reflect the driven effect of the construction industry on another specific industry, it cannot express the driven effect on other industries in general. Therefore, the driven coefficient was employed, which was calculated in Section 2.2.1. The driven coefficients of the construction industry in 30 provinces are shown in Figure 3.

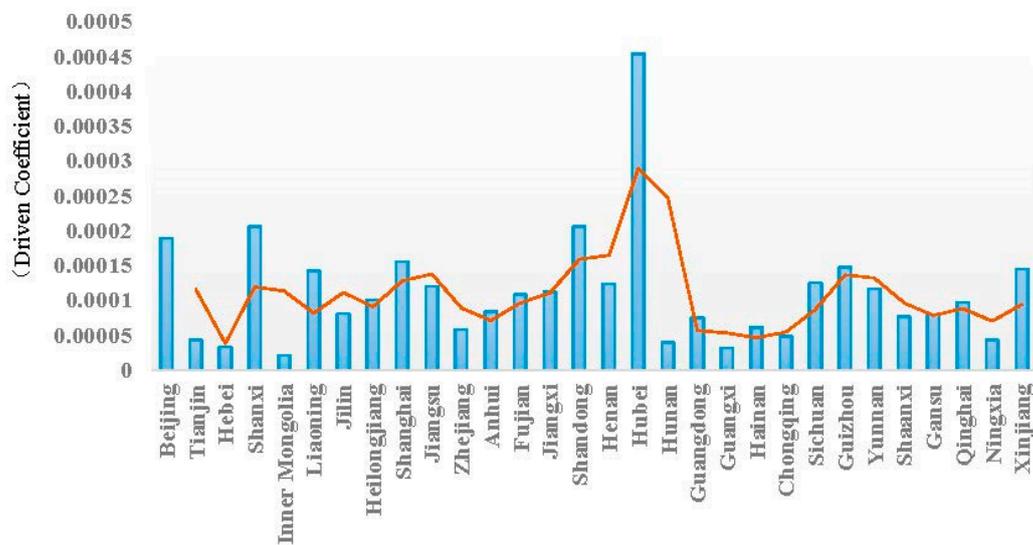


Figure 3. The driven coefficients of the construction industry in 30 provinces.

Figure 3 depicts that the driven ability of the construction industry in Hubei has the highest driven coefficient of 0.000453979. The second highest coefficients are those of the construction industries in Shandong and Shanxi, where the driven coefficient is 0.000205567. After that, the construction industries in Beijing and Shanghai have strong driven abilities with coefficients of 0.000188718 and 0.000155371, respectively. The driven abilities of the construction industry in Guizhou, Xinjiang, and Liaoning are in the fourth group. The provinces of Sichuan, Henan, Jiangsu, Yunnan, Jiangxi, Fujian, and Heilongjiang have relatively strong driven abilities with coefficients ranging from 0.000100744 to 0.000124965. The driven coefficients of other provinces are less than 0.0001.

3.1.2. Total Distribution Coefficient and Driving Coefficient

The total distribution coefficient represents the products and services that are directly and indirectly assigned to different industries. This paper only lists the top 10 industries' codes, and the results are shown in Table 2.

Table 2. The top 10 industrial sectors ranked by the total distribution coefficient of the construction industry.

Construction Industry Code	Codes of Top 26 Industrial Sectors
A24	A13, A9, A5, A15, B5, A14, A18, B14, E13, C13
B24	B13, B5, B14, B9, B4, B28, B15, A13, B21, B2
C24	C5, C13, C9, C15, C14, C2, C4, C3, C22, C23
D24	D13, D5, D14, D4, D9, D18, D7, D15, D12, D28
E24	E5, E13, E28, E18, E14, E15, E20, E29, E4, E22
F24	F5, F13, F15, F2, F14, F25, F29, F22, F4, F20
G24	G13, G5, G14, G18, G15, G11, G2, G28, G22, G21
H24	H13, H14, H4, H5, H28, H21, H15, G13, H25, H2
I24	I13, I9, I14, I24, I15, I28, I23, I21, I22, I26
J24	J5, J13, J14, L5, J4, L13, J15, J2, J9, J28
K24	K5, K13, K29, K14, K2, K22, K9, K15, K25, K4
L24	L5, L13, L28, L15, L14, L23, L11, L2, L22, L29
M24	M14, M13, M5, M4, M15, M25, M2, M29, M11, M22
N24	N5, N13, N2, N11, N29, N22, N14, N15, N28, N25
O24	O5, O13, O9, O29, O14, O2, O4, O15, O22, O25
P24	P5, P13, P3, P11, P21, P26, P14, P15, P4, P22
Q24	Q13, Q29, Q28, Q5, Q14, Q4, Q2, Q22, Q10, Q18
R24	R5, R13, R14, R4, R2, R18, R29, R22, R25, R15
S24	S13, S5, S15, S29, S14, S22, S26, U20, S23, U12
T24	T13, T5, T15, T2, T14, T21, T11, T4, T26, T22
U24	U5, U13, U14, U15, U9, U29, U18, U28, U16, U22
V24	V5, V13, V15, V22, V11, V14, V9, V4, V25, V2
W24	W13, W5, W14, W15, W11, W4, W21, W9, W22, W3
X24	X13, X5, X14, X20, X4, X29, X18, X11, X22, X21
Y24	Y13, Y5, Y15, Y9, Y14, Y21, Y25, Y18, Y20, Y4
Z24	Z13, Z5, Z9, Z28, Z14, Z15, Z4, Z22, Z18, Z29
AA24	AA13, AA5, AA15, AA9, AA14, AA4, AA28, AA18, AA2, AA25
AB24	AB14, AB13, AB5, AB21, AB11, AB4, AB2, AB22, AB29, AB12
AC24	AC13, AC9, AC5, AC26, AC22, AC25, AC15, AC28, AC23, AC29
AD24	AD13, AD14, AD5, AD4, AD15, AD22, AD2, AD26, AD9, AD21

Table 2 shows that the products of the construction industry are mainly supplied to the industries of nonmetal products, wood processing and furnishing, nonmetal mining, metal products, nonmetal mining, metallurgy, electrical equipment, metallurgy, and nonmetal products. The driving ability of the provinces of Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang, 27 of 30 provinces, introduce their products to within the province. The products of the construction industry in Beijing are supplied to the nonmetal product industries of Inner Mongolia and Hebei. Similarly, the construction products consumed by the nonmetal mining industry in Jiangsu are from Anhui. The construction industry in Hainan is the main provider of products for the instrument and chemical meter industries in Guangdong.

To reflect the driving ability of the construction industry in 30 provinces, I employed the driving coefficient calculated in Section 2.2.2. The driving coefficients of the construction industry in 30 provinces are shown in Figure 4.

As shown in Figure 4, the industry with the maximum driving coefficient is Jiangsu, with a driving coefficient is 0.007812513. Next are the provinces of Yunnan and Chongqing, where the driving coefficients are 0.005748049 and 0.005477132, respectively. Xinjiang and Liaoning are the provinces in which the construction industry has a significant influence on the driving ability to stimulate production activities. Shanxi, Shandong, Gansu, Hunan, and Guangxi are provinces that are highly dependent on the driving ability of the construction industry, and they have driving coefficients of 0.004766199, 0.004640367, 0.004567559, 0.004531502, and 0.004530184, respectively. The driving

coefficients of Hubei, Hainan, Jiangxi, and Ningxia are also greater than 0.004. Other provinces—13 out of 30 provinces—have relative lower driving coefficients of less than 0.004.

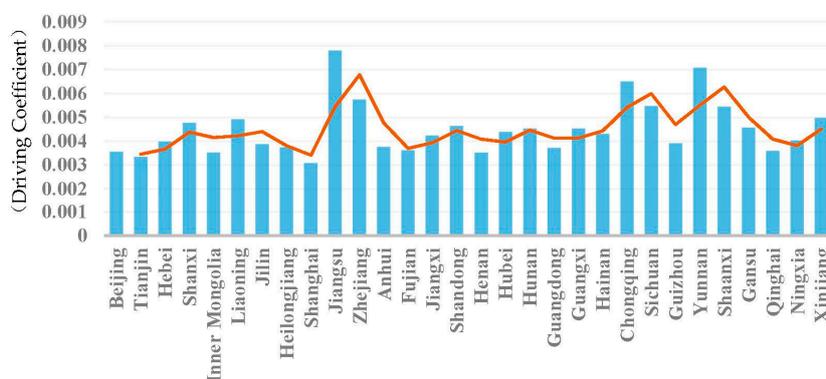


Figure 4. The driving coefficients of the construction industry in 30 provinces.

3.2. Complex Network Analysis

The total consumption matrices and total distribution matrices were dichotomized by the thresholds of the driving network and the driven network. The thresholds are shown in Table 3. Ucinet 6.0 software was used to construct the complex networks of China’s 900 industries according to the 0–1 matrices.

Table 3. The thresholds of the driving and driven networks.

Year	Driven Network Threshold	Driving Network Threshold
2012	0.00171703	0.00193083

From the results, the industrial structure between the 900 industries in China in 2012 is considered a typical small world network due to the smaller average path length and higher clustering. The average path length of each year is 1.6, indicating that each industry node only needs to pass 1.6 edges on average to reach another industrial node. As the total number of nodes is 900, the average path length is short. The clustering coefficients of industrial networks range within 0.5 of the average in each year, indicating that the actual number of edges between industries accounts for 50% of the edges possibly connected. Therefore, the industrial complex network can be measured.

3.2.1. Density Results

The densities of the driving complex network and driven complex network in 2012 are shown in Table 4.

Table 4. The densities of the complex network of industries in 2012.

Year	Density of Driven Complex Network	Density of Driving Complex Network
2012	0.1155	0.0018

The densities of the complex driving and driven networks reflect the level of closeness of the relationships between industries. The higher the density, the closer the relationships between industries. The densities of the driving and driven complex networks of the 900 industries are 0.1155 and 0.0018, respectively. The density of the complex network is relative sparse. The efficiency of resources and information circulation in the complex network of industries has potential for improvement.

3.2.2. Degree of Point Centrality Results

The degree of point centrality includes the point-out degree and point-in degree, which respectively represent the number of the sides entering and exiting the construction industry in the complex network. Point-out and point-in centrality represent the industrial sector that has a direct relationship with the construction industry. The degree of point centralities of 900 industries in 2012 were calculated using Ucinet 6.0 software. This paper only lists the top 10 industries ranked by the degree of point centrality due to the length limitation. These industries are located in critical positions in the complex network and significantly influence the other industries. The top 10 industries ranked by point-out and point-in centrality are shown in Table 5.

Table 5. The degree of point centrality of the construction industry in China.

Code	Driven Network		Driving Network	
	Point-Out	Point-In	Point-Out	Point-In
A24	0.245	1.794	0.139	5.550
B24	0.056	2.133	0.030	5.222
C24	0.033	2.178	0.014	6.219
D24	0.267	2.197	0.120	7.436
E24	0.021	1.383	0.009	5.508
F24	0.186	2.057	0.061	7.680
G24	0.102	1.914	0.035	6.054
H24	0.112	1.933	0.049	5.816
I24	0.104	1.700	0.066	4.705
J24	0.157	2.036	0.046	12.209
K24	0.060	2.018	0.021	8.969
L24	0.092	1.898	0.036	5.860
M24	0.138	1.442	0.045	5.648
N24	0.127	2.184	0.047	6.600
O24	0.265	2.333	0.104	7.237
P24	0.149	2.000	0.060	5.483
Q24	0.596	1.645	0.181	6.835
R24	0.043	1.926	0.016	7.076
S24	0.071	1.544	0.031	5.782
T24	0.042	1.716	0.013	7.083
U24	0.074	1.915	0.030	6.733
V24	0.058	2.101	0.015	10.165
W24	0.153	2.019	0.049	8.545
X24	0.198	1.964	0.090	6.110
Y24	0.074	1.946	0.019	10.995
Z24	0.085	1.907	0.028	8.500
AA24	0.095	1.939	0.034	7.128
AB24	0.096	1.762	0.020	5.584
AC24	0.047	1.836	0.019	6.284
AD24	0.182	2.001	0.038	7.766

Table 5 is the result of the degree of point-out and point-in centrality of the construction industry. The degree of point-out centrality is far less than the degree of point-in centrality in both the complex driving and driven networks.

The maximum degrees of point-out centrality of the construction industry, both in the driving and driven networks, occur in the provinces of Hubei, Shanxi, and Shandong. The degree of point-out centrality reaches 0.596 and 0.181 in the driven and driving networks, respectively, which are far higher than in other provinces. The lowest degrees of point-in centrality of the construction industry in both the driving and the driven networks were found in the provinces of Guangxi, Hebei, and Inner Mongolia. The degree of point-out centrality of the construction industry in Inner Mongolia is only 0.021 and 0.009 in the driven and driving networks, respectively. Notably, the degree of point-out

centrality in the provinces of Hubei, Shanxi, Shandong, Beijing, Guizhou, Liaoning, Xinjiang, Jiangsu, Sichuan, Henan, Fujian, Jiangxi, Heilongjiang, Shanghai, and Jilin (15 of 30 provinces), is more than 0.1. In other words, the degree of point-out centrality in half of the 30 provinces is less than 0.1 and in others, it is more than 0.1.

The degree of point-in centrality in both the driven and driving networks is shown in Table 5. The trend in the degree of point-in centrality of the construction industry in the driven network remains at about 2.0 with no obvious fluctuations in the 30 provinces. In contrast, the degree of point-in centrality in the driving network varies considerably among different provinces. The maximum degree of point-in centrality in the driving network occurs in the construction industries in the provinces of Jiangsu, Yunnan, Chongqing, Zhejiang, Sichuan, and Shanxi, where the degree of point-in centrality is more than 8.5. The degree of point-in centrality in Jiangsu is 12.209. The next provinces, Yunnan and Chongqing, have degrees of point-in centrality of 10.995 and 10.165, respectively. The degrees of point-in centrality in other provinces are less than 10.0. Shanghai is the only province in which the degree of point-in centrality of the construction industry is less than 5.0.

3.2.3. Betweenness Centrality Results

The results of the betweenness degree of the construction industry in 30 provinces were calculated using Ucinet 6.0 software. Table 6 lists the betweenness degree of 30 provinces in 2012.

Table 6. The betweenness degree of the construction industry.

Code	Driven Network	Driving Network
A24	9.903	1.685
B24	5.306	0.697
C24	5.306	0.410
D24	5.306	1.621
E24	5.306	0.344
F24	5.306	0.897
G24	5.306	0.695
H24	9.903	1.036
I24	5.306	1.182
J24	5.306	1.190
K24	5.306	0.672
L24	5.306	0.967
M24	5.306	1.051
N24	2.928	0.827
O24	2.928	0.746
P24	5.306	1.249
Q24	1.868	1.355
R24	5.306	0.319
S24	5.306	0.807
T24	5.306	0.302
U24	20.971	1.193
V24	26.666	0.693
W24	9.903	0.853
X24	5.306	1.722
Y24	9.903	0.556
Z24	26.666	0.909
AA24	26.666	1.049
AB24	25.367	1.957
AC24	26.666	2.183
AD24	26.666	1.406

As shown in Table 6, in the driven network, the first group of provinces, including Chongqing, Shaanxi, Gansu, Ningxia, Xinjiang, Qinghai, and Hainan, was ranked by the betweenness degree of the construction industry, where the betweenness degree exceeds 20. In Chongqing, Shaanxi, Gansu,

Table 8. The cohesion subgroup density in the driven network of China in 2012.

X	1	2	3	4	5	6	7	8
1	0.007	0.001	0.002	0.003	0.001	0.001	0.001	0.000
2	0.001	0.011	0.001	0.001	0.001	0.001	0.001	0.000
3	0.001	0.001	0.006	0.001	0.001	0.002	0.001	0.001
4	0.001	0.001	0.001	0.005	0.001	0.001	0.001	0.000
5	0.000	0.000	0.001	0.001	0.006	0.001	0.001	0.000
6	0.000	0.000	0.000	0.000	0.001	0.005	0.000	0.000
7	0.000	0.000	0.000	0.001	0.001	0.001	0.009	0.000
8	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.009

Figure 4 shows that the construction industry and crop cultivation, public administration, educational services, sporting toys, athletic, medical, and pharmaceutical products, health services, and other industrial sectors are classified into the same subgroup. However, in different years, an industry sector of a given sub group changes with the construction industry, which indicates that the industrial symbiosis relationship between China's construction industry and other industries is not stable. By comparing the density coefficients of the subgroups, the density coefficient between the first subgroup, the second subgroup, the third subgroup, and the other subgroups is larger. In addition to the construction industry in the third subgroup, the rest of the years are in the first subgroup, showing that China's construction industry and other industries have relatively strong links.

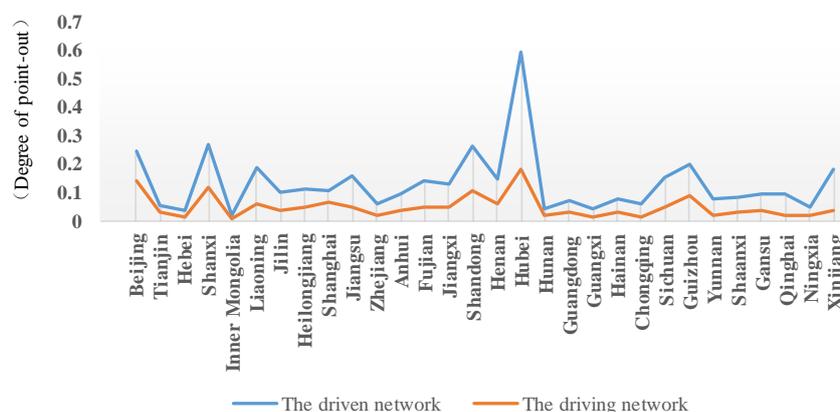
4. Discussion

4.1. Spatial Analysis of Total Consumption Coefficient and Total Distribution Coefficient

From the results of the total consumption coefficient and total distribution coefficient, the top 10 industries ranked by the total consumption coefficient include the industries from both the native provinces and non-native provinces. However, from the perspective of the total distribution coefficient, the top 10 industries ranked by the total distribution coefficient are all from native provinces. In other words, the main materials and services needed by the construction industry are from native provinces and non-native provinces. The non-native provinces and the provinces in which the construction industry is located in are relatively close to each other. As for the total distribution, the industries in the native provinces are the main consumers of the products of the construction industry. This reveals the significant immobility of the construction industry products. The products are almost fixed on the ground, forming fixed assets.

4.2. Difference in Degree of Point-In Centrality between the Driven and Driving Networks

The degree of point-out centrality and the degree of point-in centrality in the driving and driven networks are shown in Figures 6 and 7, respectively.

**Figure 6.** The degree of point-out centrality of the construction industry.

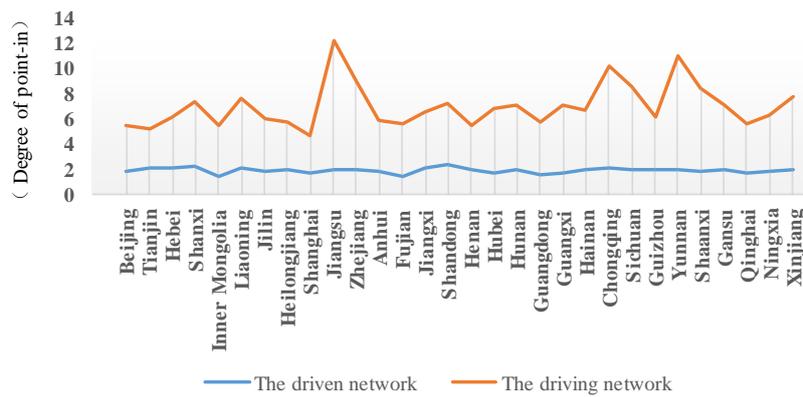


Figure 7. The degree of point-in centrality of the construction industry.

Figures 6 and 7 show that there is a significant gap between the degree of point centrality in the driven network and the driving network. Both the degree of point-in centrality and point-out centrality in the driving network are less than in the driven network. The driving ability for other industries is far less than the driven ability. In other words, the construction industry is the most important consumer in the ecological network of all 30 industries.

4.3. Difference in the Betweenness Degree between the Driven Network and the Driving Network

The betweenness degree of the construction industry in the driven network and driving network is shown in Figure 8.

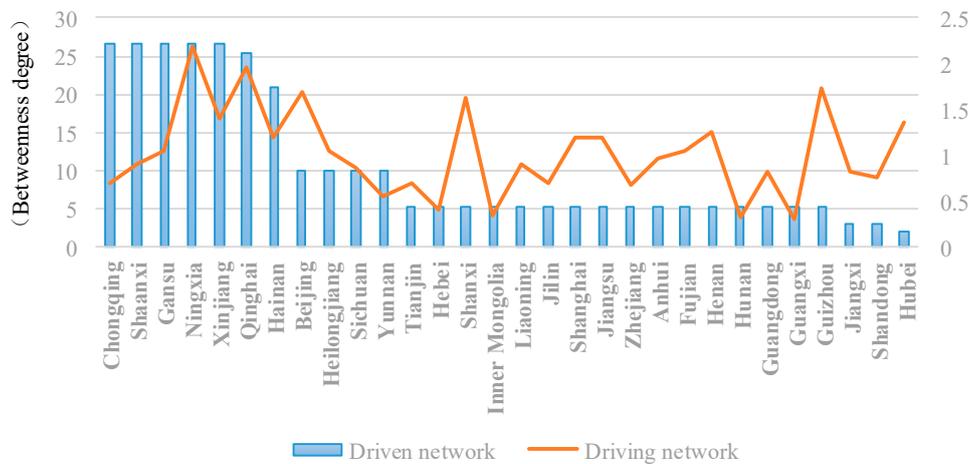


Figure 8. The betweenness degree of the construction industry.

The betweenness degree of the construction industry in the driven network far exceeds that in the driving network. This means that the construction industry is the critical-nexus industry in the driven network but not in the driving network. The construction industry significantly influences the entire driven network as the bridge that facilitates the circulation of resources and information. The trend in betweenness in the driven network, as shown in Figure 8, indicates that the construction industries in 30 provinces can be divided into four subgroups. In 16 provinces out of 30, the betweenness degree of more than half of all the provinces is 5.306. In contrast, the betweenness degree of the construction industry in the driving network fluctuates dramatically.

4.4. Forward Association and Backward Association of the Construction Industry

The forward association of the construction industry means that the construction industry's products are consumed by other industries, which significantly influence other industries. The total

consumption coefficient can be used to measure the forward association of the construction industry on other industries. Similarly, the backward association of the construction industry means that the demand for materials and services from other industries for the production activities of the construction industry results in its influence on other industries. The total distribution coefficient can measure the backward association of the construction industry on other industries. From the results outlined in Section 4.2, the hotel and restaurant, construction, agriculture, agriculture, metal products, and electricity and hot water production and supply industries are the main industries that have a vital forward association with the construction industry. The nonmetal products, wood processing and furnishing, nonmetal mining, metal products, nonmetal mining, metallurgy, and electrical equipment industries have vital backward associations with the construction industry.

4.5. General Influence of the Construction Industry

To reveal the general influences in the driving and driven networks of 30 industries in 30 provinces, the driven and driving coefficients of 900 industries were ordered from largest to smallest. The sorted results of the driven coefficients and driving coefficients of the construction industry in 30 provinces are listed in Table 9.

Table 9. The general influence of the construction industry.

Province	Driving Network Rank	Driven Network Group
Beijing	25	2
Tianjin	30	2
Hebei	30	2
Shanxi	19	1
Inner Mongolia	29	1
Liaoning	29	2
Jilin	27	2
Heilongjiang	26	1
Shanghai	25	1
Jiangsu	26	2
Zhejiang	27	1
Anhui	28	1
Fujian	27	1
Jiangxi	28	2
Shandong	29	4
Henan	29	3
Hubei	17	1
Hunan	29	1
Guangdong	29	1
Guangxi	29	1
Hainan	24	1
Chongqing	30	1
Sichuan	29	1
Guizhou	16	1
Yunnan	23	1
Shaanxi	28	1
Gansu	24	1
Qinghai	20	1
Ningxia	23	1
Xinjiang	22	2

Table 9 shows that the sorted results are opposite in the driven network and the driving network. In the driving network, the ranked results of the construction industry in the 30 provinces are of little importance. The influence of the construction industry is not proportional to its contribution to China's economic output. This shows that the construction industry has not formed a close connection with the entire industrial economy and has a limited effect on other industries from the perspective of driving

ability. However, from the perspective of the driven network, the construction industry is the most important industry, having significant driven ability on the entire industry. The production activities of the construction industry in 30 provinces require large amounts of materials and services from other industries, which facilitates the production activities of other industries. In summary, the driven ability by far exceeds the driving ability of the construction industry in the 30 provinces in China.

5. Conclusions

The construction industry is a pillar industry facilitating the economic development of China. However, the industry's development is confronting a series of challenges including its lack of efficiency, high level of pollution, capital-intensive nature, and unreasonable structure. The causes of these challenges are not only due to the construction industry, but also other industries that have correlations with the construction industry. This paper employed the total consumption coefficient and the total distribution coefficient to reveal the influencing power of the construction industry. Based on the total consumption coefficient and total distribution coefficient, the driven coefficient and driving coefficient were used to reflect the general effect on the entire industry network. The driven and driving networks were constructed using the total consumption coefficient and the total distribution coefficient to reveal the critical positions of industries in the network.

From the results, it can be seen that the top 10 industries ordered by the total consumption coefficient include industries both from the native provinces and non-native provinces. However, from the perspective of the total distribution coefficient, the top 10 industries ordered by the total distribution coefficient are all located in the native provinces. This reveals the significant immobility of the construction industry products. The products are almost fixed on the ground, representing fixed assets. Besides, the densities of the complex driving and driven networks of 900 industries are 0.1155 and 0.0018, respectively. The density of the complex network is relatively sparse. The efficiency of resource and information circulation in the complex network of industries can be considerably improved. In addition, there is significant difference between the degree of point centrality in the driven network and in the driving network. On one hand, the degrees of point-in centrality and point-out centrality in the driving network are both less than in the driven network. The driving ability for other industries is far less than the driven ability. It means that the construction industry is the most important consumer in the ecological network of all 30 industries. On the other hand, the hotel and restaurant, construction, agriculture, metal products, electricity, and hot water production and supply industries are the main industries that have a vital forward association with the construction industry. The nonmetal products, wood processing and furnishing, nonmetal mining, metal products, metallurgy, and electrical equipment industries have vital backward associations with the construction industry.

Notably, in the driving network, the ranked results of the construction industry in 30 provinces are of little importance. This shows that there are no robust correlations between the construction industry and other industries, which reflects that the construction industry has limited effects on other industries. However, the perspective of the driven network reflects that the construction industry is the most important industry, revealing that the production activities of the construction industry in 30 provinces require large amounts of materials and services from other industries. Therefore, the construction industry further facilitates the production activities of other industries. In summary, the driven ability of the construction industry far exceeds its driving ability in the 30 provinces. The different characteristics of the construction industry in the driven network and the driving network are worthy of further discussion.

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Appendix A

Table A1. Multi-input–output table showing departments and codes.

Province	Code	Industry	Code
Beijing	A	Agriculture	1
Tianjin	B	Coal mining	2
Hebei	C	Petroleum and gas	3
Shanxi	D	Metal mining	4
Inner Mongolia	E	Nonmetal mining	5
Liaoning	F	Food processing and tobaccos	6
Jilin	G	Textile	7
Heilongjiang	H	Clothing, leather, fur, etc.	8
Shanghai	I	Wood processing and furnishing	9
Jiangsu	J	Paper making, printing, stationery, etc.	10
Zhejiang	K	Petroleum refining, coking, etc.	11
Anhui	L	Chemical industry	12
Fujian	M	Nonmetal products	13
Jiangxi	N	Metallurgy	14
Shandong	O	Metal products	15
Henan	P	General and specialist machinery	16
Hubei	Q	Transport equipment	17
Hunan	R	Electrical equipment	18
Guangdong	S	Electronic equipment	19
Guangxi	T	Instrument and meter	20
Hainan	U	Other manufacturing	21
Chongqing	V	Electricity and hot water production and supply	22
Sichuan	W	Gas and water production and supply	23
Guizhou	X	Construction	24
Yunnan	Y	Transport and storage	25
Shaanxi	Z	Wholesale and retailing	26
Gansu	AA	Hotel and restaurant	27
Qinghai	AB	Leasing and commercial services	28
Ningxia	AC	Scientific research	29
Xinjiang	AD	Other services	30

References

- Zeng, S.X.; Tam, C.M.; Wang, H.C.; Deng, Z.M. Overcoming Problems Associated with Sustainable Development of the Construction Industry in China. *Archit. Sci. Rev.* **2003**, *46*, 353–361. [CrossRef]
- Zhao, Q. Discussion on the Optimization and Upgrading of Industrial Structure and the Construction of Industrial Competitiveness in Henan Province. *Innov. Sci. Technol.* **2016**. [CrossRef]
- Qingfu, G.U. Industrial Structure Optimization of Chinese Construction Industry. *Constr. Econ.* **2013**. Available online: http://en.cnki.com.cn/Article_en/CJFDTOTAL-JZJJ201302001.htm. (accessed on 22 March 2019).
- Zhong, L.I.; Fan, J.S.; Wang, Y.Y. The Research on Structure Adjustment and Upgrading of Construction Industry in China. *Constr. Manag. Mod.* **2008**. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-JCGL200805004.htm. (accessed on 22 March 2019).
- Wei, X.Y.; Lin, Z.Y. Present status and development of construction industry in China. *J. Harbin Inst. Technol.* **2004**, *1*, 34–45.
- Sha, K.; Jiang, Z. Improving rural Labourers' status in China's construction industry. *Build. Res. Inf.* **2003**, *31*, 464–473. [CrossRef]
- Chen, J. The characteristics and current status of China's construction industry. *Constr. Manag. Econ.* **1998**, *16*, 711–719. [CrossRef]
- Tang, W.; Qiang, M.; Duffield, C.F.; Young, D.M.; Lu, Y. Risk Management in the Chinese Construction Industry. *J. Constr. Eng. Manag.* **2007**, *133*, 944–956. [CrossRef]

9. Crosthwaite, D. The global construction market: A cross-sectional analysis. *Constr. Manag. Econ.* **2000**, *18*, 619–627. [[CrossRef](#)]
10. Liu, Y.; Xu, N. The status quo and causes of China's construction industry organization. *Constr. Econ.* **2003**, *18*, 9–13.
11. Turin, D.A. Construction and development. *Habitat Int.* **1978**, *3*, 33–45. [[CrossRef](#)]
12. Yang, D.; Jin, W.; Lu, X. Economic Growth Modes of China's Construction Industry. *Constr. Econ.* **2004**, 5–9. Available online: http://en.cnki.com.cn/Article_en/CJFDTOTAL-JZJJ200411001.htm. (accessed on 22 March 2019).
13. Yiu, C.Y.; Lu, X.H.; Leung, M.Y.; Jin, W.X. A longitudinal analysis on the relationship between construction output and GDP in Hong Kong. *Constr. Manag. Econ.* **2004**, *22*, 339–345. [[CrossRef](#)]
14. Zou, G. Long-term and Short-term Impacts of Construction on Economic Growth. *Civ. Constr. Environ. Eng.* **2005**, *27*, 117–122.
15. Zheng, S.; Liu, H. Econometric model and analysis of the relationship between China's construction investment and economic growth. *J. Tsinghua Univ. (Philos. Soc. Sci.)* **2001**, 45–49. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-QHDZ200104009.htm. (accessed on 22 March 2019).
16. Jiang, M.; Jiang, C. Analysis of the co-integration relationship between China's construction industry and national economic growth. *Constr. Econ.* **2007**, 46–48. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-KJSJ201423004.htm. (accessed on 22 March 2019).
17. Huang, C.; Li, Q.; Shen, L. Econometric Models and Analytical Studies of China's Construction Promotion. *J. Southeast Univ. (Natl. Sci. Ed.)* **2000**, *30*, 112–118.
18. Bilal, M.; Oyedele, L.O.; Qadir, J.; Munir, K.; Ajayi, S.O.; Akinade, O.O.; Owolabi, H.A.; Alaka, H.A.; Pasha, M. Big Data in the construction industry: A review of present status, opportunities, and future trends. *Adv. Eng. Inform.* **2016**, *30*, 500–521. [[CrossRef](#)]
19. Memon, A.H.; Rahman, I.A.; Memon, I. BIM in Malaysian Construction Industry: Status, Advantages, Barriers and Strategies to Enhance the Implementation Level. *Res. J. Appl. Sci. Eng. Technol.* **2014**, *8*, 606–614. [[CrossRef](#)]
20. Jin, R.; Chen, Q. An investigation of current status of "green" concrete in the construction industry. In Proceedings of the 49th ASC Annual International Conference, San Luis Obispo, CA, USA, 10–13 April 2013; Available online: <http://ascpro.ascweb.org/chair/paper/CPRT92002013.pdf>. (accessed on 22 March 2019).
21. Shang, M.; Dong, R.; Fu, Y.; Hao, W. Research on carbon emission driving factors of China's provincial construction industry. *Earth Environ. Sci.* **2018**, *128*, 012148. [[CrossRef](#)]
22. Hong, J.; Li, C.Z.; Shen, Q.; Xue, F.; Sun, B.; Zheng, W. An Overview of the driving forces behind energy demand in China's construction industry: Evidence from 1990 to 2012. *Renew. Sustain. Energy Rev.* **2017**, *73*, 85–94. [[CrossRef](#)]
23. Nur Syamimi, Z.; Leo, Y.L. Drivers in the implementation of sustainable construction management among main contractors. *Int. J. Eng. Technol.* **2017**, *7*. [[CrossRef](#)]
24. Baharuddin, M.N.; Bahardin, N.F.; Zaidi, M.A.; Lokman, I.; Nawati, M.N.M. An exploratory review on critical factors of IBS formwork implementation for Malaysian construction stakeholders. In Proceedings of the International Conference on Applied Science & Technology, Kedah, Malaysia, 11–13 April 2016.
25. Kshirsagar, M.; Sandbhor, S.; Botre, R. Interpreting delay factors for improving productivity in Indian construction industry. *Int. J. Appl. Eng. Res.* **2015**, *10*, 13823–13840.
26. Yang, S.D. Empirical Study on Factors Influencing the Development of Construction Industry—Based on Anhui Construction. *Appl. Mech. Mater.* **2012**, 193–194, 1300–1306. [[CrossRef](#)]
27. Wang, X.; Zhang, J.; Hui, L.I. Economic Factor Analysis of Value-added Growth for the Chinese Construction Industry. In Proceedings of the 2008 International Conference on Construction & Real Estate Management, Toronto, ON, Canada, 4–5 October 2008.
28. Zhang, Y.; Wu, S.; Dong, Y. Construction of a New Pattern of Coordinated Development of the Mining Industry in the Yangtze River Economic Belt. *Land Resour. Inf.* **2018**. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-GTZQ201804009.htm. (accessed on 22 March 2019).
29. Yang, D.; Chen, L.; Du, Y.; Cui, X. Discussion on Several Issues of Construction Industry Development Mode. *Constr. Econ.* **2015**. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-JZJJ201510002.htm. (accessed on 22 March 2019).

30. Gu, Y.-X. Current Status and Development Direction of China Construction Industry. *Constr. Qual.* **2013**. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-GCZL201301003.htm. (accessed on 22 March 2019).
31. Fugar, F.D.K.; Ashiboemensah, N.A.; Adinyira, E. Human capital theory: Implications for the Ghanaian construction industry development. *J. Constr. Proj. Manag. Innov.* **2013**, *3*, 464–479.
32. Lu, Y.; Zhu, X.; Cui, Q. Effectiveness and equity implications of carbon policies in the United States construction industry. *Build. Environ.* **2012**, *49*, 259–269. [[CrossRef](#)]
33. Ofori, G.; Toor, S.R. Leadership and construction industry development in developing countries. *J. Constr. Dev. Ctries.* **2012**, *17*, 1–21.
34. Liu, W.; Zhong, W.; Shi, Q. Forecast of China's total energy consumption in 2020 based on method of fixed base energy consumption elasticity coefficient. *Resour. Sci.* **2016**. Available online: http://en.cnki.com.cn/Article_en/CJFDTOTAL-ZRZY201604008.htm. (accessed on 22 March 2019).
35. Mi, Z.; Meng, J.; Guan, D.; Shan, Y.; Song, M.; Wei, Y.; Liu, Z.; Hubacek, K. Chinese CO₂ emission flows have reversed since the global financial crisis. *Nat. Commun.* **2017**, *8*, 1712. [[CrossRef](#)] [[PubMed](#)]



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