Development and Evolution of Digital Construction Management adoption in China's Construction Industry

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Abstract. The development of digital construction management is an important initiative to promote the digital transformation of the construction industry. But the attention to the regional difference in the development level of digital construction management in China from the industrial level is still relatively scarce. In this paper, the combination assignment method, Dagum Gini coefficient and Kernel density estimation methods are used to explore the regional difference and its dynamic evolution trend of China's digital construction management development level. The study finds that: the overall development level in China's construction industry is on the rise, but it is still at a relatively low level. The overall Gini coefficient increases, which is mainly due to uneven development between regions. There are large difference between the eastern region and the other three regions. The interregional Gini coefficient for the central-northeast and central-western regions are all growing at a higher rate.

Keywords: digital; construction management; regional differences; Dagum Gini coefficient; Kernel density estimation

1 Introduction

Industrial digitization, as an important part of the digital economy, has a profound impact on the digital transformation of traditional industries. It has become a new engine for building a modernized industrial system with high added value(Zhao and Zhao 2024). Three aspects of industrial digitization are mainly focused in current research. The first one is the coupled coordination(Liu and Yu 2021), two-way linkage(Li et al. 2021) and synergistic path(Du 2021) between industrial digitization and digital industrialization. The second one is industrial digitization itself. For example, Xiao Xu et al.(Xiao and Qi 2019) analyzed the value dimension and theoretical logic of industrial digitization. Jin Fei et al.(Jin 2023) explored the characteristics of multidimensional innovation of industrial digitization. The third one is the external effect of industrial digitization as an important driver for high-quality economic development. Scholars have researched on promoting the integration of digital and real economy in terms of high-quality development(Yang 2023), green economy efficiency enhancement(Liu et al. 2022), and industrial structure upgrading(Chen and Yang 2021).

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The construction industry is one of the important implementation areas of industrial digitization. But its transformational pace is still relatively backward, with problems like sloppy management methods (Li and Liu 2019) and low level of informatization(Hong et al. 2022). Deep-rooted conflict between the above problems and the increasing projects volume, technical difficulties and society's requirements for the environment, urgently requires the promotion of industrial digitization, which empowers the industrial transformation(Huang and Xiao 2022). Due to the complexity and danger of construction project, digital construction management has been the important grasp of the digital transformation. Scholars at home and abroad have focused on digital construction management in the fields of building information modeling (BIM) and digital twin, Internet of Things (IoT), blockchain and artificial intelligence (AI). There are strong advantages of BIM technology in the entity data and information management(Li et al. 2018), but there are problems in the current application of BIM such as low integration efficiency and disconnected information transfer chain(Lu et al. 2021). At the same time, real-time prediction, optimization, control and improved decision-making are accomplished by digital twin technology(Rasheed et al. 2020), which has received much attention(Opoku et al. 2021). Blockchain and IoT, increasingly applied to solve the problems of lack of collaboration, poor supervision, and information occlusion in construction management(Li et al. 2019), are also the focus in related fields. Automatic identification of worker behavior(Fang et al. 2018), construction prediction using neural network models(Wang et al. 2021) and effective management of construction resources(Jiang et al. 2023) of AI technology have also become hotspots.

For the problem of inadequate integration and uneven development between digital technology and construction management, scholars actively explore effective solutions. They mostly focus on the project level, with technology development and improvement as the breakthrough to promote digitization of construction management. However, current digital construction management in China is confined to single project or region, with weak migratory and universal applicability. Compatible sharing of information at the industrial level is the key to efficient collaborative development, but it is still difficult to realize cross-project, cross-organizational and cross-regional circulation of management and technology innovation. At the same time, higher requirement to strengthen the overall planning of industrial development has been put forward by the trend of construction industrialization and information synergization. Construction management should not only be digitized, but also digitized with the efficient circulation of data, balanced development between regions, and the digitalization of industrial system layout. The problem is difficult to be solved only by technological innovation at the project level. It is urgent to think about the solution from the perspective of the whole industry. However, there is a large gap in the research launched from the industrial level. Whether digital construction management has landed at the industrial level and whether there is difference in the industrial development level, attention to these issues is void in the existing research. Therefore, the regional difference and its evolution trend of the development level of digital construction management are studied from the industrial level in this paper, to promote the integrated and balanced development of digital construction management.

The possible contributions of this paper are: first, the development status of digital construction management is explored from the industrial level, which make up the lack of industry-wide perspective in the existing research, and provide new ideas for promoting the development of digital construction management. Secondly, Dagum Gini coefficient decomposition method is used to explore the difference of digital construction management in the whole country and different regions, so as to provide a path guide for the balanced development of digital construction management. Thirdly, Kernel density estimation method is used to measure the dynamic evolution trend of the development level, summarize the existing development experience, and provide historical data to support the continuous development of digital construction management.

2 Methodology and Indicator System

2.1 Research Methods

Combined Weightings. In order to reduce the influence caused by the objective weighting method and the subjective weighting method, the combination of subjective and objective weighting method is adopted to assign the indicators. The equalization assignment method is adopted as the subjective one, with the weight set as ω_1. The entropy weight method is adopted as the objective one, with the weight set as ω_2. The final weight of the indicator is calculated as $\omega = \frac{\omega_1}{\omega_2}$. Referring to Chen Jinghua et al.(Chen et al. 2020), the standardized indicator values Z_j and the final weight ω_j are calculated according to equation (1) to get the comprehensive index of digital construction management development level in the province i.

$$I = \frac{\sum_{i=1}^{n} Z_j \omega_j}{\sum_{i=1}^{n} \omega_j} \tag{1}$$

Dagum Gini Coefficient Decomposition. The Gini coefficient decomposition method proposed by Dagum(Dagum 1997) is an important method to measure the regional difference. The relative difference of digital construction management development in different regions is reflected by decomposing the Gini coefficient into three parts: intra-regional difference contribution, inter-regional difference contribution, and hyper-variable density contribution. Dagum Gini coefficient is based on the Lorentz curve, and its measurement to the inequality state is widely recognized. If a quantitative relationship of digital construction management development level in different regions can be established, it will be possible to explore the regional difference and promote balanced development.

Kernel Density Estimation. Only the sample data is used as a reference in Kernel density estimation to explore the characteristics of the sample location distribution and the trend of change, which can avoid the discrepancy between the actual and measured value caused by the preset function form. So the method is weakly dependent on the model and has strong stability, and often used to explore the spatial non-equilibrium of the data. In addition, the dynamic evolution of the development level is visualized by the three-dimensional image with smooth curves, which is ideal for analysis. $f(x)$ is assumed to be the density function of the development level index x, and is calculated with a Gaussian density kernel function.

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i-\bar{x}}{h}\right) \tag{2}$$

$$K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \tag{3}$$

In Eqs. (2) to (3), N is the number of provinces, and X_i denotes independent and identically distributed observations. $\bar{x}$ is the mean value. $K(\cdot)$ represents the Kernel density. h represents the window width.

2.2 Composite Indicator System and Data Sources

Based on existing research experience (Zhang and Xue 2023, Yang 2022), a digital construction management evaluation index system with four first-level indicators is constructed. Digital infrastructure is taken as the foundation, digital effect as the core objective, digital input as the driving force, and digital application as the engine in the system. The second-level indicators with their weights are shown in Table 1 below.

Digital input is the driving force of digital construction management, and the autonomous R&D provides strong support for digital development. The strength of digital investment in the construction industry is reflected from three perspectives. Enterprise R&D expenses(Yang 2022) is used to measure the investment in R&D expenses of construction companies. Total internal expenditure of R&D funds(Liao and Yang 2021) and R&D personnel equivalent(Yang 2022) are used to measure the investment level of R&D funding and talent. The digital innovation ability in a region can be reflected by the above indexes.

Digital application refers to the specific application of digital technology in various levels or multiple scenarios. It is the key link between the R&D and production. On the one hand, R&D promotes the production, on the other hand, production constantly puts forward new demands feedback. At this level, enterprise innovation rate(Liu and Fu 2022) and number of patent applications(Liu and Fu 2022), visual representations of the autonomous R&D achievements and their productions, are used to measure the application of digital technology in the construction industry.

Digital infrastructure is the cornerstone to the development of digital construction management(Yang 2022). The promotion of digital construction management is represented by the increase number of equipment, which is closely related to the advance of technical equipment rate, representing the application rate of digital technology too. Therefore, the digital machinery and equipment(Zheng and Cai 2014) and digital technical equipment rate(Lu et al. 2015) are used to measure the development level of digital infrastructure.

Digital effect refers to the effectiveness brought by digital construction management, which mainly includes social effect and economic effect(Zhang and Xue 2023). The application of digital technology improves the energy efficiency, so that energy consumption(Yang 2017) is used to measure the social effect. In addition, the improving degree of economic efficiency is reflected by labor productivity(Liu et al. 2016).

Table 1. Digital construction management evaluation index system

First-level indicators	Second-level indicators	Weight	Indicator attribute
Digital input	Enterprise digital R&D expenses	0.12	+
	Total internal expenditure of R&D funds	0.18	+
	R&D personnel in full-time equivalents	0.16	+
Digital application	Enterprise innovation rate	0.17	+
	Number of patent applications	0.20	+
Digital infrastructure	Total number of digital construction machinery and equipment	0.09	+
	Digital technical equipment rate	0.05	+
Digital effect	Total energy consumption	0.01	-
	Labor productivity	0.02	+

The research data are selected from 31 provinces in China other than Hong Kong, Macao and Taiwan, spanning from 2014 to 2022. The data are obtained from China Statistical Yearbook, China Statistical Yearbook on Construction, China Statistical Yearbook on Science and Technology, and the National Bureau of Statistics (NBS).

3 Empirical Results

3.1 Measuring the Development Level of Digital Construction Management

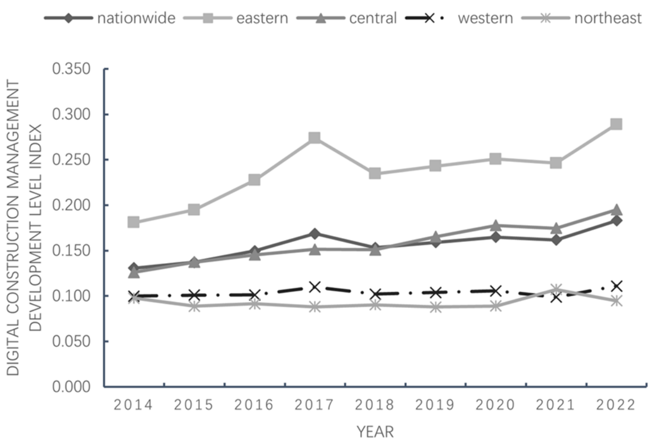

Fig. 1. Trend of the composite index of the development level

The trend of the development level in the whole country as well as in the four regions are shown in Figure 1. From a general perspective, the development level in the whole country and regions show overall upward fluctuating trends. However, the digital development level of each region is in the lower-middle level. By region, firstly, the development level in the eastern region is the highest and its growth rate is the largest. Digital construction management in the eastern region is not only better developed, but also ranks first in terms of the growth speed. Secondly, the development level in the central region is closest to the national average, while its growth rate is greater. Lastly, the development level is relatively close to each other in the northeast and the western regions, both lower than the national average.

3.2 Regional Difference in the Development Level of Digital Construction Management

Overall and Intra-regional Difference. As shown in Figure 2, the overall Gini coefficient of the development level shows a fluctuating upward trend with a total growth rate of 62%. The Gini coefficient of the regions, except for the Northeast region, are all on the rise. The eastern region is the largest and fluctuates the most, with a growth rate of 60.34%. The central and western regions are relatively close to each other. The fluctuation in the central region is relatively smooth, with a growth rate of 5.17%, while 75.51% in the western region. In addition, the northeast region is at the lowest level, with decline rate 40.68%. The above results show that the regional difference in nationwide and in the eastern, central and western regions is expanding, and in the northeast region is shrinking. The regional difference in the eastern region is always in the first place, the central and western regions in the middle, and the northeast region in the last place.

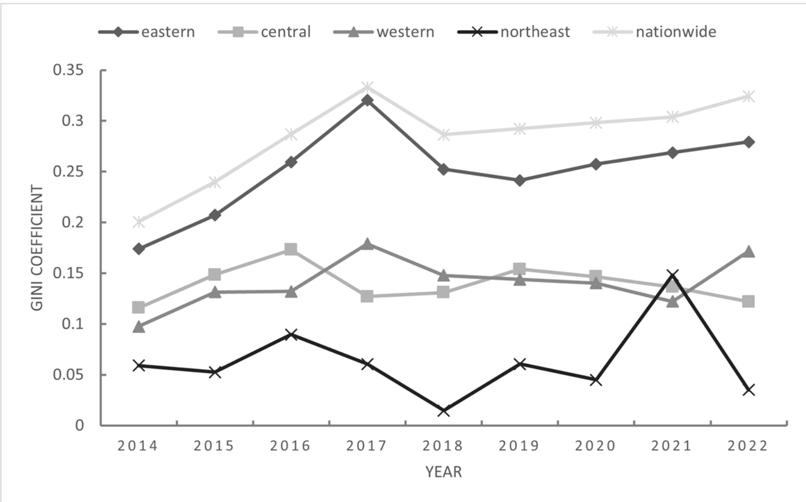

Fig. 2. Overall and regional Gini coefficient and its evolution trend

Inter-regional Difference. The inter-regional difference and its development trend between the four regions are shown in Figure 3, where there are fluctuating upward trends can be seen. The east-northeast has the largest inter-regional Gini coefficient and a large fluctuation, with a growth rate of 68.11%. The growth rate at 151.09% of the central-northeast is the largest one, while that at 97.97% of the central-west as the second. The west-northeast is at the lowest and fluctuates gently, with a growth rate of 55.42%. Which is indicated from the results is that the inter-regional difference of the development level has been expanding. The inter-regional difference between the eastern region and the western, the northeast regions are the largest, in line with the conclusion that the development index of the eastern region is much higher. The development difference between the central region and the western, northeast regions are relatively small, but the fastest growth rate.

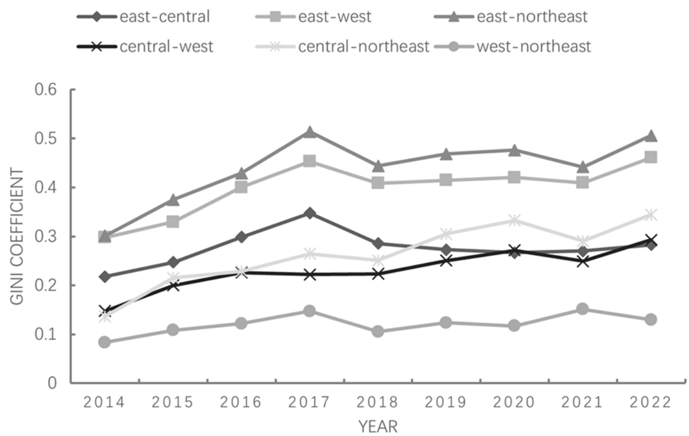

Fig. 3. Inter-regional Gini coefficients and evolution trend

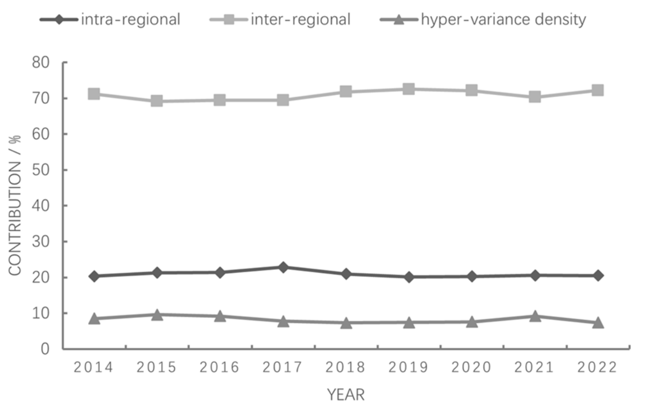

Fig. 4. Sources and contributions of regional differences

Sources and Contributions of Difference. The contribution rate of regional difference of the development level is shown in Figure 4. The contribution rate of the three kinds of difference trends gently. The contribution rate of inter-regional difference is 70.89% in average, indicating that it is the main source of the development difference. The average contribution of intra-regional difference and hyper-variable densities is 20.91% and 8.21%, respectively, without significant impacts on the difference. Therefore, reducing the development difference between regions is crucial to solve the problem of difference of the development level.

3.3 Dynamic Evolution of the Development Level of Digital Construction Management

In order to further present the dynamic distribution and evolution of difference of the development level, the location, shape and ductility of the development level distribution are analyzed by means of Kernel density estimation. As shown in Figure 5 is the evolution trend of the nationwide development level. From the position of the wave peaks, the position of the main peak shifted to the right, indicating that the development level improves. However, the height of the main peak declines and the width increases, indicating that the regional development imbalance increases. In addition, there are side peaks and the gap between the main side peaks widens between 2014 and 2019, indicating that there is bipolar or even multipolar polarization with the gap increasing.

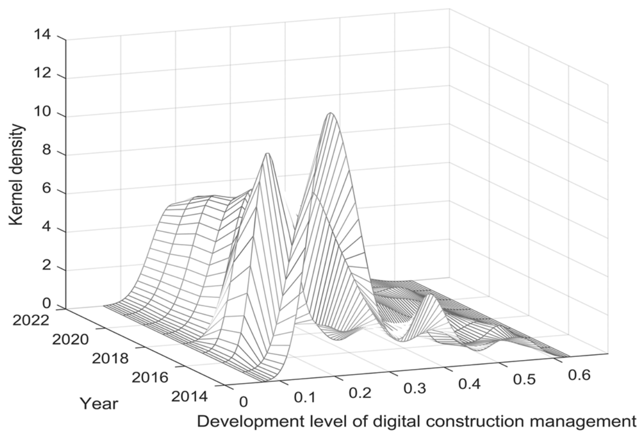

Fig. 5. Dynamic distribution of digital construction management development index

The dynamic distribution of the development level in the four regions is shown in Figure 6. In Figure 6(a), the main peak position in the eastern region moves to the right, indicating that the development level is in an upward trend. The main peak is gradually lower and wider, indicating that the unevenness of the development level increases. It can be seen that the development level in the central region increases and the regional difference increases in Figure 6(b). Side peaks exist until 2019, indicating the polarization phenomenon is obvious. In Figure 6(c), the development level and its imbalance in the western region both increase. In Figure 6(d), the polarization of development level in the northeast region increases year by year.

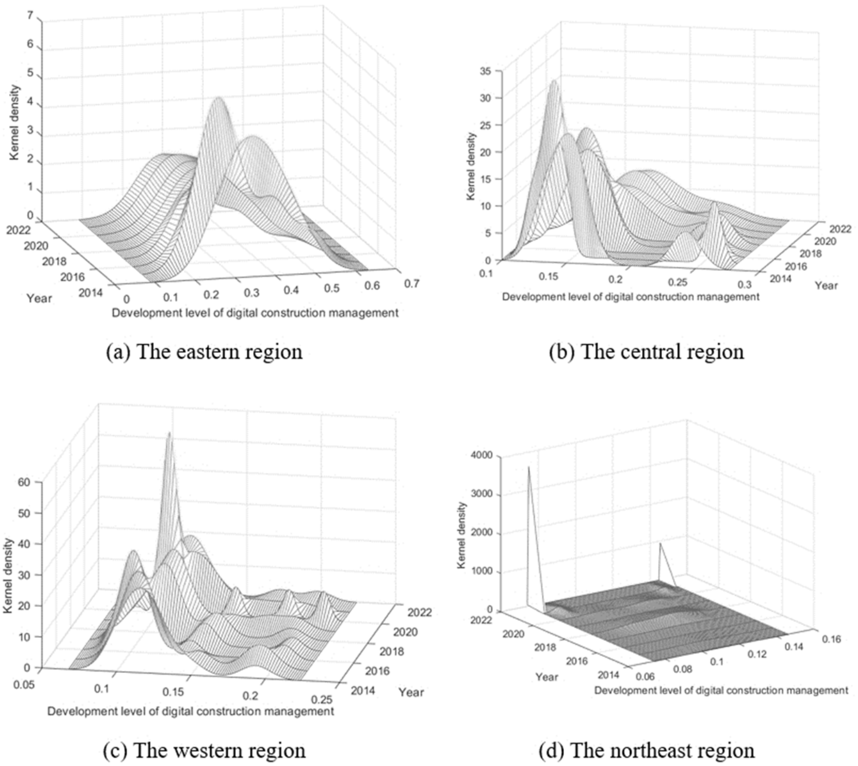

Fig. 6. Distribution of digital construction management development index in four regions

4 Conclusions

The development level of digital construction management in China's construction industry is measured from the industrial level. Dagum Gini coefficient decomposition method is used to decompose the development difference across the country and the four regions. And Kernel density estimation is used to analyze the spatio-temporal dynamic distribution and evolution trend of the development level. The empirical results show that:

(1) The development level has risen in waves. However, most regions are still at a low level and pace of development. There is large difference between regions. The development level and pace in the eastern region is ahead of the whole country and other regions. The northeast region is the only one region with negative growth. Motivating

industrial transformation and promoting quality and efficiency in digital development remain key points.

(2) The development level of regional difference shows an expanding trend. The largest intra-difference is in the eastern region. Excessive difference may pose risk and obstacle in terms of resource allocation and development activism. The smallest intra-regional difference is in the northeast region, which is the only region with a downward trend. However, this is not necessarily a good thing in the context of its development level, which implied a lack of development driver and regional “bellwether”.

(3) The development difference mainly comes from inter-regional difference. The inter-regional difference between the eastern region and the western, northeast regions are the largest. The gap of development level between the central region and the western, the northeast regions are pulling away at a relatively high speed. Therefore, narrowing the inter-regional difference is the key to solving development imbalance problem.

(4) In addition to the problem of increasing regional development imbalance in the nationwide and in the eastern, central and western regions, the phenomenon of polarization exists in the western and northeast regions. The emergence of the polarization phenomenon indicates that the unevenness of development has been serious. The government should give full play to the means of macro-control, to escort the digital transformation of construction management.

Based on the above conclusions, the following suggestions are made to narrow the difference in development level and promote the balanced and synergistic development of digital construction management from an industry-wide perspective:

(1) Innovation should be encouraged so as to drive digital construction management to speed up, increase efficiency and put into production. Digital construction management can't be used as the enterprise's “exhibition board” and the government's “face project”, but really implement in the project. The government should encourage enterprises to innovate independently, provide a clear direction of development and improve industrial standards. The eastern region should take its own advantage to open up new development space. The other regions should formulate differentiated and diversified development strategies, to broaden the development path actively.

(2) Information should be shared to narrow the development gap within regions. On the one hand, the industrial exchange and sharing platform should be built in the eastern region, and cooperation between enterprises with higher and lower digitization degree is also encouraged. On the other hand, the hardware conditions in the central, western and northeast regions should be optimized, to improve the information flow channels between government, industry, academia, research and application.

(3) Cross-regional exchange and cooperation should be encouraged to promote synergistic industrial development. Effective regional coordination and linkage measure must be taken at the national level to reduce inter-regional difference. Cross-regional cooperation mechanism should be established to optimize resource allocation and improve experience-sharing and assistance mechanisms. While maintaining its first-mover advantage, eastern region should promote the spatial spillover of innovation achievements and the gradient transfer of technology. The central, western and

northeast regions should recognize the shortcomings of their own development, and build on strengths and weakness through cooperation and exchange.

(4) Comprehensive measures should be taken to reduce the risk of polarization. Support for small and medium-sized enterprises needs to be strengthened in order to promote the resources distribution within the industry. Diversification of construction enterprises should be encouraged so that they can expand their business fields and reduce their dependence on a single market. A system for monitoring and evaluating the development level should be established to ensure the healthy development of the industry.

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