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Level Measurement and Obstacle Diagnosis of High-Quality Development of The Construction Industry Empowered by Digital Intelligence

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Abstract: As a fusion application of digital technology and intelligence, digital intellectualization has a great role in promoting economic development and social life change and realizing high-quality development. Based on the panel data of 31 provinces in China from 2012 to 2021, this paper selects indicators from three dimensions: infrastructure conditions of empowerment, subjects of empowerment, and subjects of empowerment, and constructs an evaluation system to measure the level of high-quality development of the construction empowered by digital intelligence and analyze the obstacle factors. It is found that the overall trend of high-quality development level of the digital intelligence-enabled construction industry from 2012 to 2021 is upward, and there is a wide gap in the level of regions, with the south, north, and east areas having a high level of high-quality development of the construction industry empowered by digital intelligence, the center and southwest area having a low to medium level, the northeast and northwest area having a low level. The results of the obstacle degree show that input indicators, output indicators, industrial efficiency, broadband penetration rate, and facility sharing are the main obstacle factors restricting the high-quality development of the construction industry empowered by digital intelligence. In the future, accelerating the high-quality development of the construction industry empowered by digital intelligence should start with strengthening regional collaborative development, providing a good policy environment and resource protection, accelerating the absorption and proliferation of digital intelligence industry technology, and strengthening the sharing of facilities and resources among relevant participants in the construction industry.

Keywords: Digital Intelligence, High Quality Development in Construction Industry, Level Measurement, Barrier Degree Analysis.

1. Introduction

"The Outline of the 14th Five-Year Plan of the National Economic and Social Development of the People's Republic of China" pointed out that the promotion of the synergistic development of the intelligent construction industry and new building industrialization as the driving force accelerates the transformation and upgrading of the construction industry, realizes green and low-carbon development, and effectively improve the quality and efficiency of development. The high-quality development of the construction industry can not only achieve the sustainable development of the construction industry but also promote the transformation and upgrading of related industries (Sun Jide et al., 2019). However, the construction industry has long been characterized by insufficient technological innovation, sloppy development of the industry, inadequate resourcing of construction industry waste, labor-intensive, high energy consumption, and a backward project organization and production system with a low level of industrialization and informatization (BARBOSA F et al., 2017). The integration of digital technology and intelligent application of digital intellectualization has a huge role to play in promoting economic development and social life change and promoting a digitally intelligent economy and digital intellectual transformation. Therefore, in the context of the booming development of digital intelligence, it is of great significance to analyze the internal mechanism of the high-quality development of the construction industry empowered by digital intelligence, scientifically measure the level of high-quality development of the construction industry empowered by digital intelligence and regional differences, and explore the obstacles that impede the high-quality development of the construction industry empowered by digital intelligence, to promote the high-quality development of the construction industry empowered by digital intelligence.

On the topic of digital intelligence research, scholars discuss more about the definition (Chen Jian et al., 2021; Wu et al., 2022), connotation (Wang Bing, 2023; Mithas et al., 2017; Munir et al. 2021; Vial, 2019), and they generally agree that digital intelligence is the fusion of digitization and intelligent application (Jianfeng Zhang et al., 2022). The intelligence of digital intelligence at the level of governance and algorithm profoundly affects the process of empowerment and value creation (Chen Guoqing et al., 2022). On the research theme of high-quality development of the construction industry, most of the scholars discuss the connotation of high-quality development of the construction industry as well as the realization path by combining the new development concept and the connotation of high-quality development (Li Shichun, 2020; Xiang Yong et al., 2019), and some of the scholars construct the index system of the level of development of the construction industry to evaluate it (Yang Chengqian et al., 2020; Yang Deqin et al., 2020) Some scholars have also begun to pay attention to the impact of digitalization on the high-quality development of the construction industry. Yang Yingnan et al. (2022) [18] discuss the path of digital development and transformation of the construction industry in Beijing, China, under the background of high-quality development from the perspective of "techno-logic", and argue that the social evolution from software to digitization, networking, and finally intelligence has promoted the change of the construction industry's working methods, organizational forms, and business models. Some scholars have also begun to pay attention to the impact of digitalization on the high-quality development of the construction industry. Yang Yingnan et al. (2022) discuss the path of digital development and transformation of the construction industry in Beijing, China, under the background of high-quality development from the perspective of "techno-logic", and argue that the social evolution from software to digitization, networking, and finally intelligence promotes the change of the construction industry's working methods, organizational forms, and business models. Forcael et al. (2020) discuss the digital transformation trends and high-quality development strategies in the construction industry, They explain the concept of construction industry 4.0 and the types of digital technologies, and summarize the four key technologies of Industry 4.0: 3D printing, big data, virtual reality and the Internet of Things; Craveiro et al. (2019) analyzes the impact of BIM technology, the Internet of Things and other digital technologies to empower the development of the construction industry and Industry 4.0, and analyzed the impact of Industry 4.0 on the construction industry; Pan and Zhang (2021) argued that the application of technologies such as BIM, digital twins, and artificial intelligence in construction industry engineering and management drives digital transformation and efficiency in the construction industry and enables a data-driven approach to predict and optimizing problems throughout the project cycle.

In summary, existing scholars generally recognize the role of digital intelligence in promoting the high-quality development of the construction industry, but there is no consensus on the mechanism of how digital intelligence can empower the high-quality development of the construction industry, and there is a lack of research on the evaluation of the level of high-quality development of the construction industry by digital intelligence, and there is a lack of comprehensive and systematic analysis of the level of high-quality development of China's digital intelligence empowered by construction industry and the obstacles to the relevant research. Therefore, this paper analyzes the intrinsic mechanism of the high-quality development of construction industry empowered by digital intelligence, selects the panel data of 31 provinces in China from 2012 to 2021, and constructs the index system for measuring the level of high-quality development of the construction industry empowered by digital intelligence, panel data of 31 provinces in China from 2012 to 2021 were selected to construct an evaluation index system from three dimensions: infrastructure conditions of empowerment, target of empowerment, and process of empowerment, and the entropy method was used to assign indexes and adopts the application of the comprehensive evaluation method to assess the level of the development of high-quality development and obstacles to the construction industry empowered by digital intelligence. Using the entropy value method to empower the indicators, applying the comprehensive evaluation method to measure the level of high-quality development of the construction industry and analyze the level of differentiation between regions, using the obstacle model to analyze the factors constraining the high-quality development of the construction industry empowered by digitization, and finally providing countermeasures and suggestions for the promotion of the high-quality development of the construction industry enabled by digitization.

2. The Logic and Internal Mechanism of Digital Intelligence Enabling High-Quality Development of the Construction Industry

2.1. The Logic of Digital Intelligence Enabling High-Quality Development in the Construction Industry

Digital intelligence to empower the construction industry high-quality development refers to: based on the perfect digital intelligence infrastructure conditions and environment, digital intelligence innovation as a driver, through improving the quality and efficiency of the development of the construction industry to promote the efficiency of the construction industry, and then realize the high-quality development of the construction industry. Which should satisfy both the basic conditions of empowerment and certain requirements on the conditions of the empowering targets itself. First of all, the basic conditions of empowerment include a perfect digital and intellectual environment and digital and intellectual technology innovation drive. It mainly includes information infrastructure such as communication, post and telecommunications, computers, cell phones, etc., which collects, processes, links, and circulates construction industry information and promotes digital intelligence technology; high-quality talents who are capable of applying and creating digital intelligence technology; and financial support for technological innovation (Su Bingjie et al., 2022; Wu Guoyong et al., 2022). These infrastructures and digital intelligence environment provide the preconditions for the high-quality development of the construction industry empowered by digital intelligence, guaranteeing a more efficient integration and application of digital intelligence technology and data elements in the management of building production and construction industry. Secondly, the empowerment target is the construction industry, and its development level is directly related to the effect of empowerment, evaluate the level of development of the construction industry in terms of efficiency, greenness, sharing, coordination, and openness concerning the existing literature. (Wang Wenzhao et al. 2019; Wu Xianghua and Zhang Liting, 2021; Wang Li and Li Huimin, 2020; Kauskale et al. 2017).

2.2. Intrinsic Mechanisms of Digital Intelligence Enabling High-Quality Development of the Construction Industry

The new round of technological revolution stimulates the generation and development of digital intelligence, which relies on the core production factor data to breed a large number of new technologies, and the generation and application of new technologies lead to the formation of new industrial forms. Digital intelligence improves total factor productivity by promoting production technology innovation and project management model innovation, which in turn promotes the high-quality development of the construction industry (Xu Man et al., 2023). Among other things, digital intelligence, by promoting the upgrading of the production side, management side, and operation and maintenance side, and by using digital technology to intelligently combine with data elements, enables the construction industry to carry out elemental innovation and reorganization, innovate the whole life cycle model of the project, and form valuable digital assets. In addition, digital intellectualization can replace the manual link in the production and management process, thus significantly improving production efficiency, promoting human-machine collaboration, breaking the limitations of elements in time and space, realizing the reconfiguration of resource elements, and the reorganization of elemental circulation is also highly efficient, realizing intelligent manufacturing, and improving production efficiency and quality (Jun Wang, 2018). At the same time, digital intellectualization is a power source for achieving high-quality development, which can help the transformation and upgrading of the industrial structure and promote the rapid development of new industries. The industrial structure of the construction industry mainly includes the ownership structure, organizational structure, and business structure of construction industry enterprises (Liu Dong and Ji Ran, 2023), and the innovation and application of informatization and intelligent technology promotes the efficiency of industrial operation, promotes the process of digital intellectualization and even the transformation of digital intelligence in the industry, and then realizes the upgrading of the industrial structure.

In summary, with the basic conditions and objectives of empowerment, digital intelligence empowers the high-quality development of the construction industry through the optimization of resource allocation and upgrading of industrial structure, and the internal mechanism is shown in Figure 1.

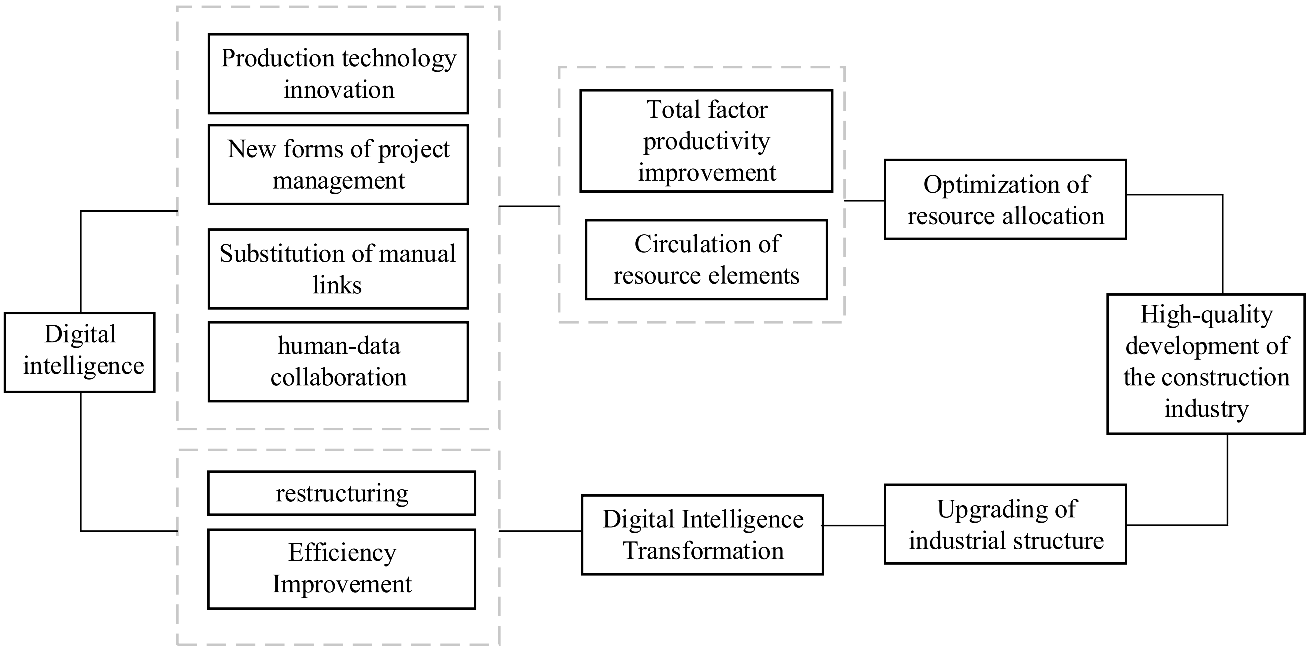

Figure 1. Digital Intelligence Enables High-Quality Development of Construction Industry Inherent Mechanisms.

3. Evaluation Index System Construction Industry, Methods, And Results

3.1. Evaluation Index System Construction Industry

Based on the previous analysis, this study refers to the research of Wang Dingxiang et al. (2023) on the construction industry of the indicator system for the integration of the digital economy and agricultural development and constructs the evaluation indicator system for the high-quality development of the construction industry empowered by digital intelligence with three guideline layers and nine first-level indicators, namely, the basic conditions of empowerment, level of empowerment targets and the process of empowerment. As shown in Table 1.

3.2. Research Methodology

3.2.1. Entropy value method

The entropy value method is chosen to calculate the comprehensive level index of the high-quality development of the construction industry empowered by digital intelligence, and the specific steps are as follows:

The first step is to standardize the raw data to eliminate the influence of the quantitative outline (the higher the value of the positive indicators, the better, and the lower the negative indicators, the better):

Positive indicators:

$$Z_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{1}$$

negative indicators:

$$Z_{ij} = \frac{max(x_j) - x_{ij}}{max(x_j) - min(x_j)} \tag{2}$$

Zij denotes the normalized value, max (xj), min (xj) denotes the maximum and minimum value of the j indicator.

In the second step, the weight pij of the indicator value of the i region under the j indicator is calculated:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{3}$$

Table 1. Evaluation Indicator System for High-Quality Development of Construction Industry Empowered by Digital Intelligence.

Guideline layer	Tier 1 Indicators	Secondary indicators	Meaning or calculation of secondary indicators
Basic conditions of empowerment	Digital environment	X1 Broadband penetration	Subscribers with Internet broadband access
		X2 Computer ownership	Number of computers per 100 population
		X3 Cell phone usage	Number of cell phones per 100 population
		X4 Long-haul fiber optic cable penetration	Length of long-haul fiber optic cable lines
	Innovation Driver	X5 Patent applications per capita in the construction industry	Number of patent applications/ Number of people employed in the construction industry
		X6 R&D expenditure per unit of construction industry output	R&D funding/ Construction industry output
		X7 Mechanization in the construction industry	Power equipment rate for the construction industry
		X8 R&D investment	Full-time equivalent of R&D personnel
Level of empowerment target	Effectiveness of the construction industry	X9 Production efficiency	Labor productivity of construction industry firms
		X10 Industry benefits	Construction industry value added/ GDP per capita
	Greenness of the construction industry	X11 Greening coverage in built-up areas	Green area in built-up areas/ Built-up area
		X12 Resource utilization (—)	Consumption of cement, steel, and wood per unit of production value
	Shareability of the construction industry	X13 Sharing of facilities	Urban road space per capita + Green space per capita in parks
		X14 Economic benefit	The average wage of persons employed in the construction industry
	Harmonization of the construction industry	X15 Harmonization of scales	Construction industry output of State-owned enterprises/ Construction industry output
		X16 Coordination of organizations	The output value of enterprises in the construction industry of special-grade and first-grade general contractors/ Construction industry output
	Openness of the construction industry	X17 Open to the outside world	Construction industry output of foreign-invested enterprises/ Construction industry output
		X18 Internal and external linkage	Output value of subcontracted work by construction industry enterprises/ Construction industry output
Process of empowerment	Optimization of resource allocation	X19 Input indicators	Total assets of construction industry enterprises/ GDP per capita
		X20 Output indicators	Construction industry output/ GDP per capita
	Upgrading of industrial structure	X21 Share of value added of tertiary and secondary industries	Value added of tertiary industry/ Value added of secondary industry

In the third step, the entropy value ej of the j metric is calculated:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \times \ln p_{ij}\,;\, k = -\frac{1}{\ln m} \tag{4}$$

In the fourth step, the entropy weight Wj of the j indicator is determined:

$$\omega_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{5}$$

In the fifth step, the composite score is calculated:

$$C_i = \sum_{j=1}^{n} \omega_j \times X_{ij} \tag{6}$$

3.2.2. Data sources

In this paper, panel data from 31 provinces in mainland China from 2012 to 2021 are used as a sample for the study. The original data come from the China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Construction Industry Statistical Yearbook, China Population and Employment Statistical Yearbook, China Industrial Economy Statistical Yearbook, and each local statistical yearbook, and missing values are supplemented by linear interpolation.

3.2.3. Analysis of results

The level of high-quality development of China's digital-intelligence-enabled construction industry from 2012 to 2021 was measured using the entropy method of empowerment, and the results are shown in Figure 2.

At the national level, the level of high-quality development of the construction industry empowered by Digital Intelligence is on an upward trend year by year during the study period, with an increase of 457% in 2021 compared to 2012. From 2017, the average annual growth rate of the level of high-quality development of the digital intellectualization-enabled construction industry reached 18.2%, showing a high growth rate. The above indicates that since the new economic normal, China's digital intellectualization industry technology and construction industry industry have developed at a high speed.

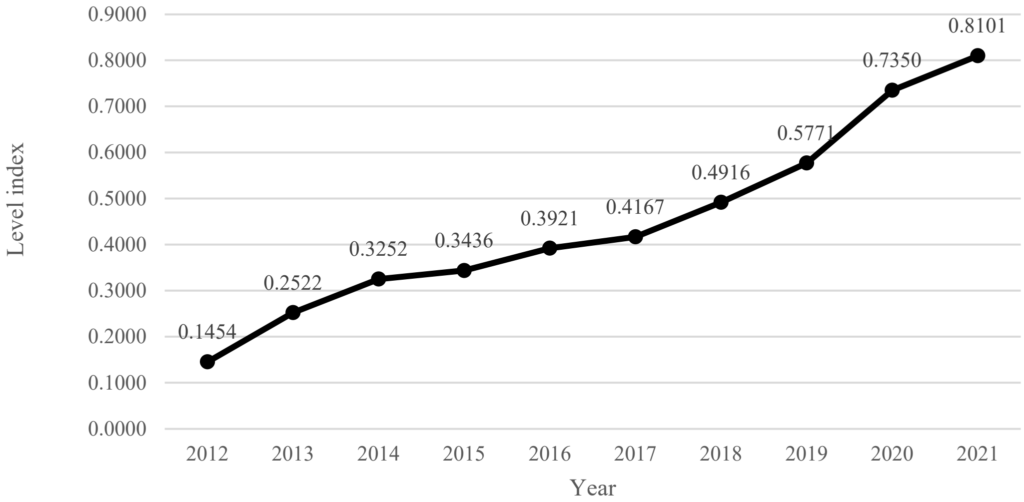

Figure 2. China's 2012-2021 Level of Digital Intelligence Enabling High-Quality Development in the Construction Industry.

Then, the annual average value of the index of the level of high-quality development of the digital intelligence-enabled construction industry in 31 provinces is calculated, and the 31 provinces are divided into seven regions, and the results are shown in Figures 3 and 4.

At the regional level, the level of the seven regions has a significant upward trend, South China, North China, East China, Central China, Southwest China, Northwest China, and Northeast China's annual average value of the level of high-quality development of the construction industry empowered by digital intelligence is 0.5033, 0.4705, 0.4600, 0.4189, 0.3057, 0.2950 and 0.2908. The reason for this is that "Beijing and Tianjin are in the first tier of the level. Because "Beijing, Tianjin," "Jiangsu, Zhejiang, Shanghai, and Guangzhou" have strong economic capacity to support the digital intelligence industry and technology and infrastructure development. They have a natural location advantage and can take advantage of the "Beijing-Tianjin-Hebei" city circle synergistic development, leading to the rapid development of the digital economy in Hebei, Shanxi, Shandong, and other neighboring regions. In the second echelon of central and southwestern China, their level of development is lower than the national average. Because of the lower level of economic development in Sichuan, Guizhou, Henan, and other regions, backward infrastructure, low level of innovation, and the lack of high economic level of the neighboring provinces to drive and lead. In the third echelon are the Northeast and Northwest regions. Because of the remote status of Liaoning, Heilongjiang, Xinjiang, etc., poor natural conditions, relatively backward transportation, lack of resources, high level of innovation economy is difficult to develop, and the research and application of new technologies, such as information technology construction industry, is lagging. In summary, there is a big difference in the level of development of the high-quality construction industry empowered by digital intellectualization in each region.

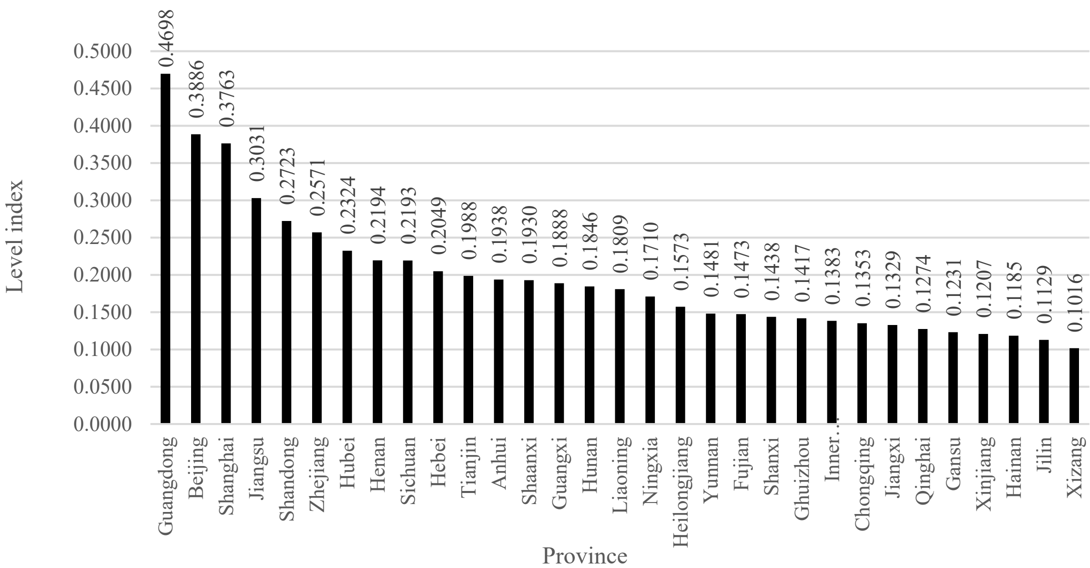

Figure 3. Annual average of the index of the level of high-quality development of the construction industry empowered by digital intelligence in 31 provinces.

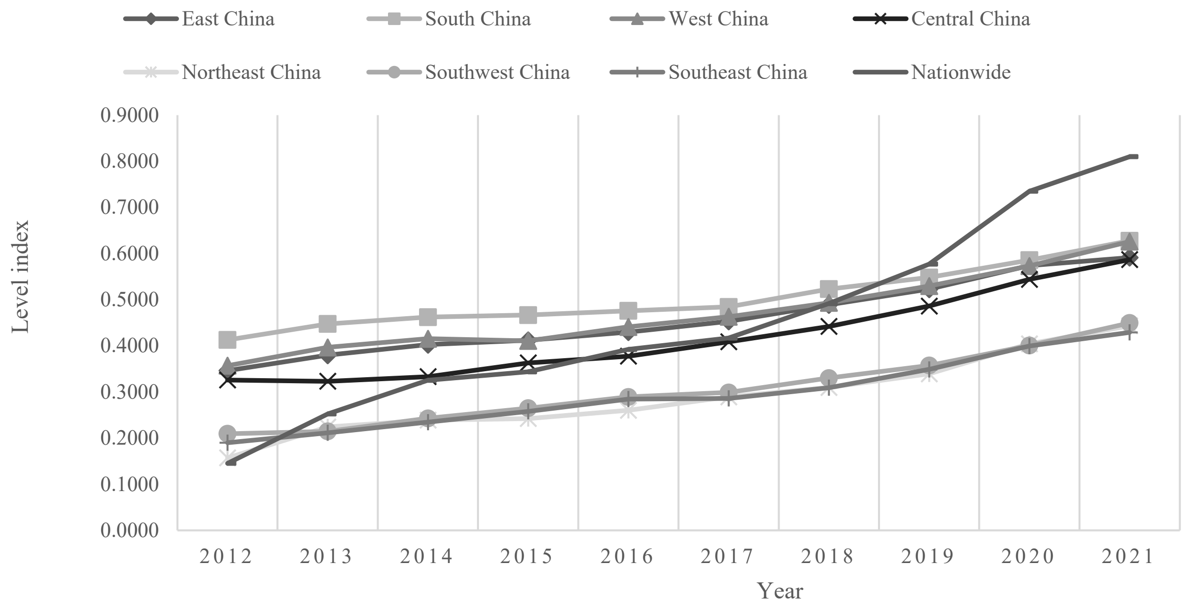

Figure 4. Index of High-Quality Development Level of Construction Industry Empowered by Digital Intelligence in Seven Major Regions of China, 2012-2021.

The mean-standard deviation grading method is used to classify the level of high-quality development of the digital intelligence-enabled construction industry industry in 31 provinces. *M* is used to denote the mean value of the data, and *SD* is used to denote the standard deviation, and values greater than (*M+SD*) are classified as high level, values in the (*M, M+SD*) range are classified as medium-high level, values in the (*M-SD, M*) range are classified as medium-low level, and values less than (*M-SD*) are classified as low level. To analyze the comparison more intuitively, the data from the three years 2012, 2017, and 2021 were selected for analysis, and the results are shown in Table 2.

At the provincial level, the number of provinces with high and medium-high levels of digital intelligence-enabled high-quality development of the construction industry is on the rise, and the overall level index is also on the rise. It shows that with economic development and social progress, the level of high-quality development of the construction industry empowered by digital intelligence has also increased. In 2012, less than 10 provinces in the country were at a medium-high level or above, of which Beijing, Shanghai, and Guangdong have always been at a high level because of their advantages in terms of location, abundant resources, relatively perfect infrastructure, and modern city management system. Jiangsu jumped to a high level in 2017, Tianjin, Zhejiang, Shandong, Henan, Hubei, and Sichuan are basically in the medium-high level. 2017 after the introduction and implementation of relevant policies to promote the rapid development of digital intelligence and the construction industry industry, as of 2021, more than half of the provinces in the country are located in the high-level and medium-high level. Among them, Tianjin, Zhejiang, Shandong, Henan, and Sichuan are elevated to high levels; Hebei, Anhui, Hunan, Shaanxi, Inner Mongolia, Liaoning, and Heilongjiang are elevated to medium-high levels. Xizang remained at a low level until 2017 and then moved to a low to medium level after 2017.

Table 2. Classification of the level of high-quality development of the construction industry industry empowered by digital intelligence in 31 provinces of China in 2012, 2017, and 2021.

Rating	2012	2017	2021
High level	Beijing, Shanghai, Guangdong, Hubei	Beijing, Shanghai, Jiangsu, Guangdong	Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong, Henan, Sichuan
Medium-high level	Tianjin, Jiangsu, Zhejiang, Shandong	Zhejiang, Shandong, Henan, Hubei, Sichuan	Hebei, Anhui, Hubei, Hunan, Shaanxi, Inner Mongolia, Liaoning, Heilongjiang
Medium-low level	Hebei, Fujian, Hainan, Shanxi, Anhui, Jiangxi, Henan, Hunan, Sichuan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang	Tianjin, Hebei, Fujian, Hainan, Shanxi, Anhui, Jiangxi, Hunan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang	Fujian, Hainan, Shanxi, Jiangxi, Chongqing, Guizhou, Yunnan, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Jilin, Tibet
Low level	Xizang	Xizang	

4. Analysis of the Degree of Obstacle

Based on analyzing and evaluating the level of high-quality development of the Numerical Intelligence-enabled construction industry, this paper further introduces the obstacle degree model to deeply analyze the factors that hinder the high-quality development of the Numerical Intelligence-enabled construction industry. The obstacle degrees of all guideline layers and all indicators in 31 provinces for 10 years are calculated, and the top five indicators hindering the high-quality development of the digital intelligence-enabled construction industry in each province are identified.

4.1. Research Methodology

Based on analyzing and evaluating the level of high-quality development of the construction industry empowered by digital intelligence in 31 provinces, this paper further introduces the obstacle degree model to dig deeper into the factors constraining the high-quality development of the construction industry empowered by digital intelligence. Its specific calculation formula is:

$$O_{ij} = \frac{(1-X_{ij})\times W_i \times 100\%}{\sum_{i=1}^{m}(1-X_{ij})\times W_i} \quad (7)$$

$$U_{ij} = \sum O_{ij} \quad (8)$$

O_{ij} denotes the degree of obstacle of the i indicator to the level of high-quality development of the construction industry empowered by Numerical Intelligence in the j year; W_i is the weight of the i indicator. U_{ij} denotes the degree of obstacle to the overall goal.

4.2. Analysis of Results

4.2.1. Analysis of the degree of obstacles at the guideline layer

As can be seen from Figure 5, from 2012 to 2021, the size and intensity of the guideline layer obstacle degree of China's provinces and counting intellectualization to empower the high-quality development of the construction industry showed different trends. At the level of role size, the overall obstacle degree tends to stabilize, and the proportion of obstacle degree of each guideline layer does not change during the 10 years. At the intensity level, the first obstacle to the high-quality development of the construction industry empowered by digital intelligence has been the level of empowerment target, followed by the basic conditions of empowerment, and finally, the process of empowerment, fluctuating around 33%, 48%, and 19%, respectively. Thus, it seems that the level of empowerment target and the problems in the basic conditions of empowerment are the main obstacles faced at present. The development level of the construction industry, the main body of empowerment, directly affects the level of high-quality development of the construction industry empowered by digital intelligence, while the basic conditions of empowerment also play a key role in the high-quality development of the construction industry empowered by digital intelligence. In the future, China needs to focus on these two aspects of development to improve the level of high-quality development of the construction industry empowered by digital intelligence.

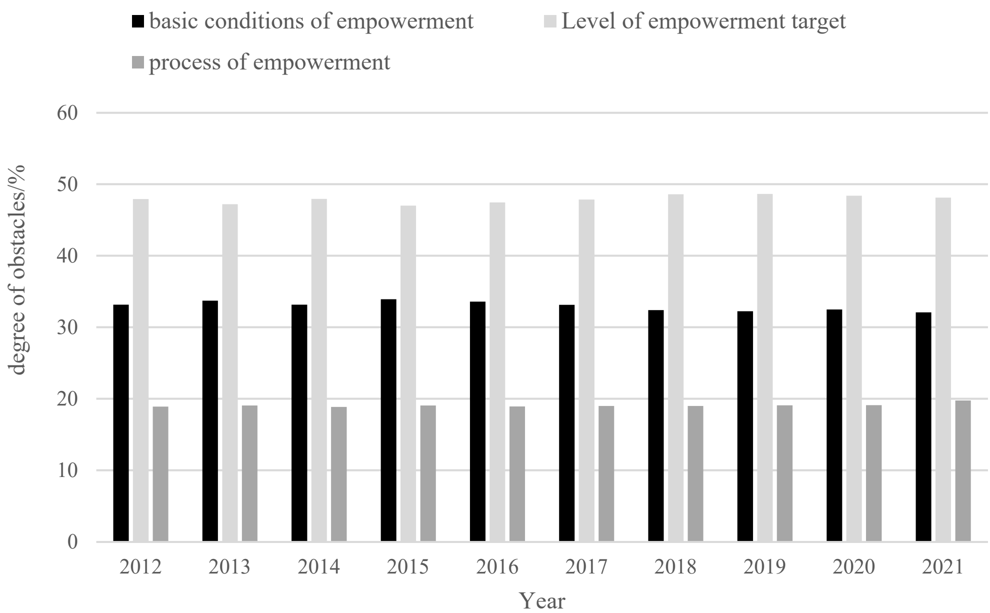

Figure 5. Guideline Layer of Digital Intelligence Empowered High-Quality Development in the Construction Industry Level Obstacles Degree

4.2.2. Analysis of the degree of obstacles at the indicators layer

Analyzing the factors constraining the high-quality development of China's digital intelligence-enabled construction industry based only on the guideline layer obstacle degree will hide the individual differences of the indicators, therefore, this paper further calculates the obstacle degree of the indicator layer of each province, taking the top five obstacle degree rankings of each province during the 10-year period, which involves a total of 12 indicators, as shown in Table 3. In descending order of the frequency of occurrence of the indicators, they are X19 Input indicators (26 occurrences), X20 Output indicators (26 occurrences), X10 Industry benefits(25 occurrences), X1 Broadband penetration (20 occurrences), X13 Sharing of facilities (18 occurrences), X12 Resource utilization (16 occurrences), X3 Cell phone usage (10 occurrences), X6 R&D expenditure per unit of construction industry output (6 occurrences), X18 internal and external linkage (5 occurrences), X9 production efficiency (3 occurrences), X11 Greening coverage in built-up areas (1 occurrence), and X21 Share of value added of tertiary and secondary industries(1 occurrence). The top five obstacles are X19 Input Indicator, X20 Output Indicator, X10 Industry Benefits, X1 Broadband Penetration, and X13 Sharing of facilities. This indicates that the overall problems of China's digital intelligence-enabled high-quality development of the construction industry are: the urgent need to optimize the allocation of resources in the construction industry, the lack of channels for the transformation of scientific and technological achievements, and the difficulty in realizing the empowerment of digital intelligence technology. Low industrial efficiency, development effectiveness, and development efficiency need to be further refined. The level of infrastructure and facility sharing needs to be further improved.

Table 3. Top 5 Indicators of Obstacles to High-Quality Development of the Construction Industry Empowered by Digital Intelligence, by Province, 2012-2021.

Rank / Province	1	2	3	4	5
Beijing	X10(13.56)	X20(12.41)	X13(9.88)	X1(8.72)	X6(7.33)
Tianjin	X10(10.87)	X20(10.81)	X19(8.40)	X1(7.34)	X13(6.86)
Hebei	X12(11.05)	X20(7.93)	X10(6.99)	X19(6.32)	X3(5.62)
Shanxi	X10(9.75)	X20(9.32)	X13(6.52)	X1(6.45)	X19(6.32)
Inner Mongolia	X20(12.33)	X19(10.28)	X10(9.72)	X1(7.34)	X18(5.35)
Liaoning	X20(8.68)	X10(8.50)	X12(7.22)	X13(6.83)	X19(6.45)
Jilin	X20(9.63)	X10(8.59)	X19(8.06)	X12(6.68)	X1(6.33)
Heilongjiang	X20(10.50)	X10(10.08)	X19(8.80)	X13(6.55)	X1(6.53)
Shanghai	X10(11.99)	X13(11.96)	X20(11.43)	X19(8.78)	X1(7.14)
Jiangsu	X12(27.69)	X10(5.59)	X18(5.33)	X9(4.77)	X3(4.77)
Zhejiang	X12(28.15)	X10(6.55)	X13(4.80)	X19(4.76)	X6(4.65)
Anhui	X12(9.29)	X20(7.73)	X19(6.86)	X3(6.80)	X1(5.98)
Fujian	X12(8.68)	X19(4.01)	X20(3.83)	X10(3.12)	X1(2.56)
Jiangxi	X19(7.68)	X20(7.54)	X12(7.30)	X10(7.23)	X3(6.34)
Shandong	X12(13.84)	X20(6.91)	X3(6.53)	X18(6.22)	X9(5.23)
Henan	X12(13.98)	X13(8.05)	X3(6.25)	X18(5.45)	X6(5.40)
Hubei	X12(17.18)	X10(7.18)	X13(6.38)	X3(5.93)	X1(5.58)
Hunan	X12(10.10)	X19(7.14)	X13(7.12)	X20(6.36)	X3(6.17)
Guangdong	X12(14.32)	X20(8.74)	X10(8.53)	X13(7.55)	X21(4.85)
Guangxi	X19(8.72)	X20(8.67)	X10(6.98)	X1(6.16)	X3(6.00)
Hainan	X20(11.90)	X19(10.53)	X10(10.27)	X1(7.28)	X13(5.43)
Chongqing	X20(8.10)	X10(7.51)	X19(7.50)	X1(6.28)	X12(6.01)
Sichuan	X12(19.79)	X13(6.97)	X6(6.05)	X3(5.66)	X18(4.99)
Guizhou	X20(9.71)	X10(7.89)	X13(7.03)	X1(6.79)	X19(6.62)
Yunnan	X20(8.31)	X13(7.12)	X1(6.47)	X19(6.15)	X6(6.11)
Xizang	X20(11.20)	X19(9.75)	X10(9.58)	X1(7.06)	X13(6.26)
Shaanxi	X20(8.60)	X10(7.67)	X12(6.97)	X19(6.91)	X13(6.48)
Gansu	X20(9.71)	X10(9.22)	X19(7.70)	X1(6.60)	X11(6.19)
Qinghai	X20(11.49)	X10(10.34)	X19(9.98)	X1(7.29)	X13(6.94)
Ningxia	X20(12.19)	X10(11.12)	X19(10.61)	X1(7.71)	X9(4.95)
Xinjiang	X20(10.41)	X10(9.15)	X19(8.71)	X1(6.73)	X6(6.01)

Further analysis of the trend of change in the degree of obstacles of each indicator from 2012-2021, the overall degree of obstacles of China's indicator layer is divided into Table 4. It can be seen that the degree of obstacles of X1 broadband penetration, X2 computer ownership, and X3 Cell phone usage showed a decreasing trend in 2012-2021, which indicates that, with the development of digitization and informatization industry, the construction industry of China's digital infrastructure is gradually strengthened, and the digitization environment is gradually improved. The obstacle degrees of X12 Resource Utilization, X15 Harmonization of scales, and X7 Mechanization in the construction industry are on the rise, indicating that with urbanization and population growth, the demand for buildings rises and the number of buildings constructed continues to increase, leading to an increase in resource and energy consumption and that many buildings do not comply with the requirements of high efficiency and energy conservation. In addition, the lack of energy-saving measures and technologies and the imperfect system of energy management have led to the waste of energy in the construction industry process and increased resource and energy consumption. The output value of the construction industry of state-owned enterprises has declined, the growth rate of the construction industry has slowed down, and the competition in the market has intensified, which has led to a decrease in the business volume of enterprises and affected the output value. In addition, changes in the market environment may also cause enterprises to face business risks, which in turn affects the output value. Compared with the traditional labor force, the maintenance and management of construction industry machinery and equipment require more investment. For example, the daily maintenance, repair, and storage of equipment require specialized personnel and premises, which increases the operating costs of enterprises. Some small enterprises may not be able to afford these additional costs, limiting their willingness and ability to use mechanized equipment. At the same time, imperfect norms and standards or the lack of effective implementation and supervision have led to the emergence of problems such as construction industry safety risks, which also affect the promotion and application of mechanization and restrict the development of the construction industry toward intelligence, informatization, and industrialization. Other indicators fluctuated within the range, with no clear trend of change.

Table 4. The degree of obstacles in the indicator layer of China's digital intelligence-enabled high-quality development of the construction industry, 2012-2021.

Guideline layer	Basic conditions of empowerment								Level of empowerment target										Process of empowerment		
Tier 1 Indicators	Digital environment				Innovation Driver				Effectiveness of the construction industry		Greenness of the construction industry		Shareability of the construction industry		Harmonization of the construction industry		Openness of the construction industry		Optimization of resource allocation		Upgrading of industrial structure
Year	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21
2012	6.48	4.00	5.52	2.89	2.45	4.71	2.99	4.12	4.28	7.59	4.02	8.82	6.61	3.37	2.51	3.13	3.25	4.35	7.39	8.10	3.43
2013	6.64	4.05	5.41	2.98	2.53	4.89	3.01	4.22	4.21	7.72	4.28	7.05	6.55	3.35	2.68	3.30	3.53	4.55	7.44	8.11	3.52
2014	6.62	3.93	5.18	2.96	2.53	4.88	2.87	4.22	4.46	7.70	3.86	8.10	6.29	3.24	3.00	3.33	3.52	4.46	7.28	8.10	3.49
2015	6.38	3.92	5.45	2.98	2.56	4.86	3.46	4.31	4.49	7.77	4.05	6.71	6.15	3.21	3.07	3.40	3.50	4.63	7.20	8.40	3.47
2016	6.20	3.83	5.30	2.98	2.57	4.87	3.51	4.33	4.43	7.86	4.04	7.33	5.96	3.13	3.10	3.43	3.57	4.61	7.06	8.48	3.41
2017	5.95	3.73	4.99	2.96	2.58	4.95	3.59	4.38	4.37	7.85	3.83	7.72	5.91	3.06	3.17	3.43	3.82	4.70	7.04	8.55	3.40
2018	5.65	3.65	4.47	3.07	2.51	5.04	3.64	4.37	4.23	7.83	3.75	8.60	5.94	2.91	3.31	3.46	3.89	4.67	6.93	8.66	3.41
2019	5.47	3.55	4.47	3.02	2.53	5.13	3.66	4.41	3.94	7.90	3.60	9.11	5.75	2.78	3.33	3.47	3.99	4.78	6.90	8.78	3.42
2020	5.43	3.47	4.64	3.09	2.38	5.25	3.75	4.49	3.70	8.17	3.47	9.07	5.47	2.69	3.39	3.52	4.17	4.74	6.70	8.92	3.50
2021	5.17	3.44	4.53	3.14	2.17	5.25	3.91	4.48	3.07	8.39	3.38	9.58	5.11	2.51	3.51	3.49	4.24	4.85	6.95	9.15	3.67
Average	6.00	3.76	5.00	3.01	2.48	4.98	3.44	4.33	4.12	7.88	3.83	8.21	5.97	3.03	3.11	3.40	3.75	4.63	7.09	8.52	3.47

5. Conclusion

Digital intellectualization is the power source to achieve high-quality development, which can help the transformation and upgrading of industrial structures and realize the value reengineering of the construction industry. Accordingly, this paper analyzes the intrinsic mechanism of digital intellectualization that empowers the high-quality development of the construction industry and lays the theoretical foundation for the scientific construction industry of the level evaluation index system. Then, based on the panel data of 31 provinces in China from 2012 to 2021, the evaluation index system for the high-quality development of digital intelligence-empowered construction industry is constructed, including three dimensions of the basic conditions of empowerment, the level of empowerment target, and the process of empowerment, and uses entropy value method and obstacle degree model to examine the level of high-quality development of the construction industry empowered by digital intelligence and the obstacle factors. The following conclusions are drawn:

At the national level, from 2012 to 2021, the level of China's high-quality development of the digital intelligence-empowered construction industry has shown a year-on-year increasing trend, with a good development trend, and an overall pattern of high level in the east and low level in the west. At the regional level, the level of South China, North China, and East China are located in the first echelon, Central China and Southwest China are located in the second echelon, and Northeast China and Northwest China are located in the third echelon, with a large difference in the level of development between the regions. At the provincial level, Beijing, Shanghai, and Guangdong are always at high levels, and the level of each province is generally on the rise; by 2021, more than half of the provinces in the country will be at high levels, and there will be no low-level regions.

At the guideline level, the key obstacles to China's high-quality development of the digital intelligence-empowered construction industry are the level of empowerment target and the basic conditions of empowerment, and the obstacle degree of each guideline layer remains stable from 2012 to 2021. On the indicator layer, input indicators, output indicators, industrial benefits, broadband penetration, and sharing of facilities are the key obstacle factors for the high-quality development of the construction industry empowered by digital intelligence. On the change of obstacle degree of each indicator from 2012-2021, the obstacle degree of broadband penetration, computer ownership, and Cell phone usage is on a downward trend, and the obstacle degree of resource utilization, harmonization of scales, and mechanization in the construction industry shows an upward trend.

Based on the above conclusions, the following recommendations are made:

First, strengthen intra- and extra-regional ties and cooperation, and promote synergistic development in all regions. Increase the construction industry of digital intelligence infrastructure in the northeast and northwest regions, and guide the inflow of technology, talent, and capital to regions with a lower level of development of digital intelligence and construction industry industry through financial investment and policy promulgation. Give full play to the leading and driving role of regions with a higher level of high-quality development of the construction industry empowered by digital intelligence to the surrounding areas, promote the sharing of digital intelligence infrastructure and resources in the surrounding areas, and realize the development mechanism of regional synergistic development and value co-creation.

Second, vigorously promote the digital-intelligent transformation of the construction industry, increase technological investment in the construction industry, encourage government departments, industry associations, enterprises, and other empowerment targets to support the development of high-quality development of construction industry empowered by digital intelligence, and provide a favorable policy environment and resource protection. Accelerate the absorption and proliferation of digital intelligence industry technology, realize the transformation of scientific and technological achievements, promote the transformation of digital intelligence in the whole cycle of the project, and enhance the effect of the digital intelligence-enabled construction industry's high-quality development. Strengthen the construction industry of digital intelligence infrastructure, improve the efficiency of resource utilization, and reduce operating costs. It will build a platform for resource sharing, standardized construction industry, and supervision, make full use of new-generation information technologies such as big data, the Internet of Things, BIM, GIS, and CIM, and encourage all relevant parties in the construction industry to share facilities and resources.

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