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Policy analysis of smart construction pilot cities policies in China based on policy tools

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Abstract: In response to the challenges posed by the traditional construction industry, the importance of smart construction in driving the digital transformation of this sector has been widely acknowledged. Many countries have introduced supportive policies to foster the growth of smart construction. However, there is no one-size-fits-all approach to implementing smart construction. Therefore, this paper aims to assess the smart construction policies implemented by 24 pilot cities in China and identify relevant policy tools. Our analysis reveals that pilot cities often adopt supply-type and environment-type policy tools, but there is a growing need for demand-type policies. These findings contribute to the existing body of research on policy evaluation in the field of smart construction. Furthermore, we offer concrete recommendations to policymakers for formulating more effective and targeted policies and strategies to further the development of smart construction.

Keywords: smart construction; pilot cities; policy evaluation; PMC-Index model

1. Introduction

The world is experiencing the fourth industrial revolution and the digital transformation, which is commonly referred as Industry 4.0 [1]. Under the Industry 4.0 environment, digital transformation of business processes deploying smarter machines and devices may offer numerous advantages such as productivity, resource efficiency and waste reduction [2]. Although global production value of construction industry achieves $12 trillion, the whole industry has been among the slowest to digitize and innovate [3]. Engineering and construction companies suffer from low margins and productivity, high accident rate, and poor environmental performance. Hence, it is pressing for the digital transformation of construction industry by adopting automation and information technologies [4]. These technologies facilitate the development of smart construction, which is characterized as high degree of digitalization, information and industrialization of the construction industry [5].

Considering the advantages of smart construction, previous studies have been conducted to review the literature on application of different technologies in smart construction field. Liu *et al.* [6] conducted a review on smart construction sites and focused on authors, countries and research interests, but not specific technologies. Ahn *et al.* [5] identified nine required technologies in smart construction and evaluated applicability of technologies and pointed out research direction for each required technology. Yevu *et al.* [7] presented a mixed-method review on digital twin application for prefabrication supply chain and demonstrated the effectiveness of smart technologies such as radio frequency identification (RFID), global positioning system (GPS), laser scanners and sensors. Xu *et al.* [8] conducted a holistic view of on-site application of smart technologies for health, safety and environment. Wu *et al.* [9] reviewed the application of natural language processing for understanding unstructured data in construction industry and explored the application trends of natural language processing for smart construction. However, the investigation on smart construction related policies is still lacking. There are limited quantitative evaluation on smart construction policies.

Many countries such as the United States, the United Kingdom, Japan and China have issued policies and regulations in order to promote the development of smart construction [10]. The Chinese government has published several national policies to support the development of smart construction. From 2011, China's Ministry of Housing and Urban-Rural Development had issued the outline for development of informatization in construction industry and promote the application of BIM in construction projects [11]. In the period of 13th five-year plan, integration of BIM, big data, cloud computing, internet of things and information technologies were encouraged to be adopted for digital transformation of construction industry [12]. In 2020, 13 governmental ministries in China cooperatively issued a guideline to promote the integration of smart construction and construction industrialization. This guideline emphasized the application of smart construction in whole life cycle of construction projects and set the objective to build the world-class smart construction industry. In 2022, there are totally 24 pilot cities to develop smart construction which were announced by the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MHURD). These pilot cities have published city-level implementation plan on smart construction and relevant standards. In 2023, a summary of a typical case application of smart construction was released by MHURD. It was promoted nationwide, giving great publicity to smart construction technology.

In fact, there is no common paradigm for developing smart construction. Different pilot cities in China choose different paths to promote smart construction. However, there is no systematic and comprehensive comparative investigation on practices of smart construction pilot cities. Therefore, this paper endeavors to analyze the future direction of smart construction from the policies that have been enacted in 24 pilot cities. By classifying and counting policy tools, this paper supports the quantitative evaluation of smart construction policy development of 24 pilot cities. The results of this study can contribute to comparing supportive policies among different smart construction pilot cities and enabling policymakers to address pressing issues strategically with different resource allocation.

2. Literature review

The application of smart construction technologies makes the construction processes more efficient and safer. It provides beneficial services and resources for every stage of the construction project life cycle, including project planning, management, prefabrication manufacture and building process [5,13]. A widespread investigation has emphasized on the benefits of smart construction technologies and also critical success factors [13]. Smart construction helps increase the productivity of construction sites and machinery [14], decrease construction wastes and greenhouse gases [15], improve working conditions [5] and ensure on-site safety [16]. The major challenges to apply smart construction technologies might be costs, data security and transformation of business operation [17,18].

A prevalent article examined only one or few of smart construction technologies in a given project. Daryan and Palizi [19] proposed a program to determine the collapse and failure mechanism of steel-braced frames based on a genetic algorithm. Zhang *et al.* [20] developed a precise rebar inspection system using a video acquisition device that automatically acquires data. Atherinis *et al.* [21] developed a smart system for falsework inspection based on radio frequency identification and visualization BIM. Hamledari *et al.* [22] utilized the BIM models as a management and storage system of inspection data. Chen *et al.* [23] presented an automated facility inspection framework for inspection work using construction robots. As a widely used technology, 3D scan planning was adopted by Gao *et al.* [24] to collect data of construction site and reconstruct the space through the integration of an unmanned ground vehicle and UAV.

In order to clarify one technology application in construction industry, previous review studies about big data, data mining, blockchain, robotics, IoT and so many have been conducted. Zheng *et al.* [14] focused on intelligent construction machinery which realized few-manned or unattended construction sites. Big data collection and analytics have been reviewed by Li *et al.* [13] and pointed out the advantages and relevant unresolved difficulties. Yan *et al.* [25] identified major application fields of data mining technologies and reviewed research interests. Sun *et al.* [26] pointed out critical success factors for implementing blockchain technology in construction industry by systematic reviews on related studies. Baduge *et al.* [27] presented a review of artificial intelligence, machine learning and deep learning applications for the building lifecycle, from conceptual until operation and maintenance stage. Pal and Hsieh [28] conducted a review of deep learning based visual data analytics and its application on smart construction management. A comprehensive review of existing literature on human motion prediction had been presented by Xia *et al.* [29] and identified potential application in construction industry and advancements for human-robot interactions in future. For specific tunnel construction field, Li *et al.* [30] conducted a review on digital twin application in tunnel construction and shed lights on limitations of existing researches.

In fact, policy is an important driver of smart construction development. However, current researches on smart construction are deficient in terms of policy. Some scholars have already conducted evaluation on the policy about digital transformation in the construction industry. The integration of a latent Dirichlet allocation theme model and a Policy Modeling Consistency Index (PMC-Index) model was used to comprehensively analyze over 80 policies between 2017 and 2022 in order to evaluate digital transformation in the construction industry in China [31]. Some other scholars have assessed the policies of the smart city construction. The policy of building smart cities from the perspective of innovation was studied, and it was found that the impact of building smart cities on urban innovation varied from region to region [32]. A multi-period difference-in-difference model was proposed for empirical analysis to assess the impact of smart city pilot policy on carbon productivity [33].

Pilot cities are widely used by the central government of China in order to carry out the national strategies in different cities and regions. Normally, pilot cities implement national policies by combing local unique features such as fiscal resources, industries and population. The evaluation of smart city construction efficiency in 37 pilot cities was conducted by Mao *et al.* [34] by using multivariate data. A comparative evaluation of smart cities policy and sense of gain was presented by Yu *et al.* [35] by using AHP-EWM-TOPSIS method. The results were indicated that different experiences of smart cities policies among different pilot cities. In order to develop smart construction, 24 pilot cities have been identified by the MHURD in 2022. The policies published by smart construction pilot cities are varying in smart construction technologies, demonstration projects and enterprises. In order to compare policies among different smart construction pilot cities, policy texts are analyzed and policy tools are classified and counted to quantitatively evaluate supporting policies. It is expected to address existing gap in policy evaluation of smart construction and provide valuable implication for policymakers to promote the development of smart construction.

3. Research designs

3.1. Selection of 24 pilot cities in China

In May 2022, MHURD issued a notice calling for the selection of Chinese cities to develop smart construction [36]. The list of pilot cities was announced by MHURD in August 2022 after voluntary declaration by cities, review and recommendation by provincial housing and urban-rural development authorities, and evaluation by experts [37]. The 24 selected pilot cities for smart construction feature a sound industrial foundation, high government motivation, and a strong ability to lead and drive. These cities are representative of smart construction. Some Yangtze River Delta cities have a solid foundation for assembly construction, such as Hefei. Some cities, such as Guangzhou and Chongqing, benefit from rich industrial clusters and have advantages in construction robotics and intelligent equipment research and development. Some other cities such as Wuhan and Nanjing have abundant university resources. Therefore, the selection of 24 pilot cities as research objects serves to guide the development of intelligent construction effectively.

3.2. Data sources and research samples

In this paper, we use the year 2022 as the starting year to systematically and comprehensively collect policy texts on smart construction in 24 pilot cities. The official websites of the local Housing and Urban-Rural Development Bureaus in China were used to search for relevant policy documents. We eliminated documents such as letters, notices and other documents that had no substantive contents. Through the above methods, 33 governmental documents were collected. Among the 33 documents, there are a total of 24 city-level implementation plan on smart construction and 9 relevant local policies including evaluation standards on smart construction demonstration projects and enterprises, guidelines on construction industrial internet platform.

3.3. Classification of policy tools

Policy goals and policy tools mentioned by smart construction pilot cities were firstly analyzed and classified into three categories: supply-type, demand-type and environment-type categories. The frequencies of different categories and sub-categories were summarized. The classification of policy tools was proposed by Rothwell and Zegveld [38] and commonly used in previous policy evaluation studies [39]. Supply-type policy tools promote the development of smart construction industry from the aspect of fiscal subsidies, technical support, personnel training, land supply and industry cultivation. Demand-type policy tools refer to the government's efforts to lead the construction enterprise to respond positively to develop smart construction. Demand-based policy instruments mainly emphasize on demonstration project construction, government procurement, promotion, tendering and market incentives. The governmental policies foster market environment for developing smart construction through the macro deployment of regulations, standards and plans. Environment-type policy instruments thus include target planning, financial services, public services, tax benefits, standard system and R&D cooperation. Three categories of policy tools and their contents are shown in Table 1.

Table 1. Classification of three policy tools categories.

Categories	Sub-categories	Main contents
Supply-type	S1 Fiscal subsidies	Direct fiscal subsidies for the development of smart construction
	S2 Technical support	Support the application of technologies such as BIM, big data, IoT, and intelligent computing in the process of transformation of construction industry
	S3 Personnel training	Cultivate professionals and industrial workers through adjusting training system; Encourage local colleges to foster smart construction programs and establish training bases
	S4 Land supply	Guarantee land supply for smart construction application and give priority to land use and establish green channels to speed up approval
	S5 Industry cultivation	Develop smart construction industrial park and bases and foster industrial chain of smart construction

Table 1. *Cont.*

Categories	Sub-categories	Main contents
Demand-type	D1 Demonstration projects	Develop pilot demonstration projects for application of smart construction and promote the typical application scenario of smart construction
	D2 Government procurement	Provide public projects to directly apply smart construction and use government fund for purchase of products and applications related to smart construction
	D3 Tendering	Provide bonus points for the application of smart construction and pilot demonstration projects during tendering process
	D4 Market incentives	Allow presale of commercial residential buildings for application of smart construction
Environment-type	E1 Target planning	Set the short-term and long-term target for developing smart construction
	E2 Financial services	Provide financial services and support to construction projects related to the application of smart construction such as giving priority credit support and increasing loan amounts
	E3 Public services	Provide public services to construction projects related to the application of smart construction such as land planning, information service platform and industry data
	E4 Tax benefits	Relief taxes for enterprises engaging in the development of smart construction
	E5 Standard system	Establish standards related to smart construction and regulate the enterprises to apply smart construction technologies
	E6 R&D cooperation	Encourage cooperation among enterprises, universities and research institution in order to tackle key technologies of smart construction
	E7 Promotion	Promote smart construction through technical guidance, official announcement and so on

4. Results

Based on classification of policy instruments, 33 policies and regulations were analyzed and included in each policy category. The frequency of policy instruments in different policy categories were calculated. The use of policy instruments was imbalance with the frequency of supply-type, demand-type and environment-type category accounting for 38%, 23% and 39% respectively. Geographically, the use of three types of policy instruments varies, as shown in Figures 1–3. In general, supply-type and environment-type policy instruments were more frequently used than demand-type policies.

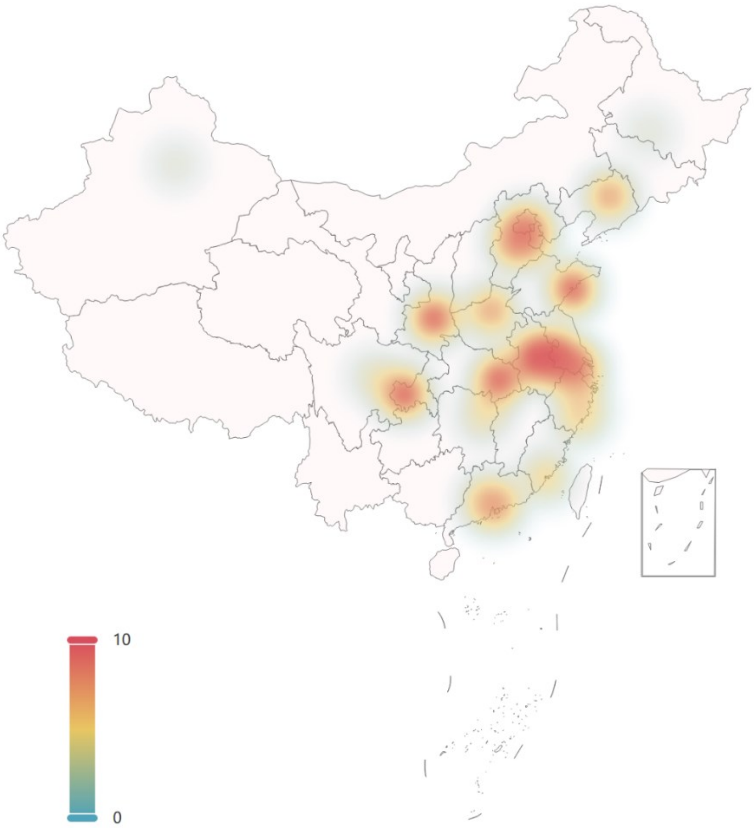

Figure 1. Geographic heatmap for supply-type policy tools.

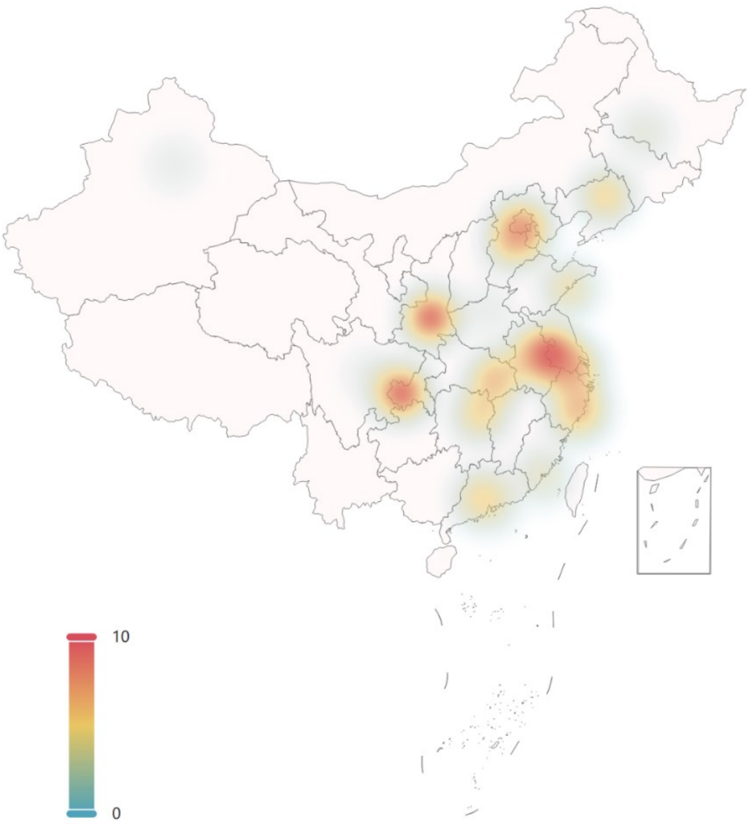

Figure 2. Geographic heatmap for demand-type policy tools.

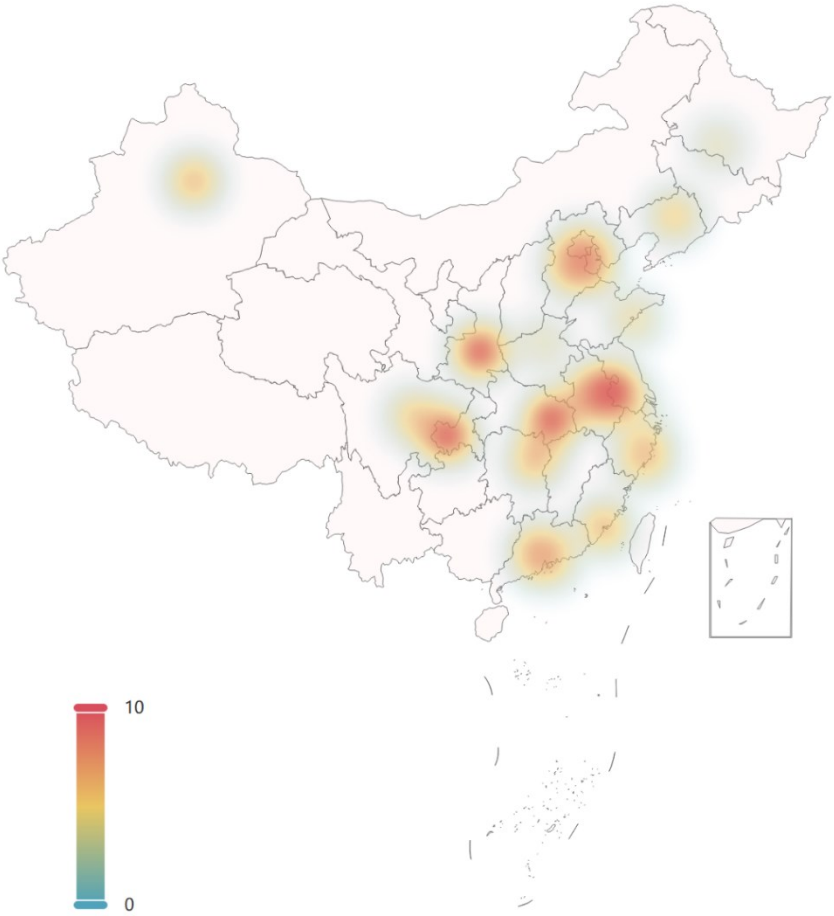

Figure 3. Geographic heatmap for environment-type policy tools.

Among supply-type policy category, smart construction cities paid attention on technical support, personnel training and industry cultivation, while fascial subsidies and land supply were less adopted (Table 2). Ten out of 24 cities provided fiscal subsidies for construction enterprises to adopt smart construction technologies, while only 6 cities (i.e., Taizhou, Hefei, Xiamen, Zhengzhou, Wuhan and Xi'an) promised the priority for land supply to support the application of smart construction.

Table 2. Frequency of supply-type policy tools.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
S1	0	0	1	0	0	2	0	1	0	1	0	0	1	0	0	1	2	0	0	1	0	1	1	0
S2	4	2	11	4	2	2	1	4	6	2	2	1	4	3	6	2	5	3	3	2	0	1	7	1
S3	2	1	4	2	3	2	1	3	1	1	1	1	2	1	2	1	2	1	1	1	0	1	2	1
S4	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	0	0	1	0
S5	2	1	3	1	2	2	1	1	1	0	1	1	3	1	2	3	1	1	1	3	0	1	2	1
Sum	8	4	19	7	7	8	3	9	8	4	4	4	11	6	10	8	11	5	5	7	0	4	13	3
Total frequency %	0.05	0.02	0.11	0.04	0.04	0.05	0.02	0.05	0.05	0.02	0.02	0.02	0.07	0.04	0.06	0.05	0.07	0.03	0.03	0.04	0.00	0.02	0.08	0.02

Note. C1: Beijing; C2: Tianjin; C3: Chongqing; C4: Xiong'an; C5: Baoding; C6: Shenyang; C7: Harbin; C8: Nanjing; C9: Suzhou; C10: Wenzhou; C11: Jiaxing; C12: Taizhou; C13: Hefei; C14: Xiamen; C15: Qingdao; C16: Zhengzhou; C17: Wuhan; C18: Changsha; C19: Guangzhou; C20: Shenzhen; C21: Foshan; C22: Chengdu; C23: Xi'an; C24: Urumqi.

Among 24 pilot cities, technical support was most popular policy tools. Taken Chongqing as an example, the city was devoted to build advanced and applicable technology system including digital design, industrial production, intelligent construction and informatization management. Encouraged smart construction technologies consisted of construction robots, wearable devices, internet of things, BIM application, AI technology, big data, structure inspection technology, software platform and so on.

As transformation of traditional construction industry, it is essential to foster qualified professionals and industry labors for smart construction. Therefore, pilot cities formulated policies to support multi-level personal training on the basis of local resources. The governments encouraged local universities to set up bachelor and associate bachelor program related to smart construction. Local enterprises were expected to collaborate with universities and colleges to build smart construction laboratories and exercitation bases. The application of smart construction technology was also included in the on-job training and continuing education assessment for existing construction professionals and workers.

Most of pilot cities determined to foster smart construction industry by developing industrial parks and supporting demonstration enterprises. The production value of smart construction was expected to achieve 300 billion, 100 billion and 20 billion in Chongqing, Tianjin and Baoding, respectively. Key development areas of smart construction were disparate for different pilot cities. Some cities such as Chongqing, Nanjing, Hefei and Xiamen paid attention on integration of smart construction and prefabricated construction. Several cities such as Beijing, Qingdao, Xiong'an and Zhengzhou emphasized the development of industrial internet platform. Construction robots were focused by Chongqing and Suzhou. In the implementation plans on smart construction of Suzhou, technological mature construction robots such as masonry robot, smoothing robot and spray painting robot were encouraged to be widely used in construction projects in order to improve efficiency and safety. Suzhou was also dedicated to research and develop light duty building machine to improve construction environment and ensure construction safety for high-rise building projects.

The use of supply-type policy instruments was imbalance among 24 smart construction pilot cities. Some cities such as Chongqing, Hefei, Wuhan, Zhengzhou and Xi'an have formulated specific policies to support the development of smart construction from fiscal subsidies, technology, personnel training, land supply and industry cultivation. However, implementation plans of several cities such as Foshan, Harbin and Urumqi only mentioned to support smart construction, but without clear smart technology application and specific measures on subsidies, training and industry cultivation objectives.

In terms of demand-type policy category, demonstration projects were the most important policy tools (Table 3). All pilot cities set goals about demonstration projects. The number of demonstration projects in Xiamen was set as 130, which was the highest among all pilot cities. Demonstration projects in Urumqi was only expected to be 8, which was least comparing with other cities. Some cities (e.g., Xi'an) put forward specific mega-infrastructure projects as smart construction demonstration projects. Smart materials, machines and devices as well as Engineering Procurement Construction (EPC) procurement were encouraged to be adopted in demonstration projects.

Table 3. Frequency of demand-type policy tools.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
D1	5	1	7	2	1	2	2	3	1	1	2	2	2	1	3	2	2	2	1	1	4	1	4	1
D2	1	0	3	1	1	1	0	1	1	1	1	2	0	0	0	0	1	1	0	0	0	0	4	0
D3	0	0	1	0	1	1	0	2	0	0	0	0	1	1	0	0	1	1	1	0	0	0	2	0
D4	0	0	2	0	0	0	0	4	0	0	0	1	0	1	0	0	1	1	0	0	0	0	1	0
Sum	6	1	13	3	3	4	2	10	2	2	3	5	3	3	3	2	5	5	2	1	4	1	11	1
Total frequency %	0.06	0.01	0.14	0.03	0.03	0.04	0.02	0.11	0.02	0.02	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.02	0.01	0.04	0.01	0.12	0.01

Note. C1: Beijing; C2: Tianjin; C3: Chongqing; C4: Xiong'an; C5: Baoding; C6: Shenyang; C7: Harbin; C8: Nanjing; C9: Suzhou; C10: Wenzhou; C11: Jiaxing; C12: Taizhou; C13: Hefei; C14: Xiamen; C15: Qingdao; C16: Zhengzhou; C17: Wuhan; C18: Changsha; C19: Guangzhou; C20: Shenzhen; C21: Foshan; C22: Chengdu; C23: Xi'an; C24: Urumqi.

Besides demonstration projects, most of cities also paid attention to promote demonstration enterprises in the fields of digital design, industrial production, prefabricated construction and smart operation. In order to boost application of smart construction, pilot cities such as Chongqing, Baoding, Taizhou and so on required municipal works, public buildings and indemnificatory housing to apply smart construction technologies during design and construction process. In Chongqing, new rail transit projects, residential buildings with the building area of more than 20,000 square meters and municipal infrastructure projects with budget over RMB 0.5 billion were required to adopt smart construction technologies. There were no less than 10 projects per year including highways, airports, reservoir projects and municipal maintenance projects to adopt construction technologies.

In order to induce construction enterprises adopting smart construction technologies, several pilot cities (e.g., Hefei, Chongqing, Wuhan, Guangzhou and so on) provided bonus points during the tendering process. If construction enterprises had experience on conducting demonstration projects of smart construction, they could get extra point when they participated in the bidding process. Besides tendering method, seven pilot cities such as Nanjing, Chongqing, Wuhan, Changsha, Taizhou, Qingdao and Xi’an allowed pre-sale of commercial residential buildings for application of smart construction. The pre-sale incentives were intended to stimulate the motivation of real estate developers in those cities.

Smart construction pilot cities paid attention on target planning and standard system among environment-type policy category. All cities set up their development goals in short-term (i.e., the year of 2025), and some cities laid down long-term goals in 2035. The development goals of smart construction involved multiple dimensions, including demonstration enterprises, demonstration projects, technologies, industrial parks, industrial chain, industrial internet platform, standards and application rate of smart construction. Pilot cities also laid emphasis on the development of standard systems (E5) for smart construction application with the count of 95 (Table 4). Due to lack of standards, it reached the consensus to develop local standards to smart construction application in design, precast component production, construction and operation stages.

Table 4. Frequency of environment-type policy tools.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
E1	1	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0
E2	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	0	1	0	1	1	0	0	1	0
E3	0	1	5	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0
E4	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	1	0	1	1	0	0	1	0
E5	3	4	9	3	3	5	2	8	1	1	2	3	5	4	4	3	7	6	2	2	1	4	7	6
E6	2	1	1	1	1	1	1	2	0	0	0	1	0	1	0	1	1	0	1	1	0	1	0	1
E7	2	1	3	1	2	2	1	2	3	1	1	1	2	1	2	0	2	1	1	1	0	1	1	1
Sum	8	7	18	5	7	8	5	15	4	4	3	7	9	8	7	4	12	8	7	6	1	7	11	8
Total frequency %	0.04	0.04	0.10	0.03	0.04	0.04	0.03	0.08	0.02	0.02	0.02	0.04	0.05	0.04	0.04	0.02	0.07	0.04	0.04	0.03	0.01	0.04	0.06	0.04

Note. C1: Beijing; C2: Tianjin; C3: Chongqing; C4: Xiong'an; C5: Baoding; C6: Shenyang; C7: Harbin; C8: Nanjing; C9: Suzhou; C10: Wenzhou; C11: Jiaxing; C12: Taizhou; C13: Hefei; C14: Xiamen; C15: Qingdao; C16: Zhengzhou; C17: Wuhan; C18: Changsha; C19: Guangzhou; C20: Shenzhen; C21: Foshan; C22: Chengdu; C23: Xi'an; C24: Urumqi.

Most of pilot cities mentioned the importance of promotion for smart construction technologies. Implementation plans for smart construction pointed out the promotion of smart construction standards and application scenarios by convention, exhibition, official announcement and so on. Several pilot cities also provided public services including supervisory platform and information platform. Taken Nanjing as an example, a uniform quality supervisory platform would be built up for monitoring quality of smart construction projects. Guangzhou also promised developing an information platform for supporting industrial chain of smart construction.

Financial services and tax benefits were not popular among smart construction pilot cities, with only 8 cities proposing these policy tools. Nanjing, Wenzhou, Taizhou, Xiamen, Wuhan, Guangzhou, Shenzhen and Xi'an increased credit points for smart construction enterprises and projects when they applied loan. These cities also provide tax reduction and exemption for research and development of smart construction technologies.

5. Discussions

Based on policy classification, supply-type and environment-type policy instruments were more widely used than demand-type policy tools, which was consistent with Zhang *et al.* [40]. The results were reflected that the development of smart construction was mainly promoted by the governments, but not construction enterprises. As construction enterprises normally pursue maximum profits, they consider the costs of developing and using smart construction technologies. Hence, the acceptable smart construction technologies should provide utility to construction stakeholders with reasonable costs.

Figures 1–3 showed that the different types of policy instrument distributions were consistent. This indicated that the types of smart construction policy tools were relatively balanced from the city level. Meanwhile, cities on the east coast and in the center of the country had higher levels of policy tools than those in the western region. For example, Beijing, as the capital and center of China, many leading companies in the construction field are located there. With rich intellectual resources and R&D structure superimposed, it has the advantageous conditions to develop smart construction through the support of industrial policies. As a pilot city in western areas, Urumqi got lowest evaluation coefficient, which indicated a relatively poor performance among all pilot cities. Urumqi faces challenges on undeveloped economy, incomplete digital infrastructure and small population. Relatively poor industrial development and high logistics costs caused by remote geographical location, make market entry difficult. Moreover, the city also has a single-industry structure with slow growth in high-tech industries and services. Therefore, the development of smart construction in Urumqi is relatively slow. The results were reflected the regional development imbalance in China, which was consistent with other previous studies [41].

Cities with an industrial base like Xi'an, Nanjing, Suzhou and Hefei put forward significantly more policy tools than other cities. Hefei, for example, relies on the fabricated buildings foundation of Anhui Province. The prefabricated assembly rate is realized to increase while the new construction area in Hefei City remains basically stable from 2014 to 2020 [42]. Hefei introduced foreign assembly enterprises such as Yuhui PC, Ruentex, Baoye Group, Hangxiao Steel Structure and so on. Meanwhile, it vigorously supports the development of local enterprises and the union of enterprises. In the government policy support, Hefei assembly type building development rapidly. The annual design and production capacity of concrete parts and components manufacturers has reached 2.1 million cubic meters, which can construct about 8 million to 10 million square meters of assembled buildings [43]. The cumulative completion of demonstration projects is about 1 million square meters. Relying on the planning of Digital Yangtze-Huaihe region, Hefei's informatization construction has also made remarkable achievements. Cloud computing and big data industry clusters in Hefei are gradually growing. China Speech Valley has become the first national-level intelligent voice industry cluster. By 2020, the province's digital economy reached $112.2 billion [44]. The accelerated integration of informationization and industrial development has laid a solid foundation for the development of intelligent construction in Hefei.

6. Conclusions

As an inevitable trend of digital transformation in construction industry, smart construction is encouraged by the Chinese government from the national level to the local level. In order to compare different practice among smart pilot cities, this study classified policy instruments into three types and quantitatively evaluated policy consistency of smart construction policies. The results were indicated that supply-type policy tools were most popularly used, while demand-type policy tools were least used.

Based on the findings of the study, the use of demand-based policy instruments is encouraged to be emphasized by pilot cities. It is suggested that demonstration projects and public projects invested by the local government should be considered to facilitate the adoption of smart construction technologies. Presale of commercial residential buildings is suggested to be used in order to boost the demand of real estate enterprises. It is also suggested to provide additional bonus points in tendering process to construction contractors for the application of smart construction technologies. It is strongly recommended to defining clear and specific responsibility of management institutions and cooperating with multiple departments when promoting smart construction.

This study presents a quantitative evaluation of smart construction policies among different pilot cities. However, it has some limitations. As there are only 24 pilot cities, the policy sample sizes are limited with only 33 policies. Content analyze was not conducted in consideration of the limited policies. It is thus suggested to enlarge the study scale and conduct systematic content analyze of the implementation of smart construction in further studies. It is also suggested that the policy effect of smart construction pilot cities can be investigated by using Difference-in-Differences model. In consideration regional difference, it is recommended to evaluating spatial heterogeneity among different pilot cities and comparing pilot cities with other cities by adopting spatial econometrics analysis methods.

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Conflicts of interests

The authors declare that they have no known potential conflicts of interest that could have appeared to influence the work reported in this paper.

Authors' contribution

All the authors contributed to the study conception and design. Material preparation, data collection and analysis carried out by all author. All authors read and approved the final manuscript.

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