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Visualization Analysis of Construction Robots Based on Knowledge Graph

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Abstract: Construction robots are pivotal in advancing the construction industry towards intelligent upgrades. To further explore the current research landscape in this domain, the CNKI Chinese database and the Web of Science core database were employed as data sources. CiteSpace software (version 6.2R4) was utilized to visualize and the analyze relevant literature on construction robots from 2007 to 2024, generating pertinent maps. The findings reveal an annual increase in the number of publications concerning construction robots. An analysis of institutions and authors indicates closer collaboration among English institutions, while Chinese authors exhibit stronger cooperation. However, overall institutional and author collaboration remains limited and fragmented, with no prominent core group of authors emerging. Research hotspots in both the Chinese and English literature are largely aligned, focusing on intelligent construction, human-robot collaboration, and path planning. Notably, the Chinese literature emphasizes technical aspects, whereas the English literature is more application-oriented. Future trends in the field are likely to include human-robot collaboration, intelligent construction, robot vision technology, and the cultivation of specialized talent.

Keywords: construction robots; visual analysis; CiteSpace; research hotspot

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1. Introduction

The construction of buildings is fundamental to human existence, representing a substantial component of the material production sector within the broader national economy [1]. However, several challenges are currently faced by the construction industry, even amidst its growth. In numerous countries, an aging population, alongside a decline in both the quantity and quality of the labor force, is presenting a significant challenge [2]. Simultaneously, increasing concerns are being raised regarding the efficacy of development methods, workforce productivity, quality of output, incidence of engineering safety accidents, and levels of energy consumption and emissions within the industry. An urgent transformation towards intelligent practices is needed to drive advancements with innovative construction models [3].

Scientific and technological innovation is currently highly valued across all sectors of society, with robots constituting a significant element of the intelligent construction industry due to their substantial research and application benefits. Construction robots have emerged as a central focus within this domain, contributing to enhanced construction efficiency and quality while reducing costs and risks. These advancements facilitate industrial upgrading, attract policy support, and bolster international competitiveness. In January 2023, the "Robot+" Application Action Implementation Plan was issued by China's

Ministry of Industry and Information Technology along with seventeen other departments. This plan explicitly advocates for the promotion of construction robots to expand their application scope. Additionally, it aims to synergize the development of intelligent construction with new building industrialization. The plan further details the implementation of "Robot+" application innovation and practice, the establishment of international and domestic exchange platforms, and the cultivation of a conducive environment for the widespread adoption of robotic applications [4].

This study was conducted to enhance the understanding of the current state of research in construction robots and to identify potential future research hotspots. Prior to 2007, the number of journal articles on construction robots in the CNKI Chinese database and the WOS core database was nearly nonexistent, indicating that related research was minimal and lacked reference value. The CiteSpace bibliometric method is employed in this study to conduct a metrological analysis of the research literature on construction robots from 2007 to 2024 in the CNKI Chinese database and the WOS core database. The objective is to analyze research institutions, authors, research vectors, hotspots, challenges, and trends within the field of construction robots.

2. Data Collection and Research Methods

In this study, CiteSpace software is utilized to quantify and examine the relevant literature within the domain of construction robots from the CNKI Chinese database and the WOS core database. The objective is to generate a series of knowledge maps to analyze publication volume, research focal points, research vectors, and emerging trends in this field.

2.1. Data Collection

An advanced search was conducted in the CNKI Chinese database, selecting "academic journals" as the literature type and using "Topic = construction robot" as the search term. Similarly, in the WOS Core Database, an advanced search was performed with the term "TS = construction robot" and a time range from 1 January 2007 to 30 June 2024. After de-duplication and the manual elimination of the unrelated literature, conference notices, interviews, and policy document interpretations, 710 valid documents were obtained from the CNKI database, while 2237 valid documents were retrieved from the WOS Core database. The findings in this paper are based on this dataset. Figure 1 illustrates the annual publication count in both databases, revealing a consistent upward trend in overall volume. Notably, a significant increase in article volume was observed starting in 2018. Based on the upward trend and article volume in the first half of 2024, it is reasonably inferred that CNKI will publish approximately 130 articles, while WOS will publish around 400 articles in 2024.

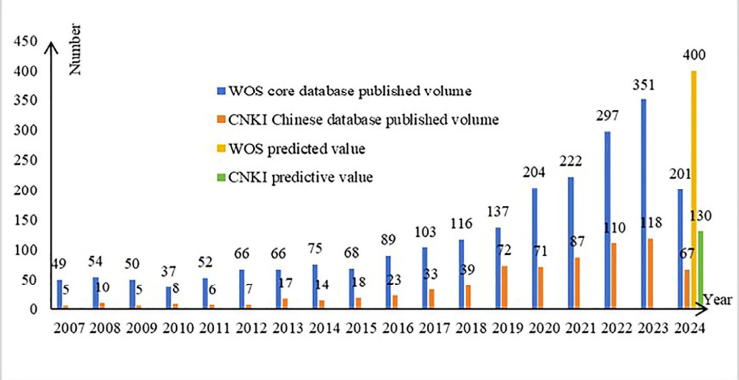


Figure 1. The annual number of construction robots-related publications from 2007 to 2024.

2.2. Research Methods

CiteSpace, a scientific bibliometric visualization and analysis software developed by Prof. Chaomei Chen of Drexel University on the Java platform, is employed in this study [5]. CiteSpace6.2R4 is utilized to enumerate the annual publication count in order to analyze trends in article volume, as well as the distribution and collaboration among authors and institutions, thereby elucidating research trends in this field. Keywords are analyzed through co-occurrence, clustering, and prominence to identify research hotspots, thematic veins, and trends. Based on this analysis, the representative literature is examined, and all results are comprehensively assessed to explore future development trends in the field of construction robots.

3. Results

3.1. Analysis of Institutional Cooperation Network

The comparative analysis of the literature revealed notable discrepancies in publication output among the top ten organizations in each database, as shown in Table 1. While the CNKI Chinese database documented a modest total of 15 articles, the WOS Core Database demonstrated a significantly greater output, with 72 articles—nearly five times that of the CNKI. Furthermore, the tenth-ranked organization in the WOS database published more than ten articles, which is beyond what the leading organization in the CNKI database achieved. This highlights the considerably smaller number of articles in the CNKI database compared to the WOS Core Database.

Network density is a measure defined as the ratio of the actual number of relationships to the theoretical maximum number of relationships within a network. In a directed network comprising n nodes, where the actual number of relationships is m, and the theoretical maximum is $n(n-1)$, the network's density is expressed as $\frac{m}{n(n-1)}$, with a maximum achievable value of 1. An increase in density indicates a higher level of cooperation among organizations as the limit of 1 is approached [6]. The Institutional Co-occurrence Network can illuminate the authoritative standing of a particular research domain, analyze the characteristics of inter-institutional collaboration, and offer a new perspective for assessing the academic influence of research institutions. Figure 2 illustrates the Institutional Co-occurrence Network within the CNKI Chinese database. The prominence of fonts representing the School of Architecture and Urban Planning of Tongji University and Bright Dream Robotics signifies a substantial number of published articles, suggesting notable engagement in the field of construction robots and demonstrating strong research capabilities. The network depicted in Figure 2 consists of 329 nodes and 111 connecting lines, resulting in a network density of 0.0021, which is significantly lower than 1. This low density indicates a scarcity of cooperation among institutions, particularly between universities and enterprises, and underscores a lack of awareness regarding the necessity for such collaboration. Consequently, it is recommended that research on construction robots should be directed towards enhancing institutional collaboration and developing a university-enterprise linkage model to further progress in this field.

The institutional co-occurrence network map of the WOS core database is depicted in Figure 3. The network consists of 423 nodes and 693 connecting lines, with a network density of 0.0078. A relatively close collaboration between institutions is evident, with several prominent networks having formed around key institutions such as the Chinese Academy of Sciences, the Swiss Federal Institutes of Technology Domain, Harbin Institute of Technology, Zhejiang University, the French National Center for Scientific Research, and Shanghai Jiao Tong University. This configuration within the WOS core database illustrates the prevalence of extensive and intimate collaborations among these institutions.

Table 1. Top 10 institutions in database annual publication volume from 2007 to 2024.

	Institution	Count
CNKI Chinese database	School of Architecture and Urban Planning, Tongji University, Shanghai, China	15
	Bright Dream Robotics, Foshan, China	13
	Guangdong Bogarto Construction Technology Co. Foshan, China	8
	China Construction Eighth Engineering Bureau Co. Shanghai, China	6
	School of Electro-mechanical Engineering, Guangdong University of Technology, Guangzhou, China	5
	School of Geodesy and Geomatics, Wuhan University, Wuhan, China	5
	School of Mechanical and Aerospace Engineering, Jilin University, Changchun, China	4
	Wuhan Business University, Wuhan, China	4
	School of Robots Science and Engineering Northeastern University, Shenyang, China	4
	Guangdong Nonferrous Engineering Survey and Design Institute, Guangzhou, China	4
WOS core database	Chinese Academy of Sciences, Beijing, China	72
	University of Michigan System, Michigan, America	52
	Swiss Federal Institutes of Technology Domain, Zurich, Switzerland	38
	Harbin Institute of Technology, Harbin, China	37
	Zhejiang University, Hangzhou, China	32
	Centre National de la Recherche Scientfique, Paris, France	32
	Shanghai Jiao Tong University, Shanghai, China	28
	Tsinghua University, Beijing, China	27
	Hong Kong Polytechnic University, Hong Kong, China	27
	Beijing Institute of Technology, Beijing, China	24

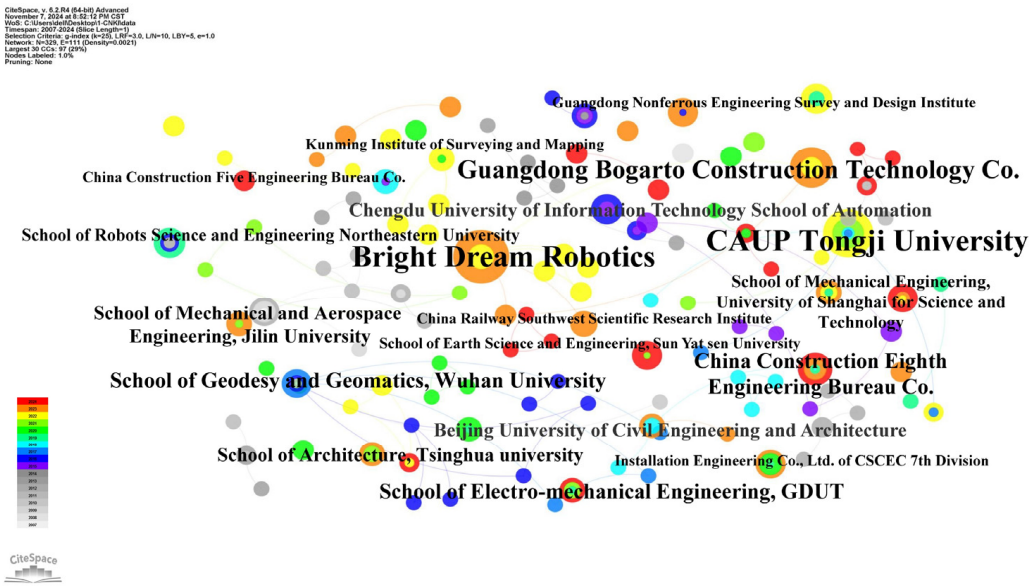


Figure 2. Institutional co-occurrence network map in CNKI Chinese database.

By analyzing the current state of inter-institutional cooperation, it is suggested that such collaboration needs to be further strengthened. Strengthening cooperation not only facilitates the integration of information, human resources, equipment, and technology to achieve resource sharing and complementarity of professional advantages for promoting collaborative innovation, but it also contributes to the cultivation and development of talent. This approach broadens individuals' horizons, enhances their comprehensive abilities, and fosters a sense of collaboration, which holds irreplaceable significance for the advancement of all involved parties and the overall progress in the field of construction robots.

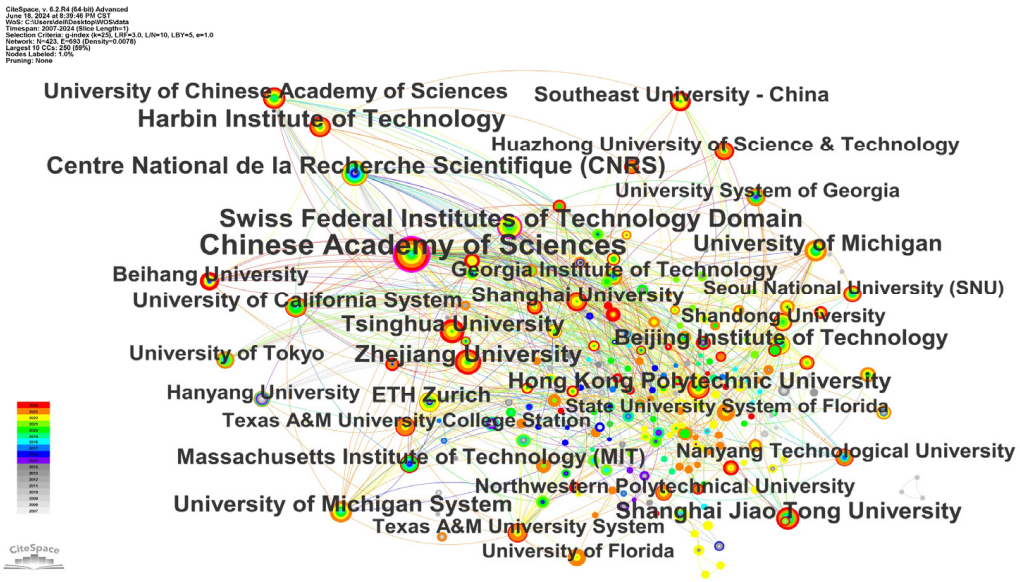


Figure 3. Institutional co-occurrence network map in WOS core database.

3.2. Analysis of Author Co-Occurrence Network

Analyzing the relationships between authors gives a clear picture of patterns of academic collaboration within a field and can help identify key authors within that field. In examining the relationship between the number of scientists and the volume of scientific publications, the renowned American historian of science, Price, identified a distinctive pattern between the total number of scientists and the number of eminent ones. This pattern was discerned through the analysis of a substantial dataset, leading to the calculation of a coefficient of 0.749. This study applies Price's theory to analyze central authors, with the condition that the number of articles considered is at least N. Generally, when the articles authored by the "core authors" constitute 50% of the total number of articles, it can be inferred that a "core group of authors" has been established. The mathematical formula for determining core authors is as follows [7]:

$$N = 0.749\sqrt{\eta_{\max}} \quad (1)$$

In the formula: N is the number of publications that meets the minimum requirement for core authors; $\eta_{\max}$ is the number of publications of the author with the highest number of publications.

By utilizing CiteSpace software to analyze and enumerate the authors within the literature, the ten most prolific authors in terms of publication volume are identified, as presented in Table 2. In the CNKI Chinese database, the author has the highest publication count and has produced 15 articles, which corresponds to the maximum value of $\eta_{\max} = 15$. According to Formula (1), this author's output can be approximated as N $\approx$ 2.901. In the WOS core database, the author with the highest publication count in the field of construction robotics has published 10 articles, which corresponds to the maximum value of $\eta_{\max} = 10$, resulting in a value of N $\approx$ 2.369 according to Formula (1). Consequently, it can be concluded that authors who have published three or more articles are considered the core contributors in this field.

Table 2. Top 10 authors in databases annual publication volume from 2007 to 2024.

	Author	Institution	Count
CNKI Chinese database	Yuan, Feng	CAUP Tongji University, Shanghai, China	15
	Duan, Han	Guangdong Bogarto Construction Technology Co. Foshan, China	6
	Wang, Peng	School of Architecture, Tsinghua University, Beijing, China	4
	Li, Xiao	School of Electro-mechanical Engineering, GDUT, Guangzhou, China	4
	Lu, Songyao	Guangdong Nonferrous Engineering Survey and Design Institute, Guangzhou, China	4
	Chen, Linxin	Guangdong Bogarto Construction Technology Co.	4
	Chen, Gaohong	Bright Dream Robotics, Foshan, China	3
	Zhang, Junhua	Kunming Institute of Surveying and Mapping, Kunming, China	3
	Liu, Jinyue	HBUT School of Mechanical Engineering, Harbin, China	3
	Lu, Chunting	Installation Engineering Co., Ltd. of CSCEC 7th Division, Zhengzhou, China	3
WOS core database	Li, Heng	Hong Kong Polytechnic University, Hong Kong, China	10
	Kamat, Vineet R	University of Michigan, Dept Civil, Ann Arbor, Michigan, USA	9
	Du, Jing	Department of Civil and Coastal Engineering, University of Florida, Gainesville, Florida, USA	8
	Zhang, Tao	School of Economics and Management, Tongji University, Shanghai, China	8
	Menassa, Carol C	Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, Michigan, USA	8
	Zhou, Tianyu	Department of Civil and Coastal Engineering, University of Florida, Gainesville, Florida, USA	8
	Zhu, Qi	Department of Civil and Coastal Engineering, University of Florida, Gainesville, Florida, USA	6
	Kromoser, Benjamin	University of Natural Resources and Life Sciences, Green Civil Engineering Institute, Vienna, Austria	6
	Jebelli, Houtan	Department of Civil and Environmental Engineering, University of Illinois at Urbana-Campaign, Urbana and Champaign, Illinois, USA	6
	Menges, Achim	Institute for Computational Design and Structures ICD, University of Stuttgart, Stuttgart, Germany	6

The author co-occurrence network map, produced using CiteSpace, serves to quantify the extent of scholarly contribution and collaboration among researchers [8]. Figure 4 illustrates the co-occurrence network map of authors in the CNKI Chinese database. As evidenced in conjunction with Table 2, Yuan Feng, from the School of Architecture and Urban Planning at Tongji University, who focuses on intelligent building design and the construction of building robots, emerges as the most prolific author. In terms of collaborative groups, several have been established, with notable research groups centered around Yuan Feng and Duan Han of Guangdong Bogarto Architecture Technology Co. Overall, Figure 4 features 436 nodes and 311 connections, resulting in a network density of 0.0033. The number of connections is lower than the number of author nodes, and the low network density indicates a relatively dispersed group of researchers with limited collaboration. The author co-occurrence network map in the WOS core database is depicted in Figure 5, in conjunction with Table 2. This map consists of 566 nodes, 269 connecting lines, and a network density of 0.0017, forming a collaborative network centered on Kamat, Vineet R., and Menassa, Carol C., which includes Liu, Yizhi, Lee, Sang Hyun, as well as Zhou, Tianyu, and Du, Jing, as part of the core collaborative group.



Figure 4. Author co-occurrence network map in CNKI Chinese database.

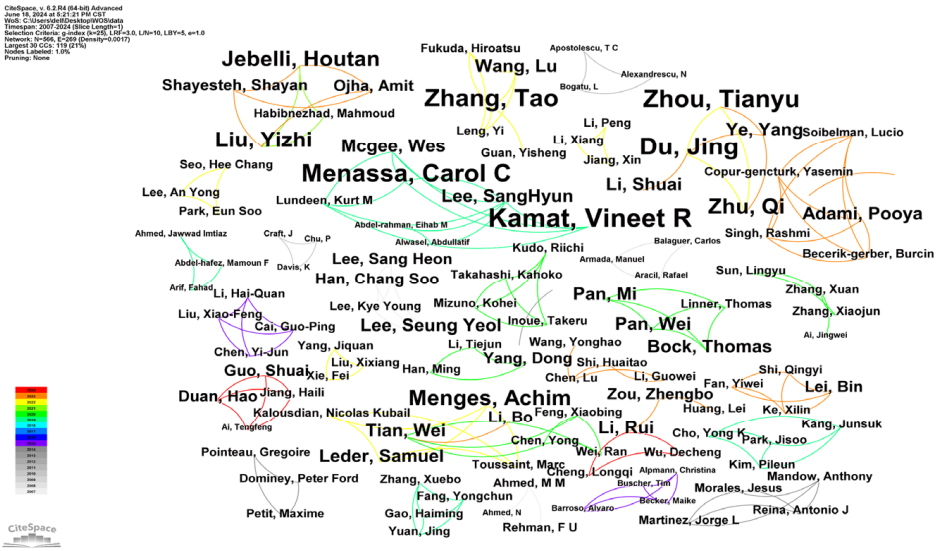


Figure 5. Author co-occurrence network map in WOS core databases.

In conclusion, it can be observed that authors in the CNKI Chinese database engage in more frequent and extensive collaboration with each other. However, the level of interconnectivity among authors across both databases remains comparatively limited and dispersed. The analysis revealed that 23 core authors in the CNKI database account for 12.29% of the total number of articles, while 46 core authors in the WOS database represent 9.03% of the total articles. Notably, none of these authors constitute a core group, as defined by the proposed Formula (1).

3.3. Analysis of Hot Research Topics

Keywords are of great importance to the research topic of the article, reflecting the core of the research and the direction of the literature. They play a crucial role in revealing the development of the research topic [9].

3.3.1. Keyword Co-Occurrence

The data were imported into CiteSpace software, with the time interval set to one year to facilitate the analysis of keywords. Figure 6 presents the keyword co-occurrence map for the Chinese literature, which comprises 366 nodes and 447 connecting lines, resulting

in a network density of 0.0067. The nodes represent keywords, while the connecting lines indicate the co-occurrence relationships between them. Table 3 illustrates the ten most frequently occurring keywords in the Chinese literature, where "year" denotes the year of the keyword's first appearance. A review of Figure 6 and Table 3 reveals that "robot" is the keyword with the highest frequency, accompanied by a centrality score of 0.44, indicating that robots are the most prominent research topic in this domain. Conversely, the prevalence of keywords such as deformation monitoring, intelligent construction, and artificial intelligence suggests a heightened interest in research related to construction robots. In addition to keywords with high frequency and centrality, terms like new engineering, talent cultivation, teaching reform, and curriculum system reflect the ongoing educational reforms being implemented by various universities in response to contemporary developments.

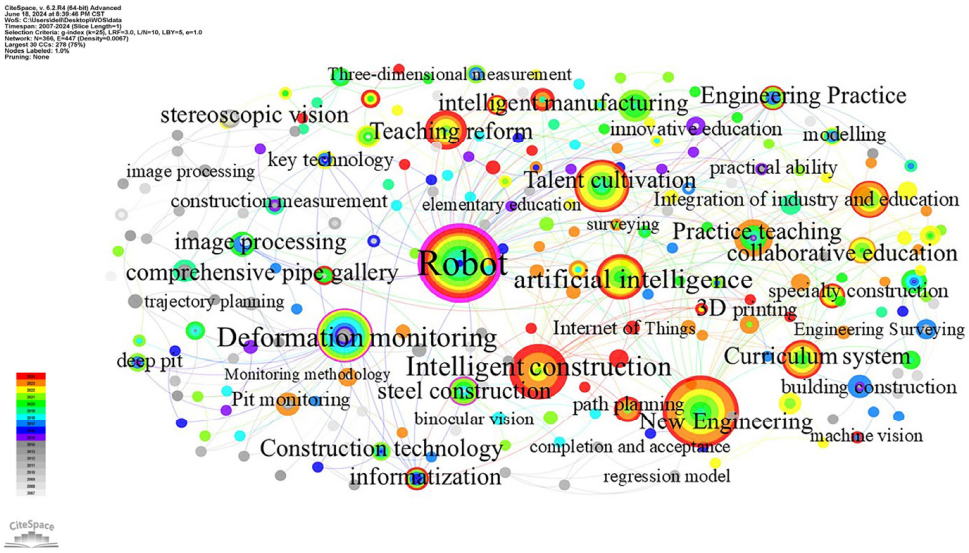


Figure 6. Keyword co-occurrence network map in the Chinese literature.

Table 3. Top 10 keywords in the Chinese literature frequency.

Keyword	Count	Centrality	Year
Robot	64	0.44	2007
New engineering	47	0.04	2019
Deformation monitoring	32	0.2	2008
Talent cultivation	31	0.02	2013
Intelligent construction	30	0.07	2021
Artificial intelligence	21	0.05	2019
Teaching reform	18	0.01	2010
Curriculum system	18	0.04	2019
Practice teaching	12	0.01	2013
Integration of industry and education	12	0.01	2019

Figure 7 illustrates the co-occurrence map for English keywords, consisting of 562 nodes and 2718 connecting lines, resulting in a network density of 0.0172. Table 4 presents the ten most frequently occurring keywords in the English literature. An examination of Figure 7, in conjunction with Table 4, reveals that the keywords "construction", "robot", and "mobile robots" demonstrate high centrality, which aligns with the prevalent research themes in this field. Furthermore, the substantial word frequency and centrality of keywords such as "design", "system", "model", "algorithm", "optimization", "path planning", "tracking", and "task analysis" reflect the research methodologies employed within

this domain. Specifically, path planning, tracking, and task analysis are representative of the methodologies utilized in this field.

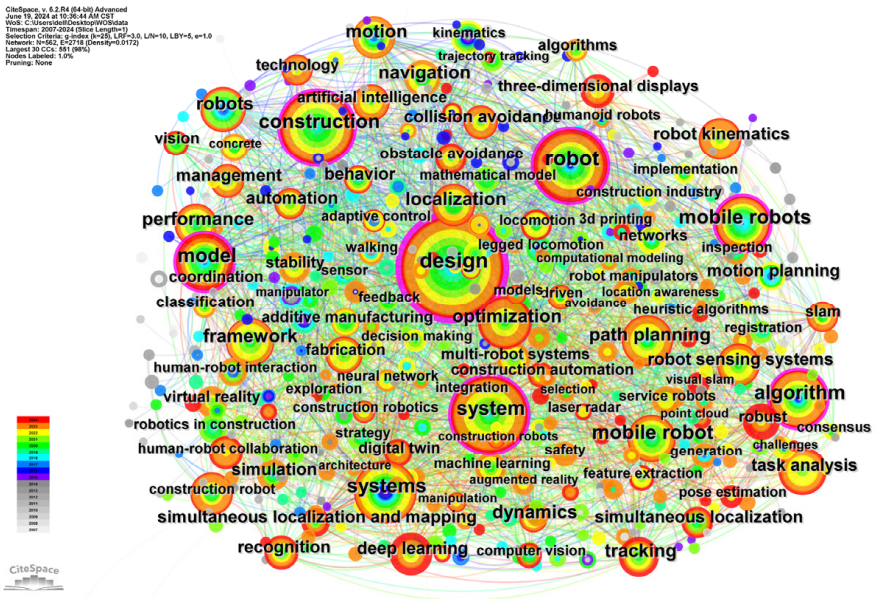


Figure 7. Keyword co-occurrence network map in the English literature.

Table 4. Top 10 keywords in the English literature frequency.

Keyword	Count	Centrality	Year
design	235	0.23	2007
construction	150	0.18	2007
system	146	0.12	2008
robot	134	0.17	2007
mobile robot	82	0.09	2008
model	79	0.13	2008
mobile robots	78	0.12	2007
systems	76	0.09	2011
algorithm	75	0.11	2007
optimization	67	0.06	2012

3.3.2. Keywords Cluster Analysis

Cluster analysis is a widely employed technique in the fields of statistical data analysis and knowledge discovery, utilized to uncover hidden themes within textual data. Through the application of cluster analysis, a substantial number of keywords can be classified into various research themes. This process allows for the categorization of keywords into related themes, thereby facilitating the identification of research trends and the interconnections within a given research field. Utilizing CiteSpace software, the literature was clustered to ascertain the relevance of the keywords. The ordinal number of a smaller cluster signifies its size, where larger and more cohesive clusters suggest greater activity and potential as current or future hotspots [10]. Figure 8 illustrates the keyword clustering timeline mapping of the Chinese literature, comprising nine clusters. It is evident that the clustering scale of robot engineering, path planning, and the related literature is larger. Similarly, Figure 9 presents the keyword clustering timeline mapping of the English literature, which also indicates that clusters pertaining to humanoid robots, path planning, and task analysis are notably larger. From this analysis, it can be initially inferred that path planning emerges as a significant research focus and a prominent topic within the field of construction robots.

The Chinese keyword clustering timeline mapping produced a total of 366 nodes and 447 connecting lines, resulting in a network density of 0.0067. The findings included a Modularity Q of 0.7609 and a Weighted Mean Silhouette S of 0.9678. A Q value greater than 0.3 indicates that the delineation of the structure is significant and that the clustering results are optimal. Similarly, an S value greater than 0.5 suggests that the clustering results are reasonable [11]. As shown in Figure 8, the English keyword clustering timeline mapping consists of 562 nodes. The Q value, recorded at 0.3891, surpasses 0.3, signifying that the discerned structure is significant and the clustering outcome is optimal. Furthermore, the Weighted Mean Silhouette is 0.7372, which demonstrates that the clustering is efficient and convincing when the S value is at 0.7. This implies that the homogeneity of this clustering mapping is high, and the overall clustering quality is excellent.

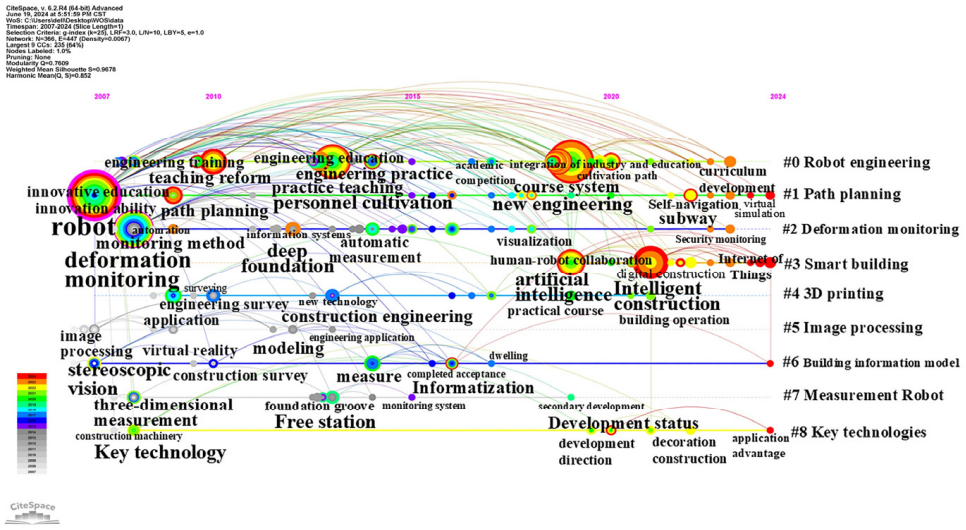


Figure 8. Keywords clustering time map in Chinese literature.

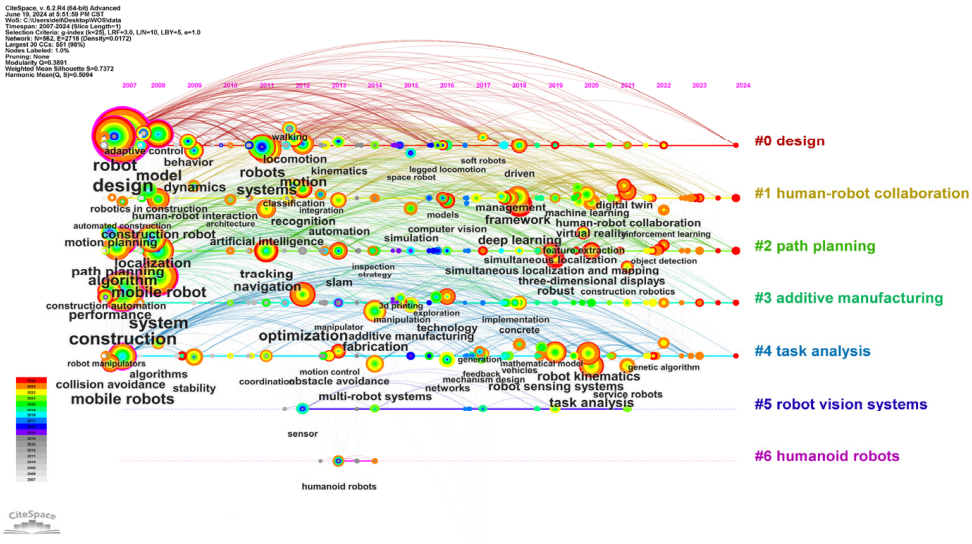


Figure 9. Keywords clustering time map in the English literature.

As illustrated in Figure 8, the keyword clustering timeline mapping of Chinese literature indicates that robot engineering, path planning, deformation monitoring, and intelligent construction are the current research focal points within the domain of construction robots. Research related to robots was initially introduced in the field of construction engineering in 2007 and has continually evolved to the present day. Teaching reform was first introduced in 2010, with the subsequent reform in 2013 placing greater emphasis on

practical teaching in talent cultivation. In 2019, the concept of "new engineering" was proposed, leading to a transformation in talent cultivation modes and pathways. The focus shifted towards the integration of industry and education, emphasizing the learning of artificial intelligence, intelligent construction, robot engineering, and related knowledge areas. Additionally, innovative applications such as digital construction were promoted. As illustrated in Figure 9, the English keyword clustering timeline mapping reveals that design and human-robot collaboration have emerged as significant research foci. Since 2007, research on construction robots in English literature has predominantly concentrated on these areas, along with path planning, task analysis, and robot vision systems.

3.3.3. Analysis of Research Hotspot

A timeline mapping of keyword clustering, examined alongside the theme of construction robots, reveals that current research in this field is concentrated on several key areas, including path planning, deformation monitoring, intelligent construction, 3D printing, human-robot collaboration, task analysis, and robot vision systems. The objective of this article is to review and analyze representative papers related to these topics.

1. Path planning

The term "path planning" refers to the process of employing automated systems and algorithms to determine optimal movement paths. In the realm of construction robots, path planning is of paramount importance as it relates to how robots navigate and execute tasks with efficiency and safety on construction sites. A hybrid genetic ant colony algorithm was proposed by Zhang et al. [12], which integrates pheromones of genetic algorithm chromosomes and ant colony algorithm search paths to study construction robot pathways. Wang et al. [13] developed a navigation map based on a BIM model, combined with an optimized A* algorithm, to achieve optimal global path planning for construction robots, enabling real-time obstacle avoidance. Fernando Torres et al. [14] introduced a Lidar-based plain valley path method that is immune to OSM errors, thereby compensating for the low local accuracy of OSM and facilitating seamless obstacle avoidance and task execution by construction robots. Yang et al. [15] enhanced the traditional RRT algorithm using BIM navigation maps, integrating it with the DWA algorithm to increase obstacle avoidance flexibility for moving construction robots. Gao et al. [16] proposed an autonomous exploration method for mobile robots utilizing graph-based SLAM with 2D laser technology, with experimental validation demonstrating its efficacy in robot mapping and exploration tasks. Huang et al. [17] generalized the emerging edge computing paradigm to multi-robot SLAM by combining a multi-robot laser SLAM system for efficient co-processing in the cloud. Liu et al. [18] introduced a semantic-assisted Lidar tightly-coupled SLAM method to reduce interference from dynamic objects and environments, extending its applicability to complex 3D dynamic environments. Concurrently, Li et al. [19] employed a method integrating Euclidean space and angle thresholds to enhance the efficiency and accuracy of the SLAM algorithm point cloud processing, verifying the algorithm's feasibility and reliability in real-world scenarios. Current research in path planning predominantly focuses on three critical areas: enhancing localization accuracy, advancing autonomous navigation, and mitigating the impacts of dynamic environments on robot performance. The aim of this research is to improve the precision and resilience of construction robots in their operational activities.

2. Deformation monitoring

Deformation monitoring technology is employed not only to ensure the safety and stability of structures but also to facilitate the advancement of construction robotics. Zhou et al. [20] introduced a deep foundation pit monitoring and early warning system that

utilizes a Leica TPS1200+ measuring robot. This system collects data via a VB platform, GeoCOM interface, and remote wireless transmission to enable communication control between the robot and a computer. Data processing is subsequently conducted using wavelet analysis. Zhang et al. [21] proposed a real-time detection method based on Grubbs' criterion, which is explored as a type of historical data analysis. Zheng et al. [22] developed software for automated pit deformation detection using the Android operating system, Bluetooth communication, and a measurement robot as its hardware foundation. This software satisfies the requirements for convenience, accuracy, and timeliness in pit deformation detection. Zhang et al. [23] investigated the bonding properties of UHPC to stone under various interface treatment methods to enhance building stability through material selection. Ji et al. [24] proposed an integrated approach combining GNSS technology, inclination sensors, and high-precision measuring robots for the horizontal deformation monitoring of ultra-high-rise buildings. Research in deformation monitoring technology aims to improve the precision and responsiveness of monitoring processes. Currently, these techniques are predominantly applied in the monitoring of pits and the deformation of high-rise structures to ensure the safety of construction projects.

3. Intelligent construction

The advancement of construction robots represents a promising development within the realm of intelligent construction. The increasing demand for intelligent construction has spurred innovation in the design, manufacturing, and control technologies associated with construction robots. Yuan et al. [25,26] introduced a digital construction technology system tailored for batch customization in prefabricated buildings, additionally proposing a digital building and intelligent design and construction process specifically for bricks. Duan et al. [27] identified construction robots as core components for optimizing quality and enabling the full-cycle digital formation of the building construction process, further emphasizing their role as key drivers in the advancement of intelligent construction. Zhao et al. [28] advocated for the integration of BIM (Building Information Modeling), detailed design, automated processing, and 3D simulation techniques to enhance the efficiency and quality of designing and constructing complex-shaped buildings. Gao [29] proposed an intelligent construction method for box house structures utilizing BIM visualization programming alongside the RT-Star algorithm. Wang et al. [30] highlighted the digital model of spatial and temporal information of buildings, which evolves with project progress, as the digital infrastructure critical to construction, forecasting that future digital building engineering will inherently possess characteristics of intelligence, platform integration, and industrialization. In addressing the construction industry's aspiration to create architecture that seamlessly integrates humans, the built environment, and technology, as well as the necessity for highly skilled technical professionals, Li et al. [31] proposed a model for cultivating talent in new engineering disciplines within an intelligent construction context. Currently, research in the field of intelligent construction is flourishing, predominantly concentrating on three areas: ongoing technological innovation, expanding application scenarios, and enhanced talent development and team-building efforts.

4. 3D printing

Currently, 3D printing technology is utilized for the rapid and precise fabrication of building components. The integration of construction robots with 3D printing technology enables the automated and intelligent production of these components, thereby improving the efficiency and quality of building construction. A comprehensive overview of the progressive integration of 3D printing in construction engineering was provided by Zuo et al. [32], who proposed a technical framework for the advancement of 3D printing technology, specifically in the context of ultra-high-rise buildings. Liu [33] proposed a

3D printing technology system for filler construction consisting of two components: a 3D printing assembly line robot operation system and a 3D printing technology adjustment system for filler construction. Hong et al. [34] suggested the use of an enhanced Q-learning technique to align the information decision-making process with the optimal robot state as identified through machine learning. This approach aims to facilitate the generation of optimal 3D printing robot paths while minimizing computational time requirements. Zeng et al. [35] introduced a novel method for the intelligent detection of porosity in 3D-printed concrete, combining a target detection algorithm with a lightweight, intelligent approach to address the limitations of existing techniques, such as dependence on manual labor, extended detection times, and high costs. At present, 3D printing is primarily employed in architecture for architectural modeling, meeting the specific requirements of the construction process. Technology is continuously advancing, with the aim of reducing time consumption, labor costs, and expenses.

5. Human-robot collaboration

The model of human-robot collaboration emphasizes the necessity of close interaction between humans and robots in the workplace, highlighting the importance of joint efforts to achieve specific work objectives. The effective implementation of human-robot collaboration not only enhances the efficiency and quality of building construction but also facilitates the transformation and upgrading of the construction industry. In their study, Huang et al. [36] employed a reinforcement learning (RL)-based construction robot to engage in active learning of automated control through environmental interactions. This approach allows the robot to operate based on its perceived state and objectives without human intervention, thereby reducing personnel workload. Additionally, Zhu et al. [37] proposed deep reinforcement learning (DRL)-based optimization methods that are directly applicable to various robot-assisted construction scenarios. Liang [38,39] and his team introduced a model of human-robot interaction employing the 12PL-DT-VR system, where humans are responsible for high-level task planning and workflow supervision while robots execute physical tasks. This model facilitates telecollaboration between construction workers and robots. Concurrently, the team proposed a novel method for categorizing collaborative human-robot work, indicating a promising direction for future research in this field. Yang et al. [40] suggested a framework designed to serve as an organizational tool to support future research and exploration in human-robot collaboration by interlinking the domains of systems, design, and human-centeredness. Liu et al. [41] introduced a method to enhance the safety of human-robot collaboration by focusing on the worker and using electroencephalography to capture brainwaves. This method enables the robot to acquire relevant task information and execute it accordingly. Current research in human-robot collaboration primarily focuses on reducing the physical burden on workers while ensuring construction quality and safety. It is anticipated that advancing intelligent construction management will further enhance work efficiency.

6. Task analysis

Task analysis serves as a critical tool in advancing the construction industry toward enhanced efficiency, safety, and sustainability across various key domains. In research conducted by Bakdi et al. [42], a dual Kinect camera vision system was proposed to furnish depth information to robots. This system, coupled with image processing technology, accurately simulates the surrounding environment. Genetic algorithms are then employed to devise the optimal path for avoiding object collisions, while adaptive fuzzy logic is utilized to control the robot's speed, thus realizing the planning and execution of the mobile robot's optimal path and enhancing its overall performance. The impact of digital fabrication on the construction industry was investigated by De Soto et al. [43], who

analyzed both the cost and time requirements for the on-site construction of robotically fabricated complex concrete walls and evaluated the implications for construction productivity. Hartmann et al. [44] presented a system designed to parallelize complex task and motion planning problems using an iterative approach. In this system, smaller subproblems are iteratively solved until the desired solution is obtained. Optimization methods are integrated with a sampling-based bi-directional spatial-temporal path planner to address constraints and enable simultaneous collaboration among multiple robots. Elmakis et al. [45] introduced an innovative method to enhance the flexibility of ground-based unmanned robots. This method involves employing unmanned aerial vehicles for precise aerial localization and mapping, which enables robots to undertake site preparation tasks beyond mere sensing activities. The field of task analysis now encompasses a wide spectrum of facets related to the advancement of construction robotics technology. These facets include but are not limited to, path analysis, exploration of human-robot collaboration, data acquisition and analysis, environmental sensing and navigation, and the automation of construction tasks.

7. Robot vision systems

The integration of robot vision systems into construction robots holds significant potential to enhance automation and intelligence within the construction process, thereby improving accuracy safety, and facilitating more effective construction management and progress monitoring. A novel vision-guided path planning system has been proposed by Pinto, A.M. et al. [46], utilizing existing cable-driven robots. This system optimizes the robot's trajectory by accounting for the robot's position, the positions of targets and obstacles, as well as the interactions between obstacles, cables, and surrounding scenarios. In a recent study, Navid Kayhani [47] and colleagues introduced a cost-effective, adaptable, lightweight visual-inertial localization methodology for unmanned aerial vehicles. This approach employs a basic inertial measurement unit sensor configuration and a single-lens camera utilizing AprilTags. Mei [48] proposed a dynamic RGB-D visual SLAM dense map construction method that employs pyramidal L-K with multi-view geometric constraints. This method not only enhances the accuracy of camera position estimation and facilitates the construction of dense maps following dynamic object processing but also improves system stability and environmental reconstruction accuracy. Liu et al. [49] introduced a vision-based robot-assisted component installation system designed to address the challenges of on-site assembly of prefabricated components in building construction. Following initial alignment using a crane, two robots collaborate to precisely adjust the position and orientation of the components. Feng et al. [50] developed a planar rebar tying robot and proposed an innovative two-stage recognition method that combines a depth-of-look camera and an industrial camera to capture image information of the tying area. A review of the literature indicates that research on vision systems for robots is predominantly focused on enhancing the flexibility and accuracy of environmental perception, particularly in practical applications within the domain of construction robots.

3.4. Analysis of Research Trends

The use of keyword emergence mapping in CiteSpace software serves as a powerful tool for analyzing research hotspots within a specific field. This method effectively highlights keywords that appear suddenly and increase rapidly in frequency over a defined period—referred to as emergent words. Such emergent words signify new research hotspots or directions that experience a swift rise in attention, providing timely insights into emerging trends and prominent topics in the field. When an emergent word appears recently with high intensity and prolonged duration, it indicates that the research topic is in a stage of rapid development and may continue to attract significant attention in the near future, with the potential to become a future research hotspot or key area of development. By

employing CiteSpace software for keyword emergence analysis, Chinese (Figure 10a) and English (Figure 10b) keyword emergence maps were successfully generated. These maps were utilized to conduct an in-depth analysis of the historical development of research within this field and to identify the research hotspots that have emerged over time. The analysis revealed that the research landscape can be categorized into two distinct stages, each distinguished by a specific set of research trends and priorities.

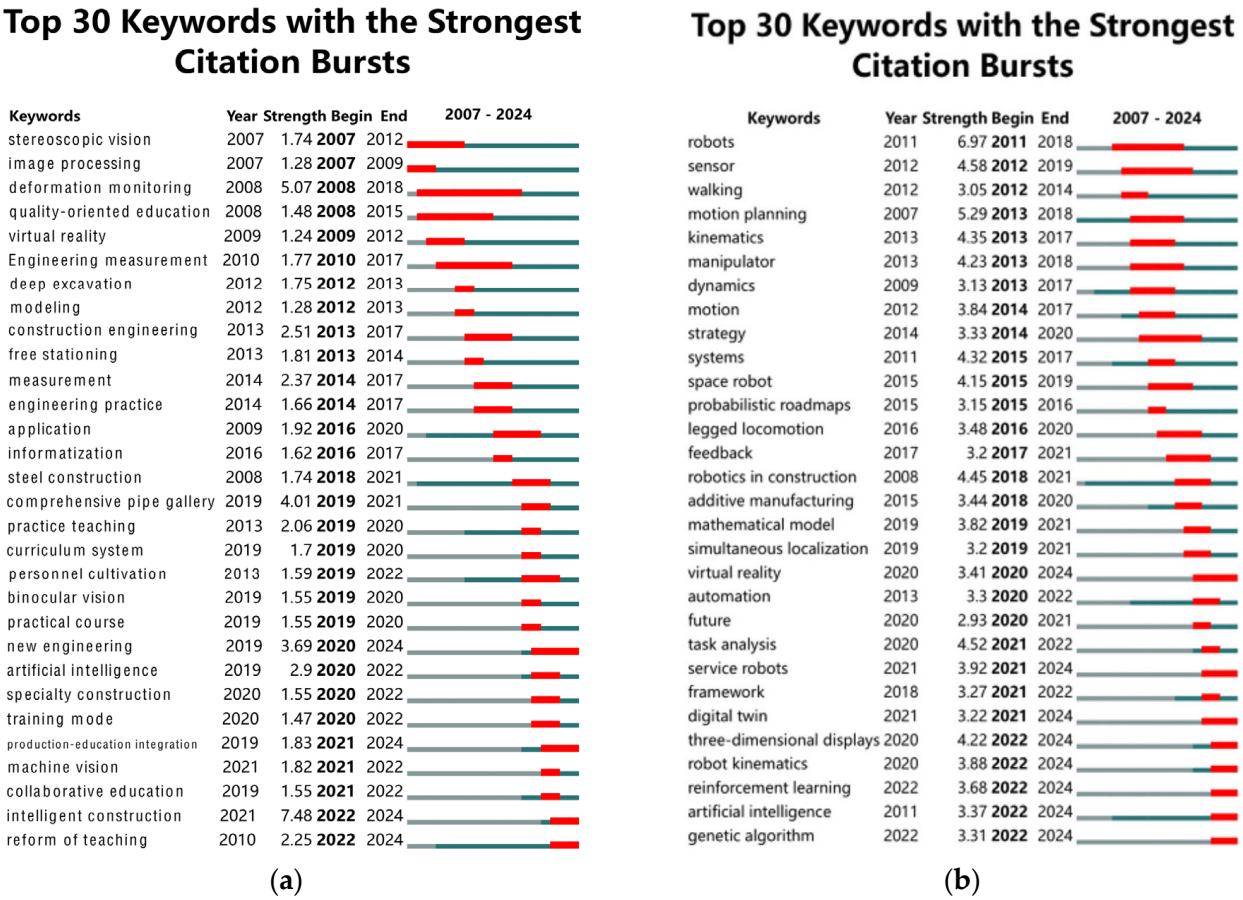


Figure 10. (**a**) Emergence mapping of Keywords in the Chinese literature; (**b**) Emergence mapping of keywords in the foreign literature.

In summary, the period from 2007 to 2016 is characterized as the initial phase of field exploration. During this time, the predominant research areas included modeling, deformation monitoring, sensors, motion planning, manipulators, strategies, space robots, engineering practice, and information technology. The subsequent period from 2017 to 2024 marks the latest phase of frontier research. The focus during this phase encompasses but is not limited to, areas such as intelligent construction, talent training, new engineering, machine vision, automation, task analysis, three-dimensional displays, robot kinematics, and artificial intelligence.

1. Keyword terms exhibiting strong emergence intensity include "intelligent construction" and "robots". The application of construction robots is contingent upon the overarching framework of intelligent construction. Robots can perform tasks automatically, either by following a preset program or by operating autonomously based on principles developed through artificial intelligence technology. In the 1980s, the Shimizu Corporation of Japan pioneered the development of the world's first construction robot, the SSR-I refractory coating robot [51]. Since that time, countries have increasingly prioritized research and development in the field of construction robots.

The application of robotic technology is now considered a pivotal area of focus within the construction industry and represents a significant trend in current research.

2. The term "deformation monitoring" has the longest documented history of use, having been practiced for a decade. The primary objective of deformation monitoring is to ensure the safety and stability of engineering structures while providing a scientific foundation for the construction and maintenance of these structures. In the current context of smart construction, deformation monitoring has become more intelligent and automated [52]. Construction robots possess the potential to facilitate real-time monitoring and early warning systems for buildings, forming an integral part of the deformation monitoring process. To better align with evolving detection requirements, construction robots must undergo continuous enhancements to optimize the performance of their sensors, measurement equipment, and other associated components. Deformation monitoring constitutes a pivotal aspect of an intelligent construction system and serves as a critical driver for the intelligent transformation and modernization of the entire construction industry.
3. The genetic algorithm is a term that has recently emerged, rooted in the principles of genetics. It optimizes problem-solving gradually by simulating the natural processes of selection, crossover, and mutation. The introduction of genetic algorithms has significantly enhanced the performance and efficiency of construction robot systems. These algorithms are applied not only to optimize the robot's path planning but also to refine the design parameters of the robots.

When combined with the timeline chart, emergent words can clearly illustrate the emergence time of keywords, their developmental history, and their appearance at different stages. By analyzing these time-series data, the evolutionary trend of research hotspots can be observed, enabling an understanding of which topics are gradually gaining attention and which are losing prominence. This analysis also allows for predictions regarding the direction of future research. In conclusion, future research on construction robots can be divided into two main areas: firstly, the incorporation of genetic algorithms and other technologies to enhance the performance and practicality of construction robots in all aspects, and secondly, addressing potential issues that may arise from the practical application of construction robots within the industry. This is aimed at fostering the collaborative advancement of all aspects of the construction robot sector and promoting the broader application of these technologies.

4. Discussion

To facilitate a deeper and more efficient understanding of the foundational overview and research progress in the field of construction robots, this paper offers a visualization and analysis of 2947 documents related to construction robots sourced from the CNKI Chinese database and the WOS core database. This analysis was conducted using CiteSpace software, which enabled an examination of temporal distribution, authorship distribution, organizational distribution, keyword co-occurrence, and keyword clustering timelines. The findings are detailed below:

1. Over the past 18 years, the number of research articles pertaining to construction robots has steadily increased, with a particularly marked surge in publications commencing in 2018. Before 2013, the volume of publications in this field was nearly negligible. This trend indicates a gradual expansion in the scope of research and a growing sophistication in the content being explored. Moreover, it underscores the pivotal role of construction robots as essential tools for the intelligent upgrading of the construction industry, highlighting their significance as a prominent area of current research within this sector.

2. The analysis of institutions and authors reveals that cooperation within the field of construction robots is limited and fragmented, lacking a cohesive research system with a core group of authors. Consequently, enhancing communication networks among various research institutions and author teams is of considerable significance. Such improvements are essential to advancing the in-depth development and broad application of construction robot technology.
3. A comprehensive keyword analysis indicates that current research hotspots in the field of construction robots are predominantly centered on path planning, deformation monitoring, vision systems, image processing, and other technological innovations in research and development. Significant advancements have been achieved in these areas in recent years. However, attention has recently started to shift towards the practical applications of robots in building construction, encompassing considerations such as environmental constraints, safety, technological maturity, and human-robot collaboration. These issues related to practical applications are also subjects of ongoing research.

A comprehensive analysis of the literature on construction robots reveals certain limitations in the current research. Technically, challenges persist in multi-robot cooperative operations and human-robot collaboration. The interaction and integration across various disciplines are insufficient, hindering the formation of effective knowledge-sharing and collaborative innovation mechanisms. From the perspective of talent and collaboration, a notable scarcity of professionals exists in construction robots, complicating efforts to cultivate expertise. Additionally, the frequency and depth of cross-organizational and cross-team collaborations are limited, impeding the development of a comprehensive, multi-level network that integrates industry, academia, research, and application. Furthermore, practical applications of construction robots face constraints. Most current robots exhibit single-functionality and lack precise adaptability for specific construction tasks. Since construction operations often demand high levels of precision, flexibility, and multifunctional integration, this mismatch restricts the functionality and applicability of construction robots in real-world engineering practices.

5. Conclusions

In conclusion, significant advancements have been witnessed in the field of construction robotics in recent times. Current research focuses on several pivotal areas, including human-robot collaboration, path planning, task analysis, robot vision technology, and the reform of university education and professional training. Future developments at the technical level may involve the integration of various technologies into the study of construction robots. Ensuring the safe coordination between humans and machines remains a central focus, particularly concerning the application of construction robots and the management of human-machine interactions.

To promote the long-term development of the construction robots' field, future research should prioritize the acceleration of core technology research and development. This objective may be achieved by enhancing communication among various institutions and authors, as well as by improving personnel training and fostering team-building. Moreover, it would be advantageous to encourage colleges, universities, research institutes, and enterprises to establish interdisciplinary and cross-field scientific research and cooperation teams. Additionally, proactive exploration and application of novel materials and processes should be encouraged.

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curation, C.C. and Z.W.; writing—original draft preparation, C.C.; writing—review and editing, R.D.; visualization, C.C. and Z.W.; supervision, R.D.; project administration, R.D.; funding acquisition, R.D. All authors have read and agreed to the published version of the manuscript.

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References

1. Tian, C.; Geng, J.; Wang, L. Supporting Role and Trend Forecast of Construction Industry in China's Economy. *Constr. Econ.* **2016**, *37*, 10–15.
2. Chen, T.; Zhang, L.; Ma, X. Exploring the Opportunities and Challenges of Cultivating Intelligent Construction Professionals in the Context of Artificial Intelligence. *Educ. Prog.* **2023**, *13*, 4563–4569.
3. Chen, C.; Li, X.; Qiu, Z.; Yao, W.; Zhu, H. Research Progress of Construction Robots. *J. Archit. Civ. Eng.* **2022**, *39*, 58–70.
4. Zang, X. Implementation program of "Robot +" application action issued. *Shanghai Educ.* **2023**, *07*, 5.
5. Chen, Y.; Chen, C.; Liu, Z.; Hu, Z.; Wang, X. The methodology function of Cite Space mapping knowledge domains. *Stud. Sci. Sci.* **2015**, *33*, 242–253.
6. Ye, J.; Fanyang, Y.; Wang, J.; Meng, S.; Tang, D. A Literature Review of Green Building Policies: Perspectives from Bibliometric Analysis. *Buildings* **2024**, *14*, 2607. [CrossRef]
7. Liu, D.; Zhang, H. Research Hotspots and Frontiers of Internet Public Opinion in Chinese Colleges and Universities. *Inf. Sci.* **2022**, *40*, 176–185.
8. Zheng, H.; Kan, X.; Chen, S.; Yuan, H. The Evolution Path and Hotspot Analysis of the Research on Aging Adaptation of Old Residential Community. *Constr. Econ.* **2023**, *44*, 72–80.
9. Bi, Q. Document Clustering Analysis on Semi-Supervised-Related Medical Literatures. Master's Thesis, Lanzhou University, Lanzhou, China, 2023.
10. Xie, C.; Feng, T.; Hu, L. A Bibliometric Analysis of the Outdoor Thermal Environment Based on CiteSpace. *Buildings* **2024**, *14*, 1384. [CrossRef]
11. En, X.; Liu, Y. Visualization analysis of high-speed railway research based on CiteSpace. *Transp. Policy* **2020**, *85*, 1–17.
12. Zhang, R.; Ren, R.; Yuan, B.; Luo, G.; Bi, L. Construction path optimization method of assembly building robot. *Comput. Eng. Des.* **2021**, *42*, 3516–3524.
13. Wang, F.; Li, T.; Liu, J.; Zhao, H. Research on Autonomous Path Planning and Obstacle Avoidance of Building Robot Based on BIM. *Comput. Eng. Appl.* **2020**, *56*, 224–230.
14. Muñoz-Bañón, M.; Velasco-sanchez, E.; Candelas, F. Openstreetmap-based autonomous navigation with lidar naive-valley-path obstacle avoidance. *IEEE Trans. Intell. Transp. Syst.* **2022**, *23*, 24428–24438. [CrossRef]
15. Yang, Z.; Zhuang, Y.; Chen, Y. Path planning of a building robot based on BIM and an improved RRT algorithm. *Exp. Technol. Manag.* **2024**, *41*, 31–42.
16. Gao, H.; Zhang, X.; Wen, J.; Yuan, J.; Fang, Y. Autonomous indoor exploration via polygon map construction and graph-based SLAM using directional endpoint features. *IEEE Trans. Autom. Sci. Eng.* **2018**, *16*, 1531–1542. [CrossRef]
17. Huang, P.; Zeng, L.; Chen, X. Edge robotics: Edge-computing-accelerated multirobot simultaneous localization and map. *IEEE Internet Things J.* **2022**, *9*, 14087–14102. [CrossRef]
18. Liu, P.; Bi, Y.; Shi, J. Semantic-Assisted LIDAR Tightly Coupled SLAM for dynamic environments. *IEEE Access* **2024**, *12*, 34042–34053. [CrossRef]
19. Li, S.; He, R.; Guan, H. A 3D LiDAR-Inertial Tightly-Coupled SLAM for Mobile Robots on Indoor Environment. *IEEE Access* **2024**, *12*, 29596–29606. [CrossRef]
20. Zhou, E.; Liu, X.; Qing, Z. Research and Implementation of Monitoring and Early Warning System of Deep Foundation Pit. *Chin. J. Undergr. Space Eng.* **2013**, *9*, 204–210.
21. Zhang, S.; Huang, S.; Yang, X. Research on real-time gross error detection method based on geo robot. *Bull. Surv. Mapp.* **2021**, 153–155+161. [CrossRef]
22. Zheng, H.; Fu, K. Design and Implementation of Foundation Pit Deformation Automatic Monitoring Software Based on Android. *Geospat. Inf.* **2022**, *20*, 120–123.

23. Zhang, Z.; Pang, K.; Xu, L.; Zou, Y.; Yang, J.; Wang, C. The bond properties between UHPC and stone under different interface treatment methods. *Constr. Build. Mater.* **2023**, *365*, 130092. [CrossRef]
24. Ji, Y.; Shi, K.; Dong, J. Research on Accuracy Improvement Method of Horizontal Deformation Intelligent Monitoring for Super High-rise Buildings. *Constr. Technol.* **2023**, *52*, 20–24+79.
25. Yuan, F.; Chai, H.; Zhang, X. Exploration of small-batch customization production mode of timber architecture based architectural robot. *Build. Struct.* **2018**, *48*, 39–43+55.
26. Yuan, F.; Chai, H. Digital construction technology system of assembled buildings for mass customization-Taking the innovation of assembled wooden buildings as an example. *New Build.* **2022**, *04*, 9–14.
27. Duan, H.; Zhang, F.; Chen, G. The Practice and Development of Intelligent Construction Driven by Construction Robots. *Constr. Econ.* **2022**, *43*, 5–12.
28. Zhao, P.; Zhang, M.; Zhang, W. Application of BIM parametric design in complex buildings with different shapes. *Build. Struct.* **2023**, *53*, 2060–2062.
29. Gao, Y.; Shu, J.; Yu, K. Research on robotic construction of light weight structures using BIM visual programming. *J. Build. Struct.* **2022**, *43*, 296–304.
30. Wang, P.; Xiao, J.; Xiao, X. Application and Prospect of Digital Technology in Building Construction. *J. Tongji Univ. (Nat. Sci.)* **2024**, *52*, 1068–1078.
31. Li, D.; Jiang, B.; Gu, W. The transformation and talent training mode of architectural engineering technology for intelligent construction. *Archit. Sci.* **2024**, *40*, 196.
32. Zuo, Z.; Huang, Y.; Zang, L. 3D printing technology and feasibility analysis of its application in super high-rise buildings. *Build. Struct.* **2022**, *52*, 95–101.
33. Liu, T. Tsinghua University State Key Laboratory of Hydro science and Engineering. 3D printing of large filled construction projects. *J. Tsinghua Univ. (Sci. Technol.)* **2022**, *62*, 1281–1291.
34. Hong, T.; Gao, X. Improve Path Generation Method of 3D Printing Robot under Q Learning. *Comput. Simul.* **2023**, *40*, 417–421.
35. Zeng, N.; Ma, Z.; Song, L. A porosity detection method for 3D printed concrete interface with self-attention mechanism. *Chin. J. Eng. Des.* **2024**, 1–10. Available online: https://kns.cnki.net/kcms/detail/33.1288.TH.20240527.1349.006.html (accessed on 12 December 2024).
36. Huang, L.; Zhu, Z.; Zou, Z. To imitate or not to imitate: Boosting reinforcement learning-based construction robotic control for long-horizon tasks using virtual demonstrations. *Autom. Constr.* **2023**, *146*, 104691. [CrossRef]
37. Zha, A.; Dai, T.; Xu, G. Deep reinforcement learning for real-time assembly planning in robot-based prefabricated construction. *IEEE Trans. Autom. Sci. Eng.* **2023**, *20*, 1515–1526. [CrossRef]
38. Liang, C.J.; Wang, X.; Kamat, V. Human–robot collaboration in construction: Classification and research trends. *J. Constr. Eng. Manag.* **2021**, *147*, 03121006. [CrossRef]
39. Wang, X.; Liang, C.; Menassa, C. Interactive and immersive process-level digital twin for collaborative human–robot construction work. *J. Comput. Civ. Eng.* **2021**, *35*, 04021023. [CrossRef]
40. Yang, X.; Amtsberg, F.; Sedlmair, M. Challenges and potential for human–robot collaboration in timber prefabrication. *Autom. Constr.* **2024**, *160*, 105333. [CrossRef]
41. Liu, Y.; Habibnezhad, M.; Jebelli, H. Brainwave-driven human-robot collaboration in construction. *Autom. Constr.* **2021**, *124*, 103556. [CrossRef]
42. Bakdi, A.; Hentout, A.; Boutami, H. Optimal path planning and execution for mobile robots using genetic algorithm and adaptive fuzzy-logic control. *Robot. Auton. Syst.* **2017**, *89*, 95–109. [CrossRef]
43. De Soto, B.G.; Agusti-juan, G.; Hunhevicz, J. Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall. *Autom. Constr.* **2018**, *92*, 297–311. [CrossRef]
44. Hartmann, V.; Orthey, A.; Driess, D. Long-horizon multi-robot rearrangement planning for construction assembly. *IEEE Trans. Robot.* **2022**, *39*, 239–252. [CrossRef]
45. Elmakis, O.; Shaked, T.; Degani, A. Vision-based uav-ugv collaboration for autonomous construction site preparation. *IEEE Access* **2022**, *10*, 51209–51220. [CrossRef]
46. Pinto, A.; Moreira, E.; Lima, J. A cable-driven robot for architectural constructions: A visual-guided approach for motion control and path-planning. *Auton. Robot.* **2017**, *41*, 1487–1499. [CrossRef]
47. Kavhani, N.; Zhao, W.; Mccabe, B. Tag-based visual-inertial localization of unmanned aerial vehicles in indoor construction environments using an on-manifold extended Kalman filter. *Autom. Constr.* **2022**, *135*, 104112.
48. Mei, J.; Zuo, T.; Song, D. Highly dynamic visual SLAM dense map construction based on indoor environments. *IEEE Access* **2024**, *12*, 38717–38731. [CrossRef]
49. Liu, C.; Wu, J.; Jiang, X. Automatic assembly of prefabricated components based on vision-guided robot. *Autom. Constr.* **2024**, *162*, 105385. [CrossRef]

50. Feng, R.; Jia, Y.; Wang, T. Research on the system design and target recognition method of the rebar-tying robot. *Buildings* **2024**, *14*, 838. [CrossRef]
51. Zhou, L.; Liu, S.; Yang, J. Comparative study on the driving path of competitiveness of technical standards in artificial intelligence industry at home and abroad. *Sci. Technol. Prog. Countermeas.* **2024**, 1–11. Available online: https://kns.cnki.net/kcms/detail/42.1224.G3.20241017.1046.004.html (accessed on 12 December 2024).
52. Zhang, W.; Song, Y.; Zhang, N. Application of intelligent construction in safe construction management of building projects. *Eng. Constr. Des.* **2023**, *13*, 263–265. [CrossRef]

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