

A Review of Chinese Digital Architecture Research Based on CiteSpace

Cui Shan¹, Qin Zhou^{1,*}, Wenchao Gao²

¹College of Civil Engineering, Putian University, Putian Fujian 351100, China

²South China Branch of CNNC Huachen Construction Engineering Co., Ltd, Guangzhou 510335, China

*Corresponding Author.

Abstract:

Driven by the rapid development of China's digital economy and society, the construction industry, as the pillar of China's economy, will also face a comprehensive digital transformation, and the digital technology of the construction industry represented by BIM technology will be fully popularized. This paper uses CiteSpace6. 1. R6 software to study 406 research articles in CNKI database from 2002 to 2022. By drawing the knowledge map and combining qualitative analysis with quantitative research, this paper summarizes and analyzes the current research results related to digital architecture in China, providing certain research directions and research ideas for the researchers' follow-up research. China's digital architecture research has gone through three periods of initial exploration, rapid growth and explosive growth. At present, China's digital architecture research is in a period of explosive growth. There are few related research literatures in core journals. There are more inter-institutional cooperation among universities, especially the "985 project" and "211 Project" inter-regional cooperation among universities is remarkable. The research focuses on three aspects: digital transformation and upgrading, digital construction technology R&D, and digital technology implementation. This paper also discusses the key contents and directions of the future research of digital architecture in China.

Keywords: digital architecture, digital technology, CiteSpace, knowledge graph, literature review.

INTRODUCTION

Since the reform and opening up, China has made great achievements in science and technology along with the super-fast development of society and economy. The deep integration of digital technologies such as big data, cloud computing, artificial intelligence (AI), and the Internet of Things with the real economy, and the social form of new products, new technologies, new industries, and new forms of business can be seen everywhere, and China has long entered the digital era. "Accelerating digital development, building digital economic advantages, and jointly promoting digital industrialization and industrial digital transformation" and "promoting digital technology innovation and breakthrough projects" have become the main contents of the Chinese government's work. As the pillar of China's economy, the construction industry will also face a comprehensive digital transformation. Under the background of the comprehensive development of digital technology, digital construction and digital architecture will become the inevitable product of the high-quality development of China's construction industry. At the same time, it will certainly be another focus of Chinese construction scholars. Therefore, this paper analyzes the research literature in the field of digital architecture in China by combining qualitative and quantitative methods, hoping to provide certain research directions and research ideas for the researchers' follow-up research by summarizing and analyzing the current research results of digital architecture in China.

RESEARCH IDEAS AND DATA SOURCES

In this paper, the literature on China National Knowledge Network (CNKI) platform was searched. The search subject term is "digital architecture" OR "digital construction". The year is 2002-2022 and there is no limit to the category of the journal. Digital architecture and digital construction are emerging research focus in recent years. Due to the long review period of China's core journals, the number of articles included in the core journals is relatively small, which does not have the significance of quantitative research. Therefore, this paper starts from the relevant research results in the field of digital architecture collected in all journals, which can better reflect the research direction and research methods of Chinese popular scholars.

Knowledge graph rendering tool CiteSpace measures literature collection in a certain field based on pathfinding network algorithm, social network analysis theory and co-citation analysis theory [1]. Its application in literature review research is relatively mature, and the research conclusions are generally recognized by experts and scholars. Therefore, this paper uses CiteSpace6. 1. R6 to conduct a comprehensive analysis of 406 achievements in the field of digital architecture in China. This paper takes drawing knowledge map -- analysis of research status -- analysis of knowledge map -- prediction of future research as the main line, and conducts in-depth review of digital architecture. See Figure 1 for the specific research framework.

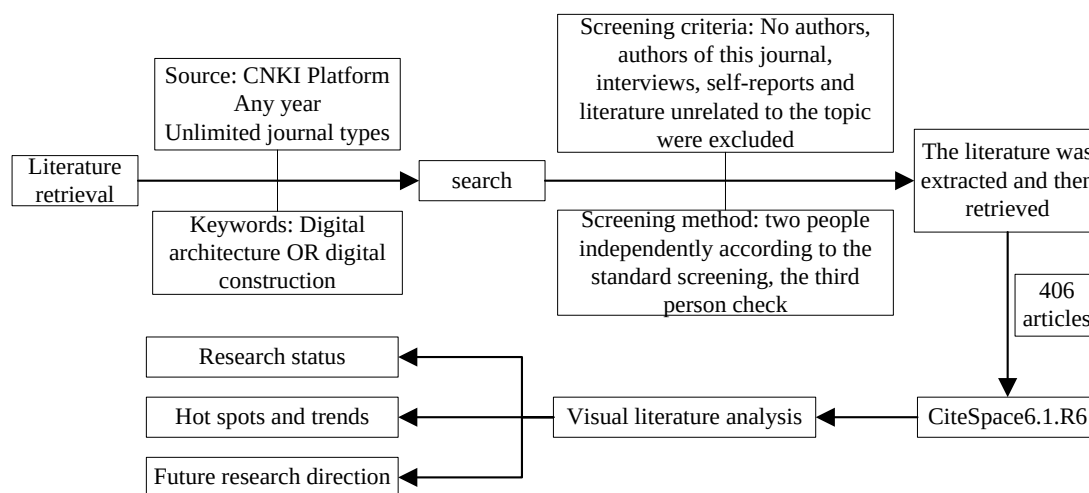


Figure 1. Research framework of the paper

ANALYSIS OF RESEARCH STATUS

Annual Trend of Research Results

According to the analysis of annual trend Figure 2 of China's digital architecture research results, the research in China's digital architecture field has gone through three periods so far.

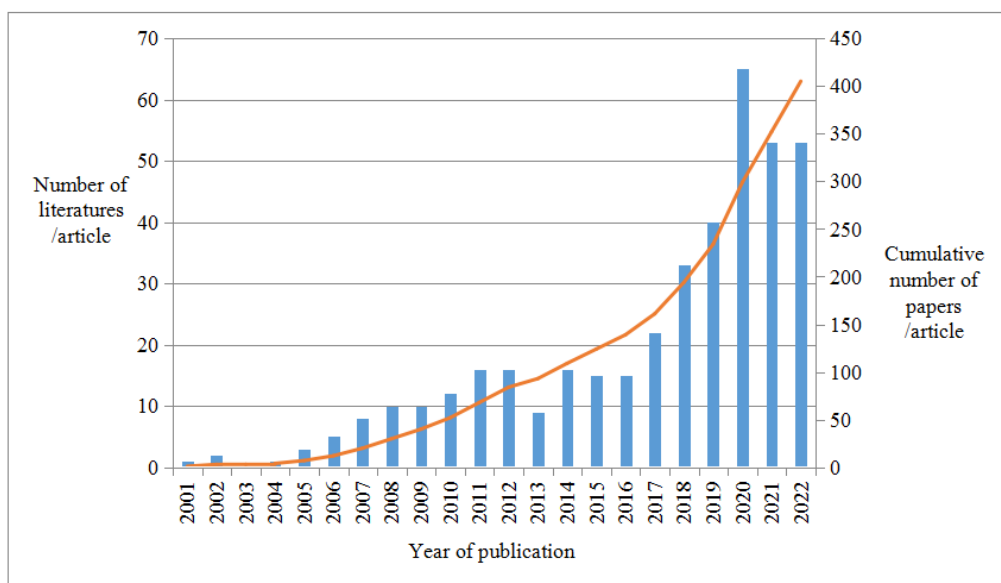


Figure 2. Annual trend of digital architecture research results

The first period was 2001-2004. This period is the preliminary exploration period, and the annual average number of publications is 1. This indicates that the attention to digital architecture was very low in this period, and the literature mainly focused on digital architectural drawing modeling [2-3]. The second period is 2005-2018. This period was a period of rapid growth, with a gradual increase in the annual average number of publications. The "Digital Beijing" and "Digital Olympics" put forward during the preparatory period of 2008 Beijing Olympic Games greatly improved the influence of digital architecture in the construction industry. At the same time, along with the development and application of digital technologies such as Building Information Model (BIM) [4], Enterprise Resource Planning System (ERP) [5], digital Construction technology (DCS) and Digital Property Maintenance System (DPMS) [6]. 3D printing and digital construction [7], parametric construction [8], human-computer interaction [9] and other digital technologies have also been deeply studied. The third period is from 2019 to the present, which is a period of explosive growth. With the maturity of building information technology and the promulgation of building industrialization and information policies, such as the Guiding Opinions of the Ministry of Housing and Urban-Rural Development and other departments on Promoting the Coordinated Development of Intelligent Construction and Building

Industrialization, it emphasizes the promotion of digital design system construction and the promotion and application of digital technology and a series of guiding opinions on promoting the development of digital architecture. The core position of digital architecture in the future construction field is clarified, which also makes architecture researchers realize the importance of digital architecture, and further increases the research heat of digital architecture. The research content goes deep into the digitalization of digital architecture in the whole life cycle of optimal design, supply chain, digital construction, construction robots, digital twins and other digital buildings.

Literature Source Analysis

From a micro point of view, the first three journals to include digital architecture literature are "Journal of Tsinghua University (Natural Science Edition)", "Building Economics" and "Journal of System Simulation", and they are all core journals. In addition, the first research paper on digital architecture is from the Department of Civil Engineering of Tsinghua University, which was published in the Journal of Tsinghua University (Natural Science Edition) in December 2001. It can be seen that digital architecture has attracted the attention of researchers since 2001, and relevant research results have also been highly recognized by experts and scholars in the field.

From a macro point of view, through the overall source statistics of literature, 406 samples of literature come from 157 journals. Among them, 55 were from 29 core journals, which accounted for 18. 5% of the total journals and 13.5% of the total samples. It shows that digital architectural literature is widely distributed. In addition, the top ten journals in terms of the number of digital architecture achievements collected were obtained through the overall source statistics of literature, and the detailed distribution is shown in Figure 3. Among them, "Construction Enterprise Management" and "Architectural skills" are the journals that collect the most digital architectural literature, with 17 articles each. "New Architecture" and "Architectural Journal" are the main core journals for collecting digital architecture literature, with 14 and 9 articles respectively. In addition, the current digital architecture research mainly in building science and engineering (50.96%), industrial economy (16.04%) and computer software and computer applications (12.99%) three fields. To sum up, the number of digital architecture research results published in core journals is relatively insufficient, and the research field is relatively concentrated. In the future, emphasis should be placed on improving the depth and difficulty of related research and improving the overall level of journals included.

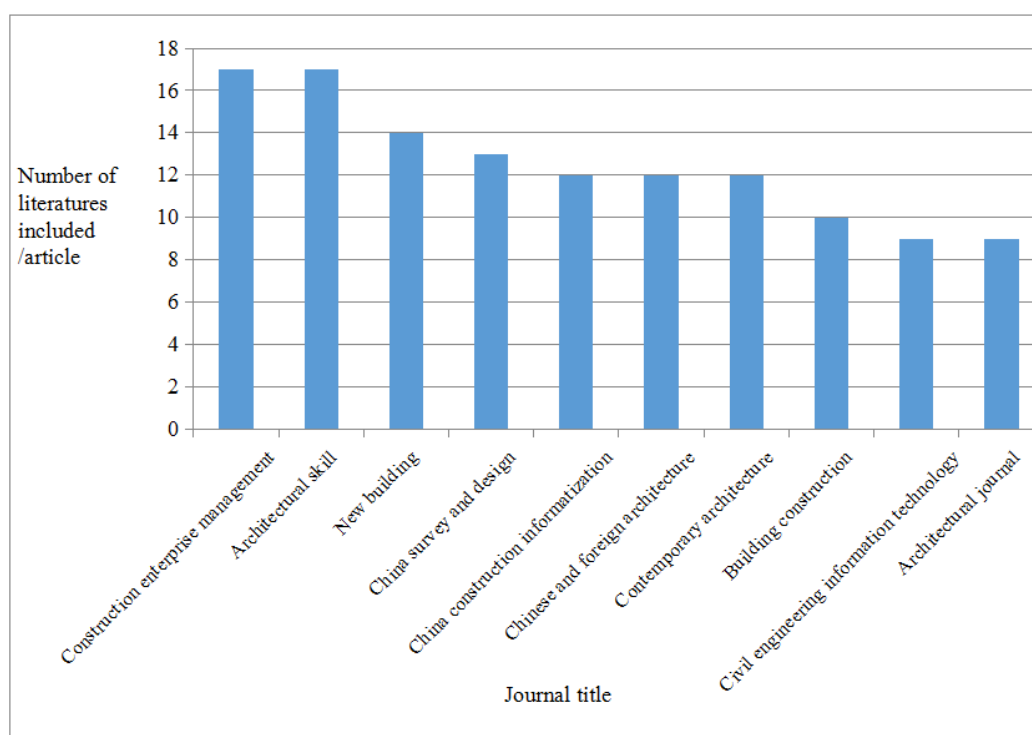


Figure 3. Top 10 journals in digital architecture publication volume

Key Author Analysis

This paper conducts key author analysis according to the square root law [10], and the formula is $U_{\min}=0.749*\sqrt{U_{\max}}$, where $U_{\min}$ and $U_{\max}$ refer to the minimum and maximum of the total number of papers published by key authors in the

research field, respectively. According to the collinear analysis of CiteSpace6.1. R6, U_max=19 and U_min=3.26 were calculated by the formula. Therefore, authors with 3 or more publications are selected as key authors in the field of digital architecture, and the specific distribution is shown in Table 1.

Table 1. Distribution of key authors and number of publications

Number of publications/ article	Author	Number of authors/ person
19	Yuan Feng	1
12	Xu Weiguo	1
8	Hu Biao, Song Gang	2
5	Liu Gang, Ding Lieyun, Yu Lei, Zhong Guanqiu	4
4	Fang Tingchen, Li Xiaojun, Zhang Qunli	3
3	Xu Zhen, WANG Xiang, SONG Ya 'nan, Geng Yuhua, Liu Qian, Sun Jinglu, Meng Nan, Yan Chao, Lin Qiuda, Shao Weiping, Zhou Jian, DU Yu, XU Haohao, Wang Yiping, Zhang Wei, CAI Shijie	16

In the CiteSpace6.1. R6 software, "Author" was selected as the network node. In Select Criteria, g-index (k=25) was selected, and other options were retained as default to obtain the network diagram of author cooperation in the field of digital architecture, as shown in Figure 4. There are 363 nodes and 303 connections, and the network density is 0.0046. The larger the number of nodes in the network diagram, the more papers published by the author, the more lines of nodes indicate the cooperation between authors, and the more lines indicate the more cooperation between the author and other researchers. In addition, the key authors represented by Yuan Feng, Xu Weiguo, Song Gang and Yu Lei have formed a large cooperative network, which is the largest and most complex. Other authors have smaller collaborative networks or fewer publications.

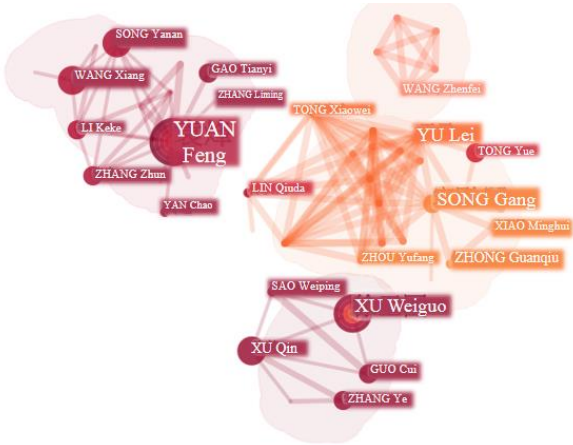


Figure 4. Author cooperation network in the field of digital architecture

Research Institution Analysis

In CiteSpace6.1. R6 software, "Institution" is selected as the network node. In Select Criteria, g-index (k=25) was selected, and other options remain default, and the cooperation network diagram of research institutions in the field of digital architecture is obtained, as shown in Figure 5. There are 248 nodes and 241 connections, and the network density is 0.006. The larger the number of nodes in the network diagram, the more the number of documents issued by the institution, and the connection of nodes indicates the cooperation among the institutions. More connections indicate more collaboration with other research institutions. Represented by the School of Architecture and Urban Planning of Tongji University, the School of Architecture of Tsinghua University, Shanghai Construction Engineering Group Co., LTD., and XWG Architecture Studio, four large-scale cooperation networks have been formed. Both Figure 5 and distribution table 2 show that there are fewer research institutions in the field of digital architecture, and the majority are universities, and the cooperation between universities and institutions is far more than that between universities and enterprises. From the analysis of the regional situation of research institutions, most research institutions belong to cross-regional cooperation, such as the School of Architecture and Urban Planning of Tongji University, the School of Architecture of Hunan University and the School of Architecture of Harbin Institute of Technology,

and cross-regional cooperation is more significant in the research institutions of the "985 project" and "211 Project" in first-tier cities in China. Such as Tsinghua University School of Architecture (Beijing), Southeast University School of Architecture (Nanjing), Tianjin University School of Architecture (Tianjin).

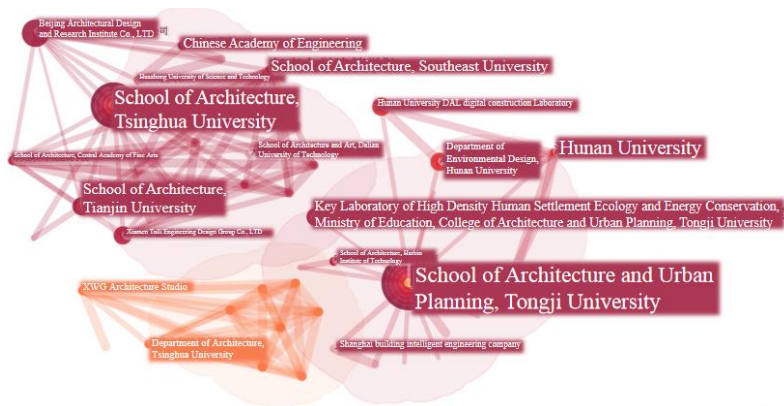


Figure 5. Cooperation network of research institutions in the field of digital architecture

Table 2. Distribution of research institutions with 5 or more publications

Number of publications / article	Research institution
27	School of Architecture and Urban Planning, Tongji University
20	School of Architecture, Tsinghua University Guanglianda Technology Co., LTD
8	School of Architecture, Southeast University
7	School of Architecture, South China University of Technology Hunan University Key Laboratory of High Density Human Settlement Ecology and Energy Conservation, Ministry of Education, College of Architecture and Urban Planning, Tongji University
6	School of Architecture, Tianjin University Shanghai Construction Engineering Group Co., LTD
5	School of Architecture and Art, North China University of Technology School of Civil Engineering, Tongji University Guangzhou Liangshe Architectural Design Co., LTD. Shanghai super high-rise building intelligent construction engineering technology Research Center

Research Content Analysis

Through the collation and analysis of the literature in the field of digital architecture research, it is found that the current research content of digital architecture is mainly concentrated in the following aspects.

Digital transformation and upgrading

This part mainly focuses on the path and strategy of digital transformation in the construction industry. The digital transformation of the construction industry is crucial to the realization of "digital China" and "smart manufacturing in China". At the same time, the digital transformation of the construction industry can be built through the coordination of supply chain, digital delivery and digital construction [11]. Ning Hailong believes that digital transformation needs to be carried out from three dimensions: organizational culture (consciousness space), engineering production (physical space) and value chain (digital space), and the overall realization of digitalization needs to be implemented from top-level design, scientific planning + specific measures and technical support, as shown in the following figure [12]. Through SWOT+ internal and external factor matrix analysis, Yao Zhen found that small and medium-sized construction enterprises should adopt positive pioneering strategies in the face of digital transformation and upgrading [13]. With the continuous exploration of the path of digital transformation, the research

perspectives are also increasing, such as the scale difference of construction enterprises [14], the financial system of construction enterprises [15], and the perspective of the whole life cycle [16].

From the above analysis, it can be seen that the path and strategy of the digital transformation and upgrading of the construction industry have been studied by experts in related fields, from the macro transformation direction to the micro transformation strategy.

Digital construction technology research and development

The research content of this part focuses on the key technologies in the construction process of digital architecture, and the principle follows from the whole to the part.

From the macro overall aspect of the research, the main analysis of digital technology development and application. For example, Wu Weiyu and Xie Chenglin were the first to study digital architectural modeling and implementation technology, proposed CSG/B-rep hybrid modeling method based on CAD integrated system, and verified the applicability of this modeling method [2]. With the research and development of BIM technology in China, digital architecture based on BIM technology has become a hot spot. Based on BIM technology, Xu Zongwu proposed a conceptual model of "digital design - parametric design - intelligent design - digital construction - digital operation and maintenance - digital architecture" from a macro level [17].

From the local micro level, the research mainly focuses on the realization of specific digital technology. For example, Lin Chengyang studied using the color output function of RP (Rapid prototyping) to materialize the digital model [18]. Yang Ruoyu and CAI Shijie realized the automatic recognition of two-dimensional architectural structure drawings to the generation of three-dimensional digital architectural models [19]. In addition, there are also studies on digital technologies such as building digital twins [20], 3D printing technology [21], Arduino-based building interactive system [22], BIM+VR technology [23], blockchain technology [24], BIM+ cloud technology [25] and so on.

From the above analysis, it can be seen that the application research of digital technology involved in the field of digital architecture has been relatively comprehensive, mainly based on BIM technology and collaborative application research with other digital technologies.

Digital technology implementation

This part mainly studies digital building construction technology and project management related content. Fang and Gong [26] expounded the application mode of digital construction technology from the aspects of construction preparation, foundation pit engineering, concrete process, steel structure process, mechanical and electrical engineering, decoration engineering and construction process management. Based on the background of digital construction, Lv and Wang [27] established a dynamic system model of evolutionary game of engineering transaction behavior supervision, and proposed the management mode of digital construction platform. Yu et al. [28] studied the precise control of visualization technology on construction safety management, laying a foundation for building intelligent and lean construction sites. Wan et al. [29] explored the promotion and application of digital construction technology in the field of project management through questionnaire survey data, summarized the technical difficulties hindering the promotion and application of digital construction technology, and proposed a breakthrough path.

From the above analysis, it can be seen that the research of digital building construction and management mainly focuses on the safety management of construction site, the supervision of engineering transaction behavior and the technical difficulties of management application.

ANALYSIS OF RESEARCH HOTSPOTS, FRONTIERS AND TRENDS

Analysis of Research Hotspots

Keywords reflect the core content of literature research, which is a highly refined and general overview of literature. Therefore, through the co-occurrence analysis of keywords, the hot spots in the field of digital architecture research are determined [1]. In the software CiteSpace6.1. R6, a statistical analysis is carried out on 406 sample literatures in the field of digital architecture, "Keyword" is selected as the network node. In Select Criteria, g-index (k=25) was selected, and other options remain default to obtain the keyword network diagram in the field of digital architecture. See Figure 6 for details. There are 421 nodes and 872 connections in the graph, the network density is 0.0099, the clustering module value is 0.6749 (greater than 0.3, significant clustering), and the average clustering corridor value is 0.7844 (greater than 0.5, high reliability of clustering results).

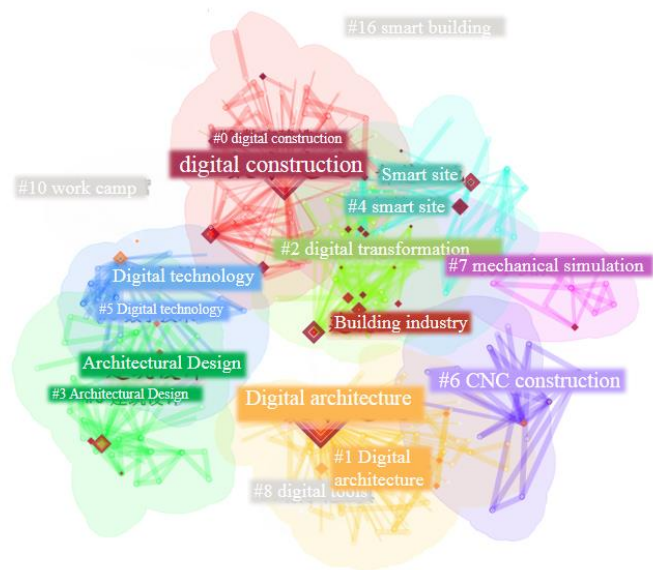


Figure 6. Cluster analysis of research keywords in the field of digital architecture

The specific distribution of the top ten keywords in the high frequency and high school heart of the research literature is shown in Table 3. Among them, the higher the word frequency, the higher the research heat, and the nodes with intermediate centrality higher than 0.1 are generally called critical nodes. "Digital construction" and "digital architecture" are the search subject terms, so their word frequency and intermediary centrality rank high. It can be seen that the current research focus in the field of digital architecture is "architectural design" and "digital technology", so that "digital design", "smart construction site", "digital construction" have also become the focus of attention.

Table 3. Top 10 keywords of high frequency and high school heart of digital architecture research literature

Sort by frequency			Sort by centrality		
Ranking	frequency	keyword	Ranking	Intermediation centrality	keyword
1	124	Digital building	1	0.69	Digital building
2	101	Digital Construction	2	0.68	Digital construction
3	22	Construction Industry	3	0.18	Architectural design
4	20	Architectural Design	4	0.13	Digital technology
5	19	Smart Site	5	0.05	Construction industry
6	19	Digital Design	6	0.04	Architectural form
7	14	Digital Technology	7	0.04	Smart Site
8	14	Guanglianda	8	0.03	Parameterization
9	14	Construction Industry	9	0.03	Construction Industry
10	9	Digital construction	10	0.03	Digital construction

Research Frontier and Trend Analysis

The time zone diagram of keyword clustering was obtained by "timelines" in CiteSpace6. 1. R6 keyword clustering, and the result was shown in Figure 7. There are 10 prominent words in the field of digital architecture research, and the research trend is divided into 5 research periods according to the time order of the emergence of prominent words.

The first phase - #1 Digital architecture, #3 Architectural Design. This part of the prominent words is the first research content. It mainly focuses on digital architectural drawing design and modeling, digital city, digitalization, and the post-digital era has become another hot spot

The second phase - #5 Digital technology. The main research focuses on the application of virtual simulation technology, RP technology, 3D model automatic generation and other digital interaction. Architectural education was also a hot topic during this period.

The third phase - #0 digital construction, #6 CNC construction, #8 digital tools, #10 work camp. Among them, digital construction is a subversive change to the traditional building construction method, so it has become a huge hot spot in the construction industry in this period. Its research mainly focuses on digital design, algorithm design, structural performance, forward design and so on. Numerical control construction mainly studies digital construction and customization, and the research in this area is gradually decreasing, indicating that the heat is declining. Digital tools are the platform for digital construction, and work camps such as technology development and talent training also emerged during this period.

The fourth phase - #7 mechanical simulation. This period focused on the study of digital architectural form and parameterization.

The fifth phase - #2 digital transformation, #4 smart site, #16 smart building. It mainly focuses on artificial intelligence, big data, cloud computing, Internet of Things, digital twin, visualization, value chain and other aspects. At the same time, the digital building software development enterprises represented by Guanglian have become the object of attention.

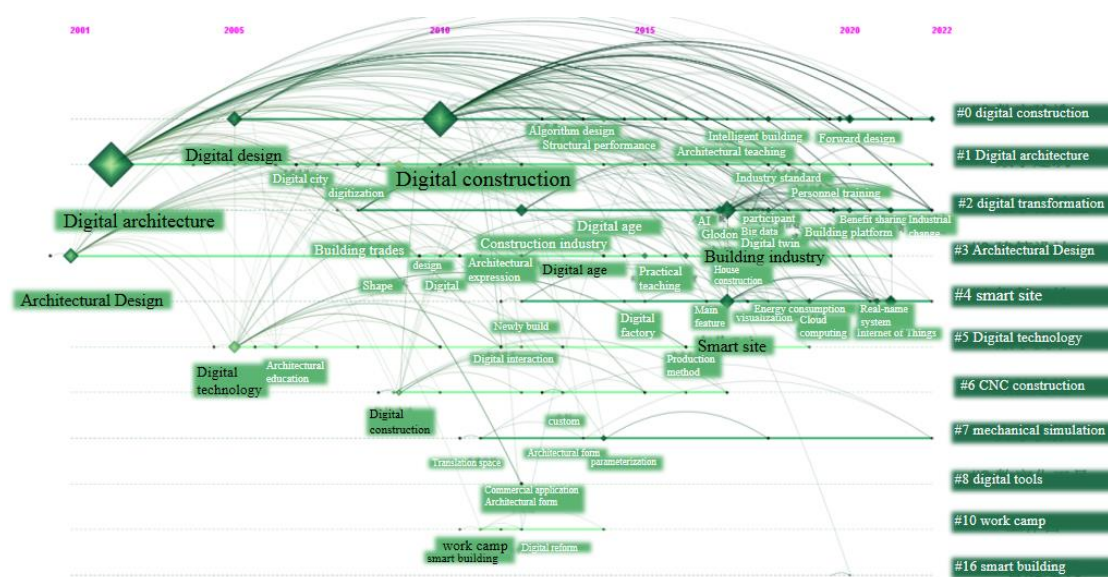


Figure 7. Time diagram of research keywords in digital architecture field

FUTURE RESEARCH FOCUS

From the above analysis, it can be seen that the number of research results in the field of digital architecture is relatively small in the core journals. The authors do not cooperate closely. There is a significant trend of cooperation between high-level universities and institutions. Future research can focus on the following aspects.

(1) In terms of research content, artificial intelligence, big data, cloud computing, Internet of Things and other digital technologies have been introduced into the field of digital architecture. In addition, green, ecological and sustainable development is an inevitable trend of the development of the construction industry. In the future, researchers can study energy consumption, carbon emission, carbon footprint and other aspects of the whole life cycle of digital buildings.

(2) In terms of research results, there are more universities and research centers in the current research institutions in the field of digital architecture, but fewer enterprises. Moreover, there is close cooperation between universities and research centers, and less cooperation with enterprises. This phenomenon shows that the current research results of digital architecture are higher in theory than in practice. In the future, cooperation between universities, research centers and enterprises should be improved, and the combination of research results and practice should be strengthened to ensure that theory is used to guide practice.

(3) In terms of research areas, most of the existing research results come from first-tier cities, while the digital era of construction industry has arrived, and digital architecture will be promoted nationwide. Scholars in the field of architecture research across the country can carry out research related to digital architecture according to the actual situation of their cities, and accelerate the implementation of digital architecture across the country.

(4) In terms of research disciplines, digital architecture can be combined with social psychology, organizational behavior and management, and human factors of digital architecture promotion can be studied in view of the competence and acceptance of digital technology of digital architecture personnel.

CONCLUSION

Using CNKI platform as data source and CiteSpace (6. 1. R3) software, this paper combined qualitative and quantitative analysis to review 406 domestic literatures on digital architecture research, and drew the following conclusions.

(1) From the annual trend of research results, the research development trend in the field of digital architecture can be roughly divided into three periods. The initial exploration period focuses on digital architectural modeling. The rapid growth period focuses on the development of digital technology software, the fine design of digital architecture and the concrete application of digital technology. The explosive growth period focuses on the coordinated development of intelligent construction and building industrialization, and the number of documents will peak in 2020.

(2) From the perspective of literature sources, key authors and research institutions, "Construction Enterprise Management" and "Architectural Skills" are the journals that collect the most digital architectural literature. "New Architecture" and "Architectural Journal" are currently the main core journals for collecting digital architecture literature. In addition to the close cooperation between individual authors, most researchers have a large space for future cooperation. There are fewer enterprises in research institutions, more universities, and more cross-regional cooperation between university institutions. In the "985 project" and "211 project" between the university is more significant.

(3) From the perspective of research content, hot spots, frontiers and trends, the research content in the field of digital architecture covers three aspects: digital transformation and upgrading, digital technology, construction and management. The focus is on digital design, digital technology, digital construction, and smart construction sites. Research frontiers and trends can be roughly divided into five research periods.

(4) From the perspective of future research focus, the research content can be introduced into building energy consumption and carbon emission. The research results can be further concretized to guide practice. The further expansion of cooperative relations is conducive to the overall promotion of construction industrialization.

ACKNOWLEDGEMENTS

This work was supported by a project grant from Fujian Provincial Innovation Strategic Research Plan Project (Grant No. 2023R0126); Natural Science Foundation of Fujian Province (Grant No. 2022J011159).

REFERENCES

- [1] LIAO Cuicheng, Luo Yazhuo, Chen Yuanze. Review of engineering project performance based on CiteSpace. *Construction Economics*, 2022, 43 (S1): 384-389.
- [2] Wu Weiyu, Xie Chenglin. Feature modeling algorithm and implementation Technology of digital Building Engineering System. *Journal of Tsinghua University (Natural Science Edition)*, 2001 (12): 78-81.
- [3] CAI Shijie, Xu Fupei, Gao Xiao. Computer reading and Digital Architecture. *Journal of System Simulation*, 2002 (12): 1652-1654.
- [4] Yang Baoming. Application status and Prospect of digital construction technology. *Building Construction*, 2006 (10): 840-844.
- [5] Yang Baoming. Building Information Model BIM and Enterprise Resource Planning System ERP. *Construction Technology*, 2008(06): 31-33.
- [6] Jiang Jiexia. Application and Prospect of digital property maintenance technology in maintenance and management of large-scale public facilities. *Building Construction*, 2008 (09): 831-833.
- [7] Ding Lieyun, Xu Jie, Qin Yawei. Research and application of 3D printing digital construction technology. *Journal of Civil Engineering and Management*, 2015, 32 (03): 1-10.
- [8] Cheng Jian, Zhang Qunli, Huang Jun, Li Jiangbo. Parametric Modeling and Structure Analysis of Digital Building. *Civil Engineering Information Technology*, 2014, 6 (06): 1-7.

- [9] ZHANG Hanyang, Lin Zhenghao, QIAN Shiqi, YAO Yidi, Kenny Constance. Research on building Interactive System based on Arduino. Southern Architecture, 2015 (03): 100-104. (in Chinese)
- [10] LIU Yuejun, Shen Yuran, Gao Yinfei, Zhou Chuanghui, Wang Long. Review of passive ultra-low energy buildings based on CiteSpace. Project Management Technology, 2022, 20 (08): 15-20. (in Chinese)
- [11] Jing Wan, Li Siqu. Approaches to digital transformation of Construction enterprises. Construction Technology (Chinese and English), 2022, 51 (17): 22-28.
- [12] Ninghaisaurus. Research on the transformation and upgrading path of construction enterprises in the digital era. Architecture, 2021 (09): 14-19.
- [13] Yao Zhen. Research on transformation strategy of Small and medium-sized construction enterprises under platform ecology. Management and Technology of Small and Medium-sized Enterprises (Junten-issue), 2020 (10): 165-167.
- [14] Gong Yin-Yin, Duan Zong-zhi. Research on the key path of digital transformation of construction enterprises considering scale differences. Construction Economics, 2022, 43 (02): 84-90.
- [15] Liu Zhikun, Cheng Biliu. Research on building construction enterprise digital transformation engine from Finance. International Business Finance and Accounting, 2020 (07): 51-53.
- [16] Yu Fangqiang. Study on the path of digital innovation and transformation of construction enterprises from the perspective of the whole life cycle. China Construction Informatization, 2022 (19): 65-67.
- [17] Xu Zongwu. Digital Architecture Design to Digital construction based on BIM technology. Contemporary Architecture, 2020 (02): 33-36.
- [18] Lin Chengyang. RP- A new method of Digital Architectural design research. Journal of Chongqing Architectural University, 2006 (06): 34-37.
- [19] Yang Ruoyu, CAI Shijie. Research on automatic generation and application of 3D Digital Architecture. Journal of Intelligent Systems, 2008 (01): 1-8.
- [20] Han Dongchen, Zhang Hong, Liu Yan, Cui Weiwen. From BIM to BDT: A conceptual study on Building Digital Twins (BDTS). Architectural Journal, 2020 (10): 95-101.
- [21] Ding Lieyun, Xu Jie, Qin Yawei. Research and application of 3D printing digital construction technology. Journal of Civil Engineering and Management, 2015, 32 (03): 1-10.
- [22] ZHANG Hanyang, Lin Zhenghao, QIAN Shiqi, YAO Yidi, Kenny Constance. Research on building Interactive System based on Arduino. Southern Architecture, 2015 (03): 100-104. (in Chinese)
- [23] Guo Wenqiang. Research on Digital architectural design based on "BIM+VR". Housing and Real Estate, 2017 (18): 80-81.
- [24] MO Shengjie, ZHANG Donglin, ZHANG Guoxing, JI Fanjie, Luo Tiantian, HUANG Fengling. Research on Construction stage cost management under Digital construction -- Based on blockchain technology application. Journal of Hebei University of Civil Engineering and Architecture, 2019, 38 (03): 121-124+145.
- [25] Fan Xiang, Du Jinyang, Yang Liqi. Digital Research of "BIM+ Cloud Technology" in the Whole life cycle of prefabricated buildings. Brick and Tile, 2021 (05): 53-54.
- [26] Fang Tingchen, Gong Jian. Research and Exploration on digital Construction Technology of Building Engineering. Building Construction, 2021, 43 (06): 1117-1120. (in Chinese)
- [27] Lv Lelin, Wang Zhuofu. Co-evolution simulation of transaction behavior supervision of major projects in digital construction context. Journal of Systems Management, 2022, 31 (03): 440-452. (in Chinese)
- [28] Yu Shuoshuo, Song Chunfei, He Yalei. Application analysis of visualization technology in Promoting Lean Construction safety management. Engineering and Construction, 2022, 36 (02): 552-554+561.
- [29] Wan Dongjun, Siyu, Juying, Sun Chengshuang. Analysis of relevant technical difficulties in the application of digital construction technology in the field of project management. Construction Economics, 2021, 42 (S2): 66-70.