A Review on Current Advances of Intelligent Construction Based on Bibliometric Analysis

Jing-Ke Yan[1],Zhe Zheng[2], Yu-Cheng Zhou[3],**Jia-Rui Lin[4]** , Yi-Chuan Deng[5]

[1] Undergraduate, School of Civil Engineering, Chongqing University, Chongqing, China, 400045, Email: 395244210@qq.com
[2] Ph.D. Candidate, Department of Civil Engineering, Tsinghua University, Beijing, China, 100084, Email: zhengz19@mails.tsinghua.edu.cn
[3] Postgraduate, Department of Civil Engineering, Tsinghua University, Beijing, China, 100084, Email: zhouyucheng98@qq.com
[4]Assistant Professor, Department of Civil Engineering, Tsinghua University, Beijing, China, 100084, Email:lin611@tsinghua.edu.cn, **corresponding author**.
[5]Assistant Professor, School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, China, 510641, Email: ctycdeng@scut.edu.cn

Abstract:
With the development of information technologies and the transformation and upgrading of architecture, engineering, and construction (AEC) industry, intelligent construction is gaining increasing attention. Integrating with construction industrialization, intelligent construction has become an important way to achieve high-quality development of the AEC industry. To grasp the research development status of intelligent construction and explore future research opportunities, this study takes the database of Web of Science (WOS) and China national knowledge infrastructure (CNKI) as the data source, and carries out a bibliometric analysis of related research based on VOSviewer and Gephi. For English articles, the studies early focused on theoretical methods, and gradually transitioned to the engineering practice. Although it starts relatively later according to Chinese articles, intelligent construction has a rapid development in recent years and shows close interactions with engineering practice. Finally, this paper puts forward research prospects, in order to provide some directions for the research of intelligent construction and contribute to the upgrading and transformation of the AEC industry.

Keywords:
intelligent construction; bibliometric analysis; knowledge graph; research progress; VOSviewer

1 Introduction

The development of information technology, such as artificial intelligence (AI), big data, Internet of Things (IoT), 5G, and blockchain, has promoted industrial transformation and upgrading in many industries, including the AEC industry (Liao, 2020). Existing initial attempts in the AEC industry show that the new generation of information technology can effectively improve the efficiency of detailed design (Li et al., 2021), component production (Han et al., 2021), construction schedule management (Bai, 2021), and other stages. But due to the low degree of integration between information technology and the AEC industry, there exist many research gaps (Liu et al., 2021). Therefore, the intelligent construction technology proposed in recent years aims to promote the efficiency of the integration between information technology and the AEC industry, which can improve the efficiency and safety of the whole construction process.

Intelligent construction integrates the new generation of information technologies such as BIM, IoT, cloud computing, AI, and 3D printing with the AEC industry (Liu et al., 2019), which aims to achieve real-time analysis, human-machine collaboration, and continuous optimization via data and physics-driven (Fan et al., 2021). Broadly speaking, intelligent construction can be divided into three main groups. Group 1, based on the BIM and IoT technologies, intelligent construction achieves information interaction between people and

things, and things and things to promote the efficiency of the construction process (Wang et al., 2020; Zhang et al., 2021); Group 2, base on the AI technology, the processes of design (Sobhkhiz et al., 2021), construction (Wang et al., 2016), and management (Lin & Wu, 2021) can be optimized. And group 3, the collection, analysis, and management of big data generated during the construction process can be conducted through cloud computing and big data technology (Li et al., 2016; Meng, 2015). It can be seen that intelligent construction is expected to improve the construction method in a new way and promote the transformation of the AEC industry (Fan et al., 2021).

In the past three decades, domestic and foreign scholars have explored intelligent construction. Due to the combination with the new generation of information technology, there are many research directions in the field of intelligent construction. Therefore, it is difficult to grasp the research focus, hotspots, and current status. At present, domestic scholars' reviews on intelligent construction are mostly focused on the engineering practice and the macro development of the AEC industry. However, the comparative analysis of Chinese and English articles is less involved. To address the research gap and grasp the research development status of intelligent construction and explore future research opportunities, this study takes the database of Web of Science (WOS) and China national knowledge infrastructure (CNKI) as the data source, and then carries out bibliometric analysis of Chinese and English articles in the field of intelligent construction based on VOSviewer and Gephi (Bastian et al., 2009; Van Eck & Waltman, 2021).

The remainder of this paper is organized as follows. First, the methodology and data collection process are illustrated in Section 2. Then, this work combines Python and Excel to analyze and visualize the number of articles per year for different keywords, and then analyze the trend of intelligent construction (Section 3). In Section 4, this work first analyzes the retrieved articles by VOSviewer. Then, the analysis results (i.e., various research networks) are imported into Gephi via CSV file for better visualization. Then the hotspots and trends are discussed. In Section 5, this work performs a comparative analysis of Chinese and English articles in the field of intelligent construction. Finally, Section 6 concludes this research.

2 Methodology and Data collection

2.1 Methodology

In this work, VOSviewer, a widely-used literature analysis tool, is used to perform bibliometric analysis, and Gephi, a social network visualization and analysis toolkit, is used to promote the analysis results. VOSviewer can perform large-scale literature analysis and visualization (Yan & Li, 2020), such as author-coupling analysis, institution-coupling analysis, literature co-citation analysis, and keywords clustering analysis (Song & Chi, 2016). The final analysis results have two kinds of representations, including the cluster view and the density view. The cluster view is often used to demonstrate the structure of the literature graph and point out the research hotspots. While the density view is often used to analyze the important areas and the research trends. Gephi takes CSV files as data sources and supports network graph generation and personalized editing and processing. It is a common tool for graph processing and visualization (Deng et al., 2014). Besides the VOSviewer and Gephi, this paper also combines Python and Excel to count and visualize the number of articles per year for different keywords, and then analyze the trend of intelligent construction.

2.2 Data collection

The Chinese and English articles are sourced from the CNKI and WOS core collections, respectively, and the retrieval time is from 1990 to 2021. For the Chinese articles, the keywords including "Intelligent Construction", "Smart Construction", "Smart Construction Site" are chosen as the theme. The article types include dissertations, academic journals, and conferences. Finally, 2,241 Chinese articles are obtained. For the English articles, the keywords including "Intelligent Construction", "Smart Construction", "Smart Construction Site" are chosen as the theme. The literature types include dissertations, conference proceedings papers, and review papers. Then, we filter the articles via WOS categories. We select WOS categories in the fields of IoT, computer technology, civil engineering, and other intelligent construction-related fields, such as

"Computer Science Artificial Intelligence", "Construction Building Technology", "Robotics", etc. Finally, 8,989 papers are collected. The selected WOS categories are shown in Table 1.

Table1WOS categories and the number of corresponding articles

WOS categories	The number of articles
Automation Control Systems	815
Computer Science Artificial Intelligence	1614
Computer Science Cybernetics	225
Computer Science Information Systems	1499
Computer Science Interdisciplinary Applications	882
Computer Science Software Engineering	448
Computer Science Theory Methods	1378
Construction Building Technology	799
Engineering Civil	1114
Engineering Electrical Electronic	2591
Engineering Geological	146
Engineering Industrial	343
Engineering Manufacturing	276
Engineering Mechanical	531
Engineering Multidisciplinary	633
Geology	11
Green Sustainable Science Technology	405
Management	318
Mechanics	153
Multidisciplinary Sciences	173
Operations Research Management Science	291
Regional Urban Planning	62
Remote Sensing	148
Robotics	273
Telecommunications	986
Transportation	81
Transportation Science Technology	269
Urban Studies	118

3 Overview of Chinese and English articles

3.1Development trend of published papers

After data collection and preprocessing, the trend analysis is firstly performed. The number of articles reflects the changes in the research interest in a research area (Xu et al., 2021). Therefore, we first compare the annual publication volume of Chinese and English articles. As shown in Fig.1, there are significant differences in the research trend between Chinese and English articles.

For the English articles, before 2004, there is a small number of English articles related to intelligent construction. Although the number of publications in English articles fluctuates to a certain extent between 1990 and 2004, it still maintains a growing trend. After 2004, the growth rate has gradually accelerated and generally has an exponential growth trend. Then, the exponential fitting analysis is carried out on the annual publication volume of 8989 English documents from 1990 to 2021. The curve fitting degree is 0.9764, which means that the number of English research works related to intelligent construction has been increasing exponentially during this period.

For the Chinese articles, there is a big gap between the total publication volume of the year during 2009-2021 and the publication volume before 2009. Although the first Chinese work on intelligent construction was

published in 1990, there was not a clear growth trend until 2009, during which the number of papers published was 0 in 5 years. Therefore, it is meaningless to perform a fitting analysis on all years. So, the exponential fitting analysis is only performed on the number of publications from 2009 to 2021. The curve fitting degree is 0.9371, which is more in line with the exponential distribution. It can be considered that the number of publications from 2009 to 2021 increased exponentially.

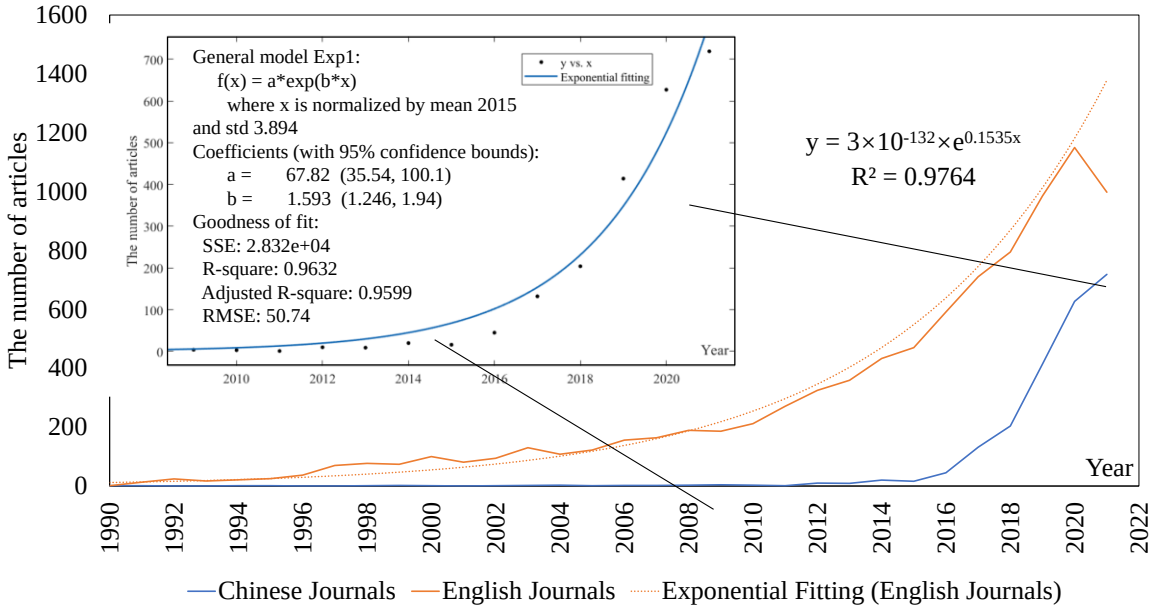

Fig. 1.The annual number of research papers on intelligent construction

3.2National technical strength analysis

Analyzing the countries of the papers related to intelligent construction is shown in Fig. 2. Specifically, the 8989 papers retrieved in WOS are counted by country, and the 2241 papers retrieved by CNKI are merged into the number of published papers in China. As Fig. 2 shows, China (56%) plays an extremely important role in the field of intelligent construction, with more than half of the publications, followed by the United States (10%), the United Kingdom (3%), and South Korea (3%). The rest of the articles are distributed in countries such as Germany (3%), Russia (2%), Australia (2%), and other countries.

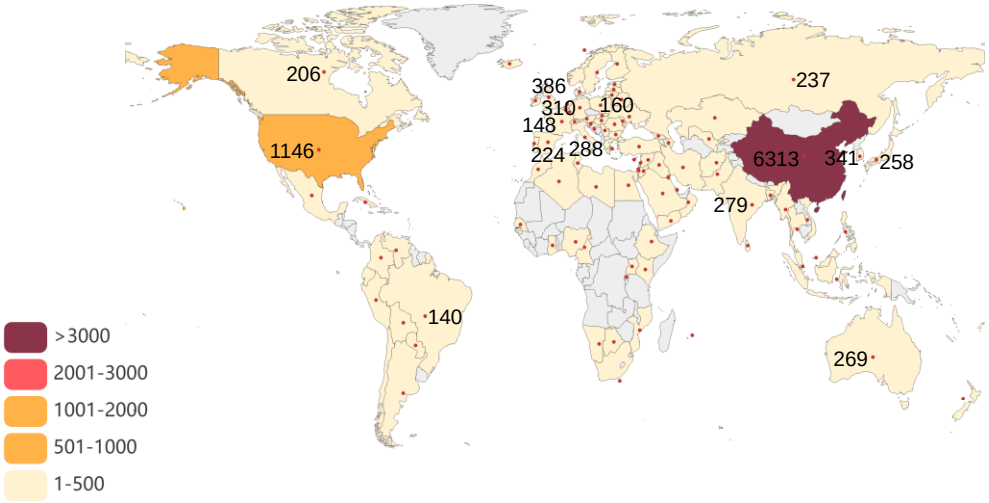

Fig. 2. Regional distribution of total published volume

4 Advances in Chinese and English articles

4.1 Advances in Chinese articles

4.1.1 Research hotspots

The keywords of the Chinese articles related to intelligent construction are analyzed for co-occurrence using VOSviewer (Fig. 3). The keywords of the 584 Chinese documents retrieved are counted to obtain 69 high-frequency occurrences. Considering that there may be more than one keyword for the same concept (e.g., BIM, Building Information Model, etc. all indicate BIM), the synonymous keywords are manually combined by experts. Finally, 58 high-frequency keywords are obtained and can be divided into 3 clusters. Cluster 1 is digital twin & industrial IoT, and the related keywords include smart city, cloud computing, digital twin, etc. Cluster 2 is construction management with BIM technology, and the related keywords include informatization, digitization, construction management, etc. Cluster 3 is construction industrialization and construction robots, and the related keywords include construction robots, integrated applications, digital transformation, etc.

In addition, we analyzed the typical studies of the three clusters as follows:

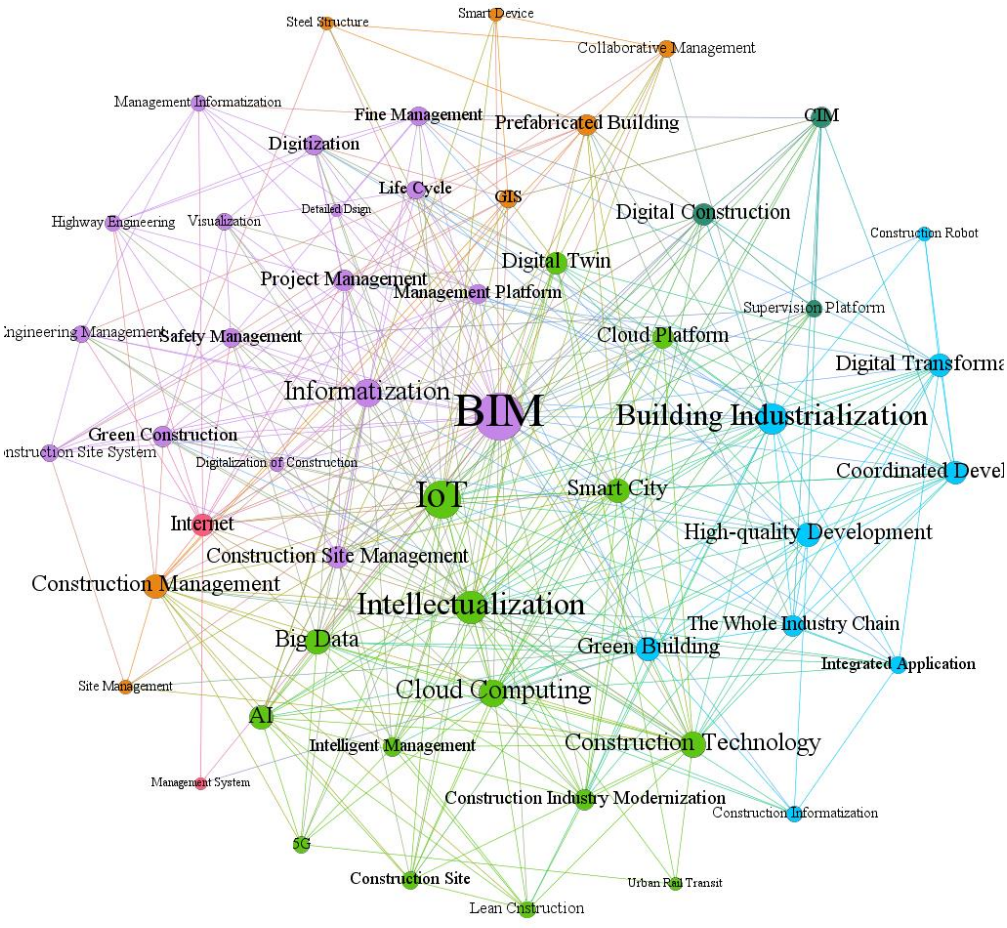

Fig. 3. Co-occurrence analysis of keywords in Chinese articles research on intelligent construction

(1) Cluster 1: digital twin &industrial IoT

The BIM model stores the geometric and semantic information of the building components (Ye, 2021). Due to its excellent 3D visualization capabilities and rich information database, the BIM model can provide a collaborative design platform for different professionals (Liu et al., 2013). Therefore, the BIM model has an indispensable position in the intelligent construction system. However, BIM also has certain limitations. The information provided by the BIM model is usually static (Xu&Ye, 2022), so the information in the model cannot be automatically updated without additional data sources. The IoT compensates for this drawback of

BIM models very well (Chen, 2021). Through various types of sensors and intelligent devices, the IoT serves as an external data source to transfer real-time data on the status of building components and the surrounding environment to the BIM model, which ensures the timeliness of the information in the BIM model and realizes the integration of various building information (Chen et al., 2021). Combining BIM and IoT, the digital twin technology of the AEC industry come out. For example, at a petrochemical construction project site in Wuhan, BIM&IoT technologies are used to build a digital twin model of construction implementation to achieve safe and precise management of the construction site. Mai et al. proposed a BIM&IoT integrated management system composed of a perception layer, a control processing layer, and an application layer. The system can integrate, fuse and process the information of the life cycle of the building to realize the comprehensive management of the project (Mai et al., 2020).

(2) Cluster 2: construction management with BIM technology

BIM technology is often used to improve the efficiency of project management, such as collision detection in the design stage (Liu et al., 2017), construction process simulation (Zhang et al., 2012), etc. In the project information management research with BIM technology as the core, the information management of prefabricated buildings is one of the most typical researches. Prefabricated buildings refer to the production and manufacture of components such as walls and panels required for the building in a factory according to standards, and transport them to the construction site for splicing and installation (Shi&Huang, 2021). Therefore, components in prefabricated buildings need to meet interchangeability requirements (Ye, 2021). At the same time, prefabricated buildings will generate a lot of semantic information (e.g., transportation time, installation time, installation personnel (Wang et al., 2021)) during the whole construction process including the design stage (Zhou et al., 2012), the production stage (Dai et al., 2017), the construction stage (Tian et al., 2017), the operation stage, and the maintenance stage (Qi&Li, 2014). The above multiple-stage complex information can be effectively managed to utilize BIM technology. Specifically, before design, a prefabricated component family library can be established in BIM software according to relevant specifications to improve modeling efficiency (Xu et al., 2021). During the design, the capabilities of collaborative design of the BIM model are used for equipment and pipelines collision checks, etc., to avoid tedious modifications in the later stage (Gu, 2021). Combined with the IoT and the semantic information stored in the BIM model, it can also coordinate the production, transportation, construction, operation, and maintenance of prefabricated components, and achieve efficient installation and management of prefabricated buildings (Ye, 2021). For example, the Qingdao International Conference Center project realized the management of the prefabricated building from design to construction through the BIM model and completed the construction work that normally takes 2 years in 6 months (Zhou et al., 2020). Wang et al. proposed an intelligent construction system for prefabricated tunnel structures based on the deep integration of lightweight BIM, RFID technology, and ERP system. The system provides technical support for the construction, operation, and maintenance of prefabricated railway tunnels throughout the life cycle (Wang et al., 2020).

(3) Cluster 3: construction industrialization and construction robots

At present, many processes in construction still rely on manual operations, with long construction cycles and high safety risks (Yu et al., 2016). In recent years, the development of digital technologies such as AI and the IoT has made intelligent construction robots a research hotspot in the field of intelligent construction (Meng, 2021). Compared with manual work, construction robots are convenient for scheduling and planning in the construction process and can maintain a good working state for a long time, especially for high-risk and high-precision work (Lin, 2021). Domestic research on construction robots is still in its infancy. Most robots cannot be put into practical application due to problems such as accuracy and specifications. Only a few preliminary and mature troweling robots can be put into use. The intelligent construction robots developed by Suet al. have been able to complete the assembly of light steel keel partitions, the construction of special-shaped walls, and the laying of floors. However, due to cost, they still cannot be mass-produced and put into use (Su et al., 2019).

4.1.2 Research Trends

Excluding Chinese documents without keywords and publication years, 2225 Chinese documents retrieved from CNKI are analyzed by keyword clustering for annual publication volume. The top ten keywords in terms of the total number of postings were selected, and their synonyms were expanded to obtain research trends in Chinese articles (Fig. 6).

Overall, with the development of information technologies, the Chinese articles in the field of intelligent construction started to show a growth trend from 2015, and the growth rate increased sharply from 2018 and remained until 2021. Since the research on prefabricated buildings and construction robots is closely related to BIM&IoT technology, the publication volume of BIM&IoT is the highest, and the growth rate is greater than the other two.

As shown in Figs. 4 and 5, from the analysis of the annual volume of keywords, it can be seen that the "BIM"," IoT ", and "construction management" have received continuous attention and gradually increased in popularity since 2015. The popularity of "Prefabricated Buildings" has grown rapidly since 2017. In 2020, with the release of relevant policies, policies interpretation and research on "Construction Robots" and "Prefabricated Buildings" related to "Industrialization of Construction" have been increasing. Therefore, related research on " Industrialization of Construction ", "BIM" and " IoT " will become the focus in the future.

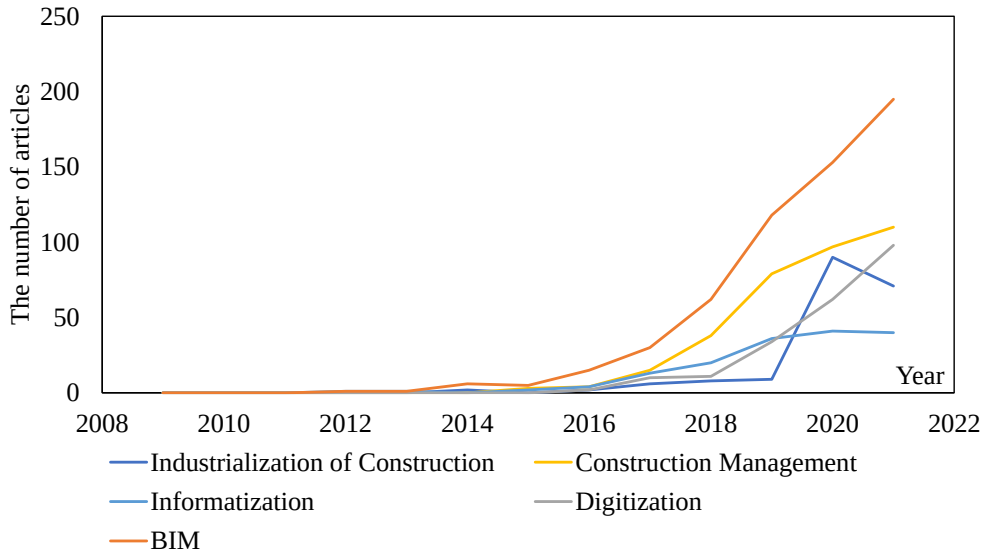

Fig. 4. Analysis of the annual publication volume of keywords ranked 1-5 in the total publication volume of Chinese articles

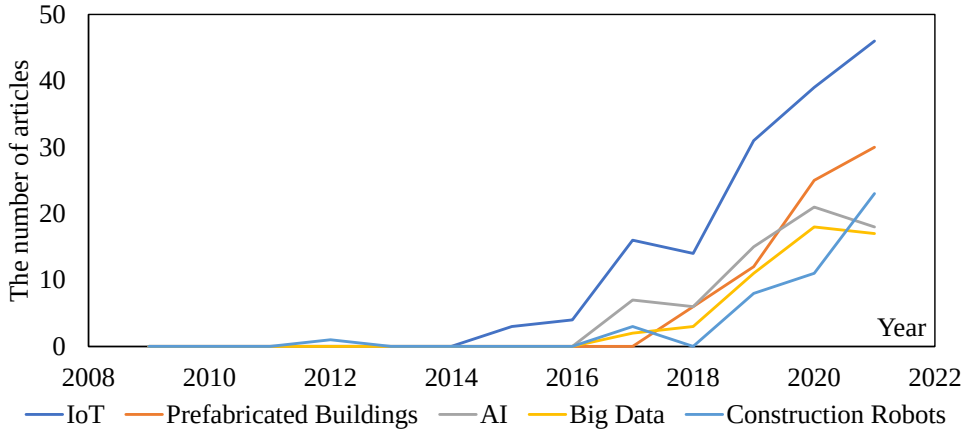

Fig. 5. Analysis of the annual publication volume of keywords ranked 6-10 in the total publication volume of Chinese articles

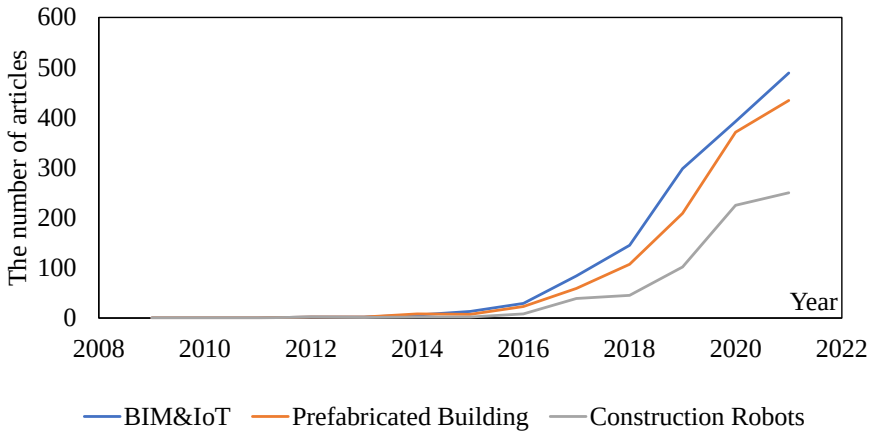

Fig. 6. Analysis of the annual publication volume of Chinese articles intelligent construction research keyword clustering

4.2 Advances in English articles

4.2.1 Research hotspots

The same method is used to analyze the keyword co-occurrence of English articles in the field of intelligent construction (Fig.7). After merging synonyms and deleting unnecessary keywords, the 98 keywords with high frequencies are reclassified into the following three groups based on the relationship of different clusters. Cluster 1 is knowledge representation, learning, and utilization, related keywords include ontology, knowledge graph, knowledge management, etc. Cluster 2 is the digital twin, related keywords includeBIM, IoT, smart city, smart building, digital twin, etc. Cluster3 is intelligent algorithms and their applications, keywords include machine learning, computer vision, optimization methods, feature extraction, etc.

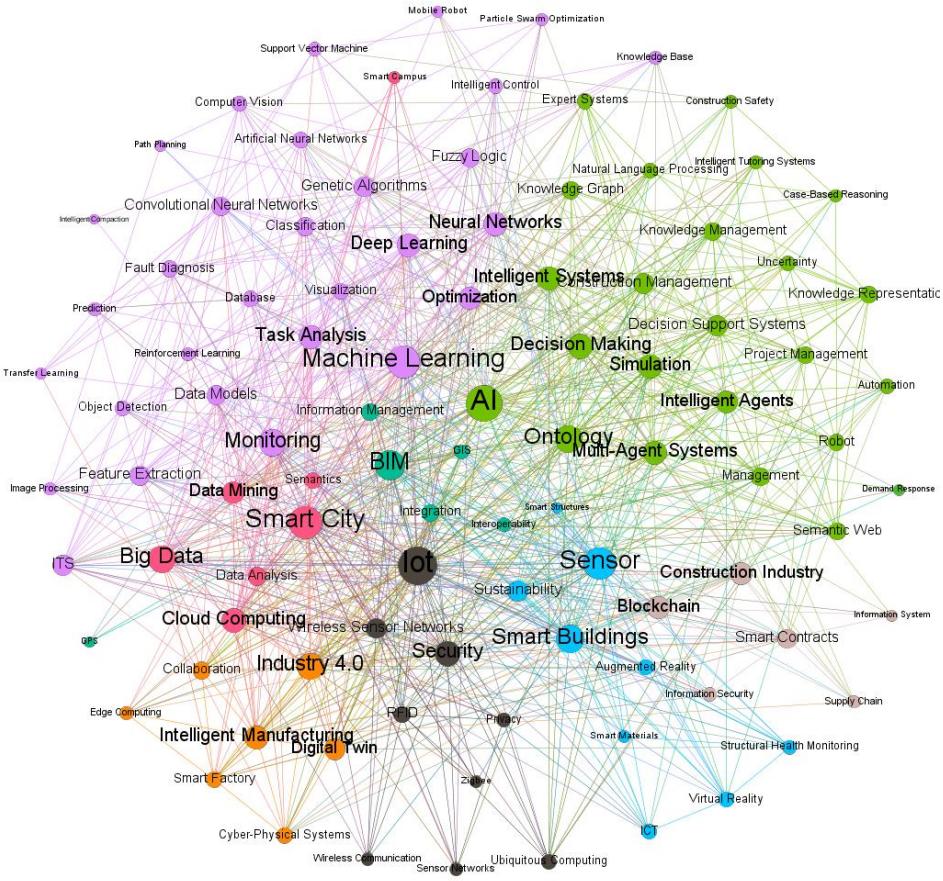

Fig. 7. Co-occurrence analysis of keywords in English articles research on intelligent construction

(1) Cluster 1: knowledge representation, learning, and utilization

Compared with images and audio, it is easier to collect text data in construction projects, however, more than 80% of text data is unstructured. So, it is important to extract and understand text data automatically, intelligently, and cost-effectively (Gharehchopogh&Khalifelu, 2011). Natural language processing (NLP) technology can analyze text structure and word meaning.NLP can replace traditional manual procedures by training machine learning or deep learning models, thereby realizing automatic extraction and analysis of text data (Wu et al., 2022). Based on Global Vectors for Word Representation (GloVe), LSTM, Gated Recurrent Unit (GRU), and Symbiotic Organisms Search (SOS), Cheng et al. implemented construction site incident documentation, which allows safety professionals to try more accurate prevention strategies (Cheng et al., 2020). Chen et al. built a fully automated platform for contract management by extracting keywords for construction project contracts through progressive scale expansion network (PSENet), convolutional recurrent neural network (CRNN), and bidirectional recurrent neural network-convolutional neural network (BRNN-CNN) (Chen et al., 2021).

(2) Cluster 2: digital twin

As mentioned in cluster 1 in Section 4.1.1, BIM and the IoT, two technologies that often appear at the same time, play an extremely important role in intelligent construction. Combining BIM and IoT, the digital twin technology of the AEC industry come out. In the digital twin related research, how to integrate the data collected by the IoT (physics world) into the BIM model (virtual world) in a timely manner has become a research hotspot. Shu Tang et al. summarized 5 integration methods from 97 articles, including calling BIM model related APIs and databases, converting BIM data into relational databases using new schemas, creating new query languages, semantic networks, semantic networks, and relational databases (Tang et al., 2019). The first two methods use a database as an intermediate and integrate BIM model data and data collected by sensors. The third method directly integrates the BIM model with the sensor data, so that the sensor data can be queried directly on the BIM model or the IFC model. The last two methods store IFC and sensor data in the file format of RDF and use SPARQL uniformly for data queries.

(3) Cluster 3: intelligent algorithms and their applications

Construction projects are often accompanied by huge data streams, which are processed with ordinary algorithms will bring huge time costs. By training appropriate models, various AI methods can learn in large amounts of data to handle rapidly growing data. Meanwhile, due to the development of BIM models and IoT technology, intelligent algorithms such as computer vision can play a huge role in automation and digitization. Sizing optimization of truss structures is a key and difficult problem in engineering structural design. Therefore, Bureerat et al. proposed a meta-heuristic algorithm to solve such problems based on the concept of differential evolution and using a strategy adaptive scheme (Bureerat&Pholdee, 2016). Cha et al. developed a structural visual inspection method based on a fast regional convolutional neural network (Faster R-CNN) to achieve fast identification of five types of damage such as concrete crack, steel corrosion with two levels (medium and high), bolt corrosion, and steel delamination (Cha et al., 2018). Chen et al. detected, tracked, and identified excavator activities based on convolutional neural networks, and analyzed the results to achieve automatic monitoring of excavator productivity (Chen et al., 2020).

4.2.2 Research Trends

This paper analyzes the annual publication volume of 7065 English articles by keyword clustering. The development trend of English articles research is obtained by selecting the top ten keywords and their synonym expansion. The results are shown in Fig.10.

In general, the English articles in the field of intelligent construction have grown rapidly since 2015and mainly focus on BIM&IoT integration research. Semantic technology-related research has been higher than the other two until 2015, but the number of articles is all low. Since 2015, the research on BIM&IoT integration has seen a large increase, which has also led to an increase in the number of publications related to semantic technology and intelligent algorithms. It can be seen that the research of semantic technology and intelligent algorithms are closely related to BIM&IoT integration.

As shown in Figs. 8 and 9, because the English articles in the field of intelligent construction started early and have a good foundation, the research direction is wide, and the annual volume of papers for different keywords fluctuates greatly. In general, the annual publication volume of each keyword is on the rise. Good engineering management can effectively reduce the occurrence of accidents(Lin et al., 2019). Therefore, "BIM" and "IoT" are inseparable from "management", so the keyword "management" ranks high in the annual number of articles most of the time. Meanwhile, the research content of English articles is gradually shifting from theoretical methods such as "Knowledge Management", "Ontology" and "Optimization" to engineering practices such as "Decision Making" and "Smart City".

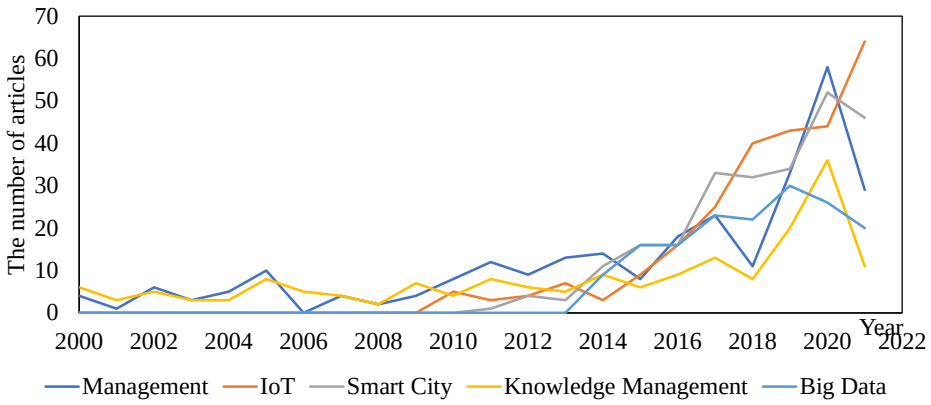

Fig. 8. Analysis of the annual publication volume of keywords ranked 1-5 in the total publication volume of English articles

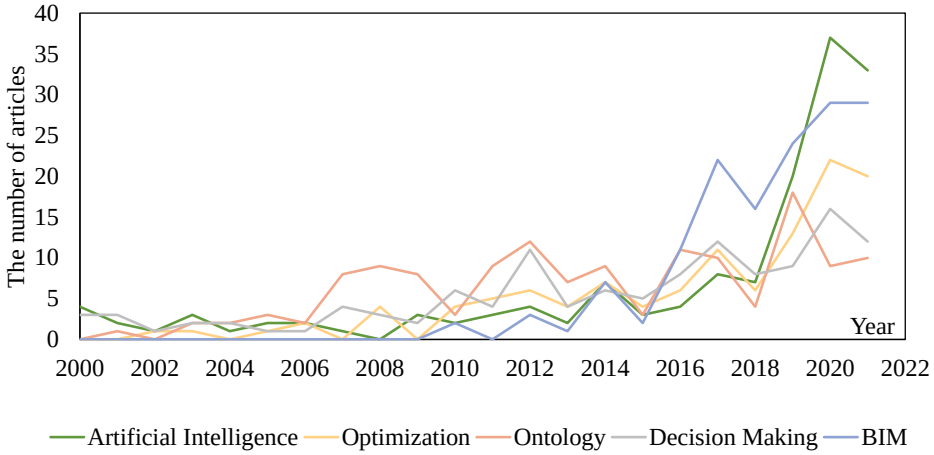

Fig. 9. Analysis of the annual publication volume of keywords ranked 6-10 in the total publication volume of English articles

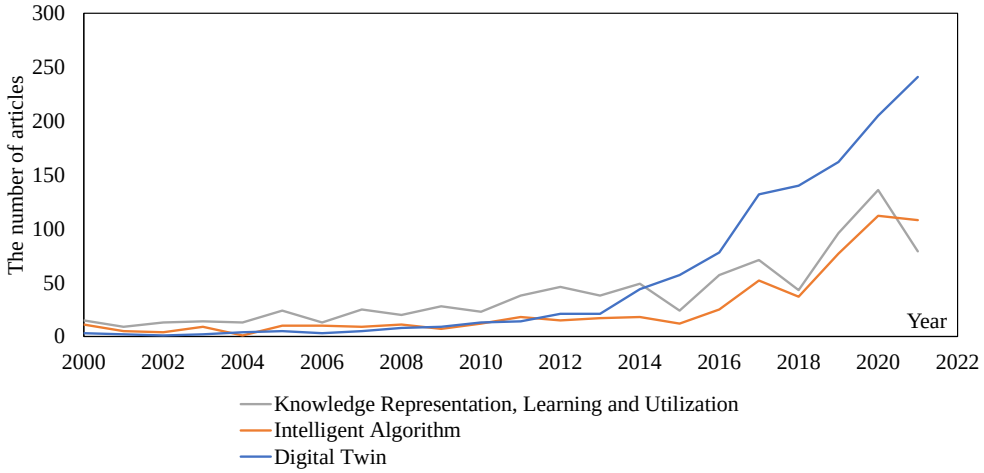

Fig. 10. Analysis of the annual publication volume of English articles intelligent construction research keyword clustering

5 Comparison of Chinese and English articles

As for the research basis, the English articles in the field of intelligent construction have a large base and a rapid growth rate. It has basically maintained exponential growth since 1990. Chinese articles have maintained a continuous growth trend since 2009. Although there has been explosive growth since 2016, the number of published articles is still lower than that of English articles due to a later start (Fig. 1).

The following are the characteristics of the research status of Chinese and English literature related to intelligent construction:

(1) In terms of research content and research trends, the English articles in the field of intelligent construction are more focused on methods and theories. In the early stage, the focus was on finding better algorithms or theoretical frameworks to adapt to the increase in the amount of data in the field of engineering construction. It was only in recent years that articles related to engineering applications gradually appeared.

(2) The evolution of the English articles has undergone the following transformation: the research has shifted from semantic technologies such as ontology and intelligent algorithms to specific applications such as task analysis, knowledge graphs, and smart city. It can be seen that the English articles have gradually transitioned from theoretical studies to applications.

(3) In the Chinese articles, the related research and engineering in the field of intelligent construction are more widely combined. Although it started late, it has been closely integrated with engineering since it has a certain foundation. The research content of Chinese articles is shifting from informatization research based on the IoT and BIM to collaborative development, building industrialization, and digital twin.

There are still more high-risk jobs in the construction industry, so the digitization and industrialization of construction are important for the improvement of this situation and even the upgrading and transformation of the whole construction industry.

6 Conclusion

Based on the bibliometric and visual analysis of Chinese and English articles in the field of intelligent construction from 1990 to 2021, this paper gives an overview of the research status and makes a comprehensive analysis of research hotspots and research trends. In summary, the characteristics of the current research in the Chinese and English articles in the field of intelligent construction and the issues that need attention can be found. In this field, Chinese articles have developed rapidly in recent years and have accumulated a certain foundation. Although it is closely integrated with engineering and has achieved a certain degree of productivity transformation, it lacks research on algorithms and theoretical frameworks such as computer version, semantic technology. The theoretical research foundation of English articles is better, and it has a certain stage. At present, it has transitioned from theoretical research to engineering application.

Combined with the development status of intelligent construction and related bibliometric analysis, it can be seen that future research and practice can make innovative contributions from the following aspects:

(1) Explore the integration methods of multi-dimensional information, improve information utilization, and eliminate information silos (Liu et al., 2021). Based on BIM technology, combined with IoT, physical engine, and other technologies, a digital twin model can be established. It can integrate various buildings' information such as geometric attributes, materials, real-time status, etc., and realize the collaborative design and comprehensive management of buildings from design, construction, operation, and maintenance.

(2) As mentioned in 4.2.1 Cluster 1 above, there are a lot of unstructured data, especially text data, in construction projects. The processing method of unstructured text data currently relies heavily on humans. Future research may focus on, automatically processing the unstructured text data into structured data based on natural language processing (NLP) technology. Thereby, the cost of processing will be greatly reduced, and the efficiency of project management and information processing could be improved.

References

Bai, X.J. (2021). Study of Prefabricated Assembly Building Based on EBIM Cloud Platform for Construction Management. *Railway Construction Technology*, 11, 165–169. (in Chinese) 白旭军. (2021). 基于 EBIM 云平台的预制装配式建筑施工管理研究. 铁道建筑技术, 11, 165–169.

Bastian, M., Heymann, S., &Jacomy, M. (2009). Gephi: An Open Source Software for Exploring and Manipulating Networks.

Bureerat, S., &Pholdee, N. (2016). Optimal Truss Sizing Using an Adaptive Differential Evolution Algorithm. *Journal of Computing in Civil Engineering*, 30(2), 04015019.

Cha, Y.J., Choi, W., Suh, G., Mahmoudkhani, S., &Büyüköztürk, O. (2018). Autonomous Structural Visual Inspection Using Region-Based Deep Learning for Detecting Multiple Damage Types: Autonomous SHM using deep faster R-CNN. *Computer-Aided Civil and Infrastructure Engineering*, 33(9), 731–747.

Chen, C., Zhu, Z., &Hammad, A. (2020). Automated Excavators Activity Recognition and Productivity Analysis from Construction Site Surveillance Videos. *Automation in Construction*, 110, 103045.

Chen, J.H., Su, M.C., Azzizi, V. T., Wang, T.K., &Lin, W.J. (2021). Smart Project Management: Interactive Platform Using Natural Language Processing Technology. *Applied Sciences*, 11(4), 1597.

Chen, H.L., Yang, X.J., Jiang, J., &Yu, Z. (2021). Research Progress of Multi-source Sensor Data and BIM Interactive Interface Technology of Internet of Things in Intelligent Construction Sites. *Sichuan Architecture*, 41(S1), 181–183. (in Chinese) 陈红林, 杨晓娇, 江军, &于忠. (2021). 智慧工地中物联网多源传感数据与 BIM 交互接口技术研究进展. 四川建筑, 41(S1), 181–183.

Chen, Y.P. (2021). Talking about The Technical Points of "Intelligent Construction Site" to Promote Construction Safety Management. *Construction Safety*, 36(12), 66–68. (in Chinese) 陈燕鹏. (2021). 浅谈“智慧工地”促进建筑施工安全管理技术要点. 建筑安全, 36(12), 66–68.

Cheng, M.Y., Kusoemo, D., &Gosno, R. A. (2020). Text Mining-based Construction Site Accident Classification using Hybrid Supervised Machine Learning. *Automation in Construction*, 118, 103265.

Dai, W.Y. (2017). Research On Prefabricated Constructions Based on BIM Technology [Master, Wuhan University]. (in Chinese) 戴文莹. (2017). 基于 BIM 技术的装配式建筑研究 [硕士, 武汉大学].

Deng, J., Ma, X.J., & Bi, Q. (2014). A Comparative Study of Social Network Analysis Tools Ucinet and Gephi. *ITA.*, 37(8), 133–138. (in Chinese) 邓君, 马晓君, &毕强. (2014). 社会网络分析工具 Ucinet 和 Gephi 的比较研究. 情报理论与实践, 37(8), 133–138.

Fan, Q.X., Lin, P., Wei, P.C., Ning, Z.Y., &Li, G. (2021). Closed-loop Control Theory of Intelligent Construction. *J Tsinghua Univ (Sci&Technol)*,61(7), 660–670. https://doi.org/10.16511/j.cnki.qhdxxb.2020.26.023. (in Chinese) 樊启祥, 林鹏, 魏鹏程, 宁泽宇, &李果. (2021). 智能建造闭环控制理论. 清华大学学报(自然科学版), 61(7), 660–670.

Han, B. (2021). Application of BIM Technology in Prefabricated Building. *Intelligent Building & Smart City*, 10, 68–69. (in Chinese) 韩冰.(2021). BIM 技术在装配式建筑中的应用. 智能建筑与智慧城市, 10, 68–69.

Gharehchopogh, F. S., &Khalifelu, Z. A. (2011). Analysis and Evaluation of Unstructured Data: Text Mining versus Natural Language Processing. *2011 5th International Conference on Application of Information and Communication Technologies (AICT)*, 1–4.

Gu, C.J. (2021). Application of BIM technology in the Deepening of Hospital Mechanical and Electrical Construction Drawings. *Detailed design & BIM technology*, 11, 60–63. (in Chinese) 顾传军. (2021). BIM 技术在医院机电施工图深化中的应用. 安装, 11, 60–63.

Li, Y.P., Ma, X.F., Liang, X., &Deng, Y. (2016). Research on Information Management of GreenConstruction Based on Cloud-BIM. *Construction Technology*, 45(18), 48–53. (in Chinese) 李英

攀, 马晓飞, 梁欣, &邓宇. (2016). 基于 Cloud-BIM 的绿色施工信息化管理研究. 施工技术, 18 vo45, 48–53.

Li, Y.J. (2021). Research on the Application of BIM Technology in Detailed Design of Prefabricated Buildings. *Intelligent Building & Smart City*, 10, 47–48. (in Chinese) 李永杰. (2021). BIM 技术在装配式建筑深化设计中的应用研究. 智能建筑与智慧城市, 10, 47–48.021.10.017.

Liao, Y.P. (2020). Accelerating the Transformation of the Construction Industry and Promoting High-Quality Development: Interpretation of "Guiding Opinions on Promoting the Coordinated Development of Intelligent Construction and Building Industrialization". *Housing Industry*, 09, 10–11. (in Chinese) 廖玉平. (2020). 加快建筑业转型 推动高质量发展——《关于推动智能建造与建筑工业化协同发展的指导意见》解读. 住宅产业, 09, 10–11.

Liu, D.D., Zhao, Y.S., Yue, Y.Y., Du, K., &Guo, Y.T. (2017). Application of BIM Technology in Assembly Building Design and Construction. *Building Structure*, 45(18), 48–53. 刘丹丹, 赵永生, 岳莹莹, 杜康, &郭衍涛. (2017). BIM 技术在装配式建筑设计与建造中的应用.建筑结构, 47(15):36-39+101.

Liu, H.Y. (2021). Application of BIM Technology in Construction Management: Taking China Zun Building as an Example. Scientific and Technological Innovation, 28, 85–87. (in Chinese) 柳红燕. (2021). BIM 技术在施工管理中的应用——以中国尊大厦为例. 科学技术创新, 28, 85–87.

Liu, Z.S., Liu, S.N., Zhao, Y.H., &Du, X.L. (2019). Development Status and Future Trends of Intelligent Construction Technology. *Architecture Technology*, 50(7), 772–779. (in Chinese) 刘占省, 刘诗楠, 赵玉红, & 杜修力. (2019). 智能建造技术发展现状与未来趋势. 建筑技术, 50(7), 772–779.

Liu, Z.S., Sun, X.T., &Shi, G.L. (2021). Summary of Application of Intelligent Construction in Civil Engineering Construction. *Construction Technology*, 50(13), 40–53. (in Chinese) 刘占省, 孙啸涛, &史国梁. (2021). 智能建造在土木工程施工中的应用综述. 施工技术(中英文), 50(13), 40–53.

Liu, Z.S., Zhao, M., &Xu, R.L. (2013). Application of BIM in the Architectural Design, Construction and Management of Buildings. *Building Technique Development*, 40(03), 65–71. (in Chinese) 刘占省, 赵明, &徐瑞龙. (2013). BIM 技术在建筑设计、项目施工及管理中的应用. 建筑技术开发, 40(03), 65–71.

Lin, F.Q. (2021). Construction Robot and Smart Site Application Starting Point and the Fall Point. *Mechanical Management And Development*, 36(02), 266–269. (in Chinese) 林凤钦. (2021). 建筑机器人及智慧工地应用出发点及着落点. 机械管理开发, 36(02), 266–269.

Lin, J.R., &Wu, D.P. (2021). An Approach to Twinning and Mining Collaborative Network of Construction Projects. *Automation in Construction*, 125, 103643.

Lin, J.R., Zhang, J.P., Zhang, X.Y., &Hu, Z.Z. (2019). Automating Closed-Loop Structural Safety Management for Bridge Construction through Multisource Data Integration. *Advances in Engineering Software*, 128, 152–168.

Mai, Y.F., Zhang, Q.W., &Sha, J.Q. (2020). An Integrated Smart Construction Management System Based on Bim+Iot System. *Construction Economy*, 41(06), 61–64. (in Chinese) 买亚锋, 张琪玮, &沙建奇. (2020). 基于 BIM+物联网的智能建造综合管理系统研究. 建筑经济, 41(06), 61–64.

Meng, C.X. (2015). Application Requirements for Big Data & Cloud ComputingTechnology in Rail Transit Engineering. *Journal of Information Technology in Civil Engineering and Architecture*, 7(05), 62–66. (in Chinese) 孟存喜. (2015). 大数据、云计算在轨道交通工程中的应用需求. 土木建筑工程信息技术, 05 vo 7, 62-66.

Meng, N. (2021). The Era of Construction Robots Has Come. *Construction and Architecture*, 16, 5. (in Chinese)孟楠. (2021). 建筑机器人时代已来. 建筑, 16, 5.

Pan, Y., &Zhang, L. (2021). Roles of Artificial Intelligence in Construction Engineering and Management: A Critical Review and Future Trends. *Automation in Construction*, 122, 103517.

Qi, B.K., &Li, C.F. (2014). Research on the Whole Lifecycle of Prefabricated Construction Manage

ment Based on BIM Technology. Construction Technology, 43(15), 25–29. (in Chinese) 齐宝库, &李长福. (2014). 基于 BIM 的装配式建筑全生命周期管理问题研究. 施工技术, 43(15), 25–29.

Shi, H., &Huang, J. (2021). Analysis of Key Points in the Design of Prefabricated Building Structures. *Engineering and Technology Research*, 6(16), 239–240. (in Chinese) 石华, &黄俊. (2021). 装配式建筑结构设计要点分析. 工程技术研究, 6(16), 239–240.

Song, X.F., & Chi, P.J. (2016). Comparative Study of the Data Analysis Results by Vosviewer and Citespace. *Information Science*, 34(7), 108-112+146. (in Chinese) 宋秀芳, &迟培娟. (2016). Vosviewer 与 Citespace 应用比较研究. 情报科学, 34(7), 108-112+146.

Su, S.L., Lei, J., Ma, S.P., Ding, P.R., &Qi, Z.R. (2019). Research and Application on Technology of Intelligent Building Robot. *Construction Technology*, 48(22), 16-18+25. (in Chinese) 苏世龙, 雷俊, 马栓棚, 丁沛然, &齐株锐. (2019). 智能建造机器人应用技术研究. 施工技术, 48(22), 16-18+25.

Sobhkhiz, S., Zhou, Y.C., Lin, J.R., &El-Diraby, T. E. (2021). Framing and Evaluating the Best Practices of IFC-Based Automated Rule Checking: A Case Study. *Buildings*, 11(10), 456.

Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., &Gao, X. (2019). A Review of Building Information Modeling (BIM) and the Internet of Things (Iot) Devices Integration: Present Status and Future Trends. *Automation in Construction*, 101, 127–139.

Tian, D.F. (2017). *Research on the Application of BIM Technology in Prefabricated Concrete Housing Construction* [Master, Hubei University of Technology]. (in Chinese) 田东方. (2017). BIM 技术在预制装配式住宅施工管理中的应用研究 [硕士, 湖北工业大学].

Van Eck, N. J., &Waltman, L. (2021) *VOSviewer Manual*. 54.

Wang, M.C. (2016). *Research on the Security Early Warning Method of Building Construction Projects Based on PSO-SVM Model* [Master, Shanghai University of Engineering Science]. (in Chinese) 汪马成. (2016). 基于 PSO-SVM 模型的建筑施工项目安全预警方法研究 [硕士, 上海工程技术大学].

Wang, X.G., Yang, R.L., &Chen, Z.J. (2020). Development and Application of Intelligent Temperature Monitoring System for Mass Concrete. Port & Waterway Engineering, 01, 118-121+143. (in Chinese) 王新刚, 杨润来, &陈智军; (2020). 大体积混凝土智能温控系统的研发及应用. 水运工程, 01, 118-121+143.

Wang, X.C., Tang Q., Dong Z.S., &Wang, R.H. (2021). Application of BIM + Technologies in Construction Management of Prefabricated Buildings. *Construction Economy*, 42(11), 19–24. (in Chinese) 王兴冲, 唐琼, 董志胜, &王瑞红. (2021). BIM+技术在装配式建筑建设管理中的应用研究. 建筑经济, 42(11), 19–24.

Wang, Z.W., Ma, W.B., Wang, Z.H., Zhang, S.L., &Guo, X.L. (2020). Prefabricated Tunnel Structure Intelligent Construction System Based on Lightweight BIM Technology, RFID Technology and ERP System. *China Railway*, 1, 16–21. (in Chinese) 王志伟, 马伟斌, 王子洪, 张胜龙, &郭小雄. (2020). 基于轻量化 BIM、RFID 技术与 ERP 系统的预制装配式隧道结构智能建造系统. 中国铁路, 1, 16–21.

Wu, C., Li, X., Guo, Y., Wang, J., Ren, Z., Wang, M., &Yang, Z. (2022). Natural Language Processing for Smart Construction: Current Status and Future Directions. *Automation in Construction*, 134, 104059.

Xu, K., Zhang, G.X., &Jiang, C.B. (2021). Design and Application of BIM-based Parametric Family Library in PC Component. *Fujian Architecture & Construction*, 11, 186–190. (in Chinese) 徐旷, 张桂雄, &蒋陈兵. (2021). 装配式 PC 构件的 BIM 参数化族库设计和应用. 福建建筑, 11, 186–190.

Xu, R., &Ye, F.Y. (2022). Three-Dimensional Visual Water Conservancy Safety Monitoring System Based on Digital Twin Technology. *Express Water Resources & Hydropower Information*, 43(01), 87–91. (in Chinese) 徐瑞, &叶芳毅. (2022). 基于数字孪生技术的三维可视化水利安全

监测系统. 水利水电快报, 43(01), 87–91.

Xu, J.Y., Chen, H., &Xiong, Y.Y. (2021). Comparison of Domestic and Foreign Research on Natural Ventilation of Buildings Based on Bibliometric Analysis. South Architecture, 6, 114–123. (in Chinese) 许江英, 陈宏, &熊鱼雅. (2021). 国内外建筑自然通风研究比较——基于文献计量分析. 南方建筑, 6, 114–123.

Yan, J.H., &Li, B.L. (2020). Research Hotspots and Tendency of Intelligent Manufacturing. *Chinese Science Bulletin*, 65(8), 684–694. (in Chinese) 闫纪红, &李柏林. (2020). 智能制造研究热点及趋势分析. 科学通报, 65(8), 684–694.

Ye, B. (2021). Current Situation and Development Trend of Intelligent Construction of Prefabricated Buildings. *Intelligent Building & Smart City*, 09, 104–105. (in Chinese) 叶斌. (2021). 装配式建筑智慧建造的现状及发展趋势. 智能建筑与智慧城市, 09, 104–105.

Ye, J.M. (2021). BIM-based Integrated Construction System for Prefabricated Buildings. Intelligent City, 7(24), 29–30. (in Chinese) 叶剑梅. (2021). 基于 BIM 的装配式建筑集成建造系统. 智能城市, 7(24), 29–30.

Yu, J.Q., Cao, J.F., &Lei, X.K. (2016). Current Situation and Prospects of Construction Robot Research. *Automation Panorama*, 08, 68–75. (in Chinese) 于军琪, 曹建福, &雷小康. (2016). 建筑机器人研究现状与展望. 自动化博览, 08, 68–75.

Zhang, W., Liao, Y.X., Jiang, L., &Zhao, T.S. (2021). Safety Monitoring System of Tower Crane Based on Internet Of Things. *China Safety Science Journal*, 31(02), 55–62. (in Chinese) 张伟, 廖阳新, 蒋灵, &赵挺生. (2021). 基于物联网的塔式起重机安全监控系统. 中国安全科学学报, 02 vo 31, 55–62.

Zhou, K.Z., Lu, N., Liu, T.Y., Li, X.M., &Huang, Y.C. (2020). Application of BIM and Prefabricated Technology in Qingdao International Conference Center Project. *Construction Technology*, 49(16), 28-30+35. (in Chinese) 周可璋, 卢宁, 刘天宇, 李晓明, &黄运昌. (2020). BIM+装配式技术在青岛国际会议中心项目中的应用. 施工技术, 49(16), 28-30+35.

Zhou, W.B., Jiang, J., &Xiong, C. (2012). Research on the Application of BIM Technology in Prefabricated Concrete Housing. *Construction Technology*, 41(22), 72–74. (in Chinese) 周文波, 蒋剑, &熊成. (2012). BIM 技术在预制装配式住宅中的应用研究. 施工技术, 41(22), 72–74.