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Review

Bibliometric analysis of internet of things (IoT) in the construction industry using Scopus database: Trends, characteristics, and future directions

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Abstract: This research examines the Internet of Things (IoT), a fast-developing technology that has transformed several industries, through bibliometric analysis of the building and construction sector. The current state of research, its features, and possible future paths are evaluated using the Scopus database. A thorough search of the literature conducted with Scopus produced a total of 2070 publications published between 2004 and 2022. Over the past five years, the number of IoT articles in the construction industry has significantly increased, according to the research. The study found that the top five countries for publications on this issue were China, Hong Kong, India, Portugal, and Sweden. The data suggests that a number of topics, such as energy management, construction automation, and smart buildings, have attracted a lot of attention. Additionally, the survey found that wireless networks and sensors were the IoT technology most frequently employed in the construction sector. The paper also makes recommendations for potential research directions, including the employment of cutting-edge technologies like blockchain and artificial intelligence, as well as the application of IoT in the building sector. The study's results shed light on market trends, unmet needs in the field, and prospective directions for Internet of Things applications in the construction sector.

Keywords: future directions; construction industry; Scopus database; sensors; wireless networks

1. Introduction

A network of physical objects that are networked and outfitted with sensors, software, and connections to gather and exchange data is referred to as the "Internet of Things" (IoT). Adoption of IoT technology has the potential to totally alter the construction sector by providing automated control, remote management, and real-time monitoring of construction processes and systems. A number of scholars have provided definitions of IoT from a review standpoint. The Internet of Things (IoT), according to researchers [1], is a "global infrastructure for the information society" that links virtual and real objects with communication and information technologies that are interoperable to allow improved services. However, researchers [2] define the Internet of Things (IoT) as the network of individually identifiable embedded computer devices within the existing internet infrastructure. Gubbi et al. [3] define the Internet of Things (IoT) as "a network of networks where each object or thing is uniquely identifiable and seamlessly integrated into the internet infrastructure."

IoT technology could potentially be applied by the construction industry in a number of ways, such as building design, construction management, building operation, and building maintenance, according to Hammad et al. [4]. IoT-enabled sensors have the potential to lower building energy consumption, verify the structural integrity of structures, and facilitate equipment and building supply tracking. IoT-based systems for monitoring concrete temperature and humidity during curing [5] and concrete deformation and stress during curing [6] are only two examples of the particular IoT applications in construction that have been the subject of other research. In order to increase the quality and efficiency of construction, Wang et al. [7] suggested a framework that blends building information modeling (BIM) with the Internet of Things.

Furthermore, sensors and wearable technologies are being used more often to collect real-time data on worker position, temperature, humidity, noise levels, and vibration on construction sites [8]. Sensible resource allocation, enhanced operational efficiency, and worker safety monitoring can all be made possible by this data. On a construction site, wearable technology—like smart helmets—can be used to track worker position and activity and measure vital indications like body temperature and heart rate. Similar to this, sensors placed across a construction site may gather information on variables like temperature, humidity, and noise levels to enhance working conditions and lower the chance of mishaps. While deploying sensors and wearable technology can increase worker safety, reduce expenses, and enhance operational performance, there are certain drawbacks, such as resolving privacy issues associated with wearable technology use and ensuring the accuracy and dependability of the data collected.

2. Research GAP analysis

The following is a potential gap analysis for Internet of Things (IoT) major and minor studies in the construction sector or on construction sites:

- Lack of standardization: The Internet of Things (IoT) offers great promise for the construction sector, but data interchange and interoperability across different IoT systems and devices are hampered by the lack of standards for communication protocols, hardware, and software [9,10].
- Limited integration with BIM: The construction sector uses BIM extensively for activities like designing, planning, and managing building projects, but there is still a long way to go before BIM and IoT are fully integrated. To enhance building procedures and results, further study is needed on how to merge the two technologies [11,12].
- Cybersecurity risks: With the proliferation of IoT devices and systems in the construction industry, there is a greater risk of cybersecurity threats and assaults. Further research is required to secure IoT-enabled construction sites and protect sensitive data and information [1,13].
- Limited attention to user experience: Although IoT systems and devices have the potential to enhance construction processes and results, their complexity, lack of user-friendliness, and low usability may prevent professionals and workers from adopting and accepting them. Thus, further study is required to design and build IoT systems that are user-friendly, intuitive, and responsive to their requirements and preferences [11,14].
- Inadequate consideration of social and organizational factors: While the majority

of research on IoT in the construction sector has concentrated on the technical aspects of the technology, more study is required to understand the social and organizational factors—such as organizational culture, change management, and stakeholder engagement—that may influence its adoption and implementation [12,14].

Based on the current literature, some possible research gaps in the field of internet of things in the construction industry or construction site are:

- IoT and BIM integration: Using IoT and Building Information Modeling (BIM) together to enable real-time decision-making and monitoring in building projects [1,7,15].
- Standardized IoT platforms: The creation of uniform and compatible Internet of Things platforms to provide easy data sharing and cooperation amongst construction project participants [14,16].
- Sensor placement and data collection: Sensitivity placement and data gathering methods optimization for precise and dependable building site parameter (e.g., temperature, humidity, noise, vibration) measurement [17,18].
- Security and privacy: A look at the security and privacy issues surrounding the usage of IoT data and devices in building projects [19].
- Barriers to adoption: Determining the primary barriers to the adoption and use of IoT technologies in the construction sector and creating plans to get around them [1,20].

3. Research methods

Bibliometrics is a quantitative research tool used to analyze and assess the worth of scientific study in a certain topic. Many bibliometric approaches are available to examine trends in publication, citation, and other bibliographic data. Commonly used methods include scientometrics, bibliographic coupling, co-citation analysis, and citation analysis. Citation analysis leverages citations within a collection of papers to identify influential authors, organizations, and publications, while co-citation analysis examines the frequency with which two publications are mentioned together [21,22]. Scientometrics studies the organization of knowledge and discourse patterns within the literature of a scientific field, while bibliographic coupling utilizes shared source analysis to map a field's intellectual structure [23,24]. These techniques have been widely applied across various academic fields, such as engineering, social sciences, and economics, to gain insights into research trends and academic impact [25,26].

3.1. Data source and search strategy

A popular resource for performing bibliometric analysis is the Scopus database. The following search approach can be used to look for articles on the Internet of Things (IoT) in the construction industry:

- Access the Scopus database through the institutional library portal.
- Click on the "Advanced Search" option.
- Enter the following search terms in the search fields:
    - TITLE-ABS-KEY ("Internet of Things" OR IoT) AND TITLE-ABS-KEY

(construction OR building).

- Set the date range to “2000–2022” to capture all relevant publications.
- Limit the search to academic journals, conference proceedings, and book chapters.
- Export the search results in CSV or Excel format for further analysis [27].

In March 2023, a search was conducted in the Scopus database to gather data on the “Internet of Things in the construction industry.” Review articles published between 2004 and 2023 were the primary focus. The search strategy employed keywords such as “Internet of Things,” “IoT,” and “construction,” yielding 2070 documents after excluding irrelevant articles. This approach provided comprehensive coverage of the field from 2004 to 2023, allowing for in-depth bibliometric analysis [28,29].

TITLE-ABS-KEY ((“Internet of things” OR “IOT “OR “IoT”) AND “Construction”) AND PUBYEAR > 2004 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE, “ar”)). This query string’s output was 2070 documents.

This search strategy retrieves publications that include the search terms in their title, abstract, or keywords. The date range can be adjusted to focus on more recent publications or to capture a longer historical period. Additionally, the search terms can be refined or expanded based on the research question and the focus of the analysis.

Steps involved in the flow chart for the collection of Internet of Things (IoT) in construction industry publications from the Scopus index (**Figure 1**):

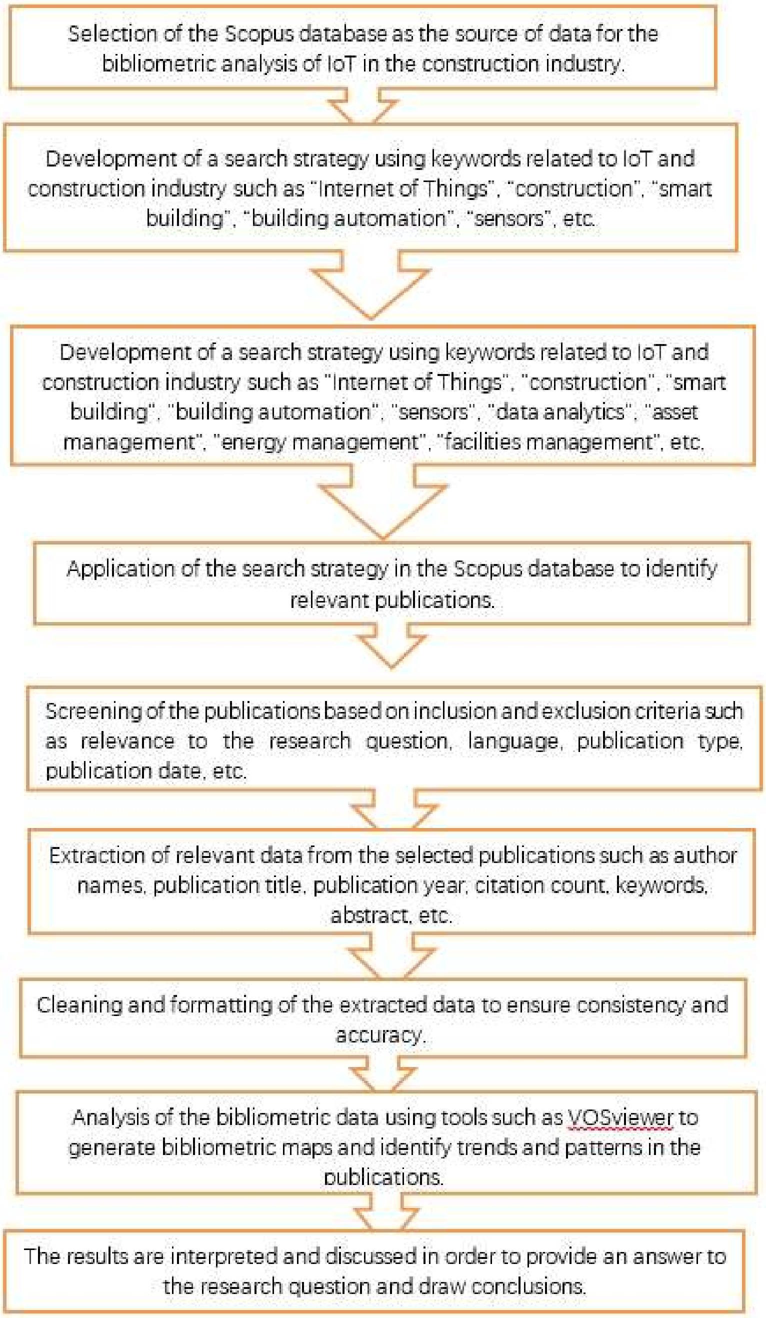

Figure 1. Methodology for doing the bibliometric analysis.

3.2. The bibliometric maps

To visually represent the connections between various authors, research topics, and academic domains, bibliometric maps may be made using specialized software like VOSviewer. The articles that are often mentioned together are identified by co-citation analysis, and VOSviewer shows clusters of these articles along with the connections between them. These maps can help find possible partners, provide crucial information about the organizational structure of various research topics, and direct funding decisions. Scholars can also find important research topics and understudied regions that need more investigation with the use of bibliometric maps using the scopus database [30–32].

Bibliometric maps have been created with VOSviewer by several investigations in diverse fields. Zhang et al. [33] employed VOSviewer to illustrate the connections across various research domains and underscore significant research subjects throughout their examination of the literature on climate change adaptation. Similar to this, Zupic et al. [34] utilized VOSviewer to determine the most significant authors and research themes in a review of the literature on digital transformation. Bibliometric maps made using VOSviewer may be a useful tool for properly seeing and comprehending the organization of research topics. These maps can also be a helpful tool for guiding collaborations and future lines of inquiry.

4. The results and discussion

4.1. Research interest in publication output and growth

There were 2070 research articles published on the subject of the Internet of Things in the construction industry between 2005 and 2022. A significant increase in interest that began in 2018 and persisted until 2022, when the number of publications doubled annually, caused a steady increase in the number of publications. This trend is anticipated to increase going forward. A fee is usually required to access the majority of these articles. This field is extremely interdisciplinary and is being studied by numerous research groups across the globe. Engineering was the primary subject of the articles (1189), which were also heavily focused on computer science (1146), mathematics (247), materials science (220), physics and astronomy (201), energy (187), social sciences (147), environmental science (133), and business management and accounting (113). This demonstrates how the social sciences are just one aspect of the Internet of Things' highly interdisciplinary nature in the construction industry. The research's articles were written in ten different languages (**Figures 2–7**).

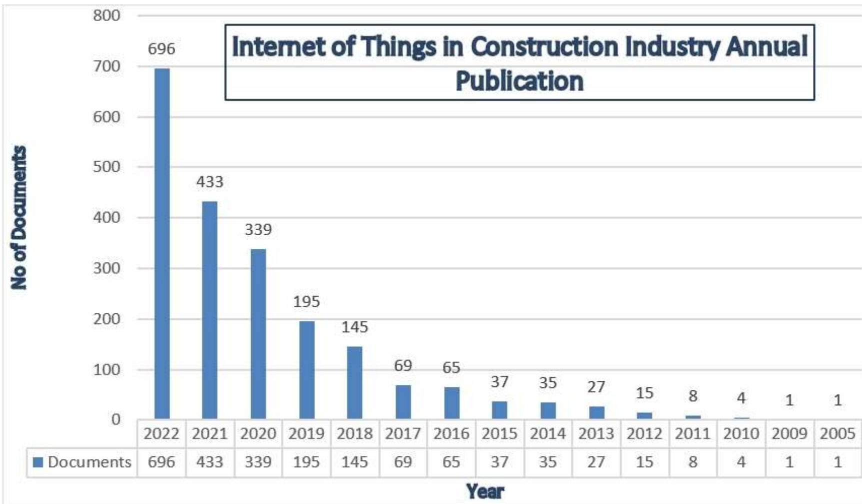

Figure 2. The annual and total number of research articles on the Internet of Things in the construction industry published in Scopus between 2004 and 2022.

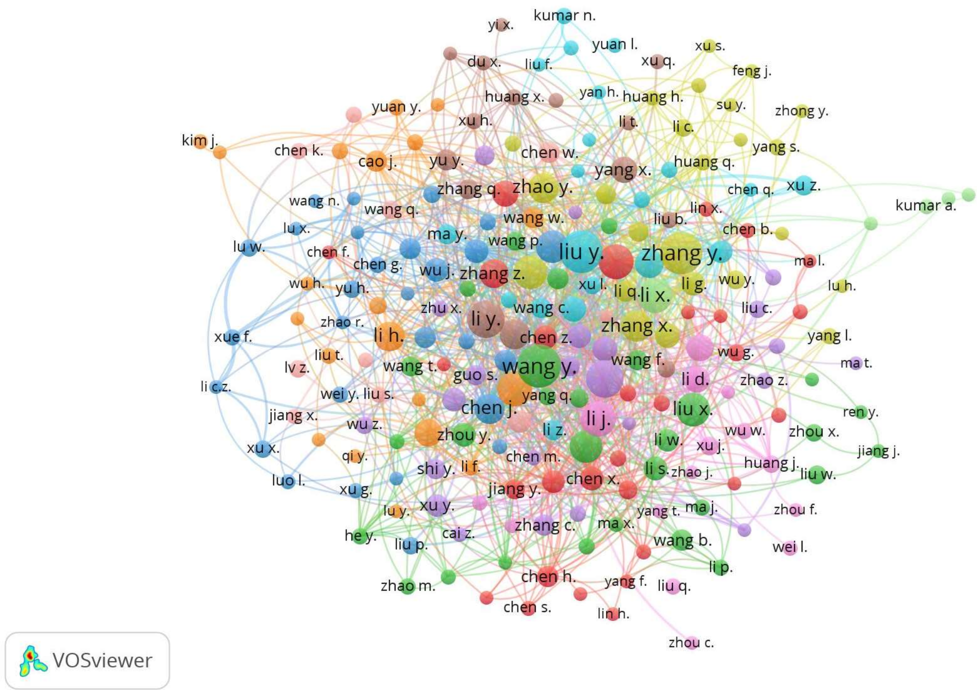

Figure 3. A graphic representation of a bibliometric map produced using network visualization that demonstrates author co-authorship links.

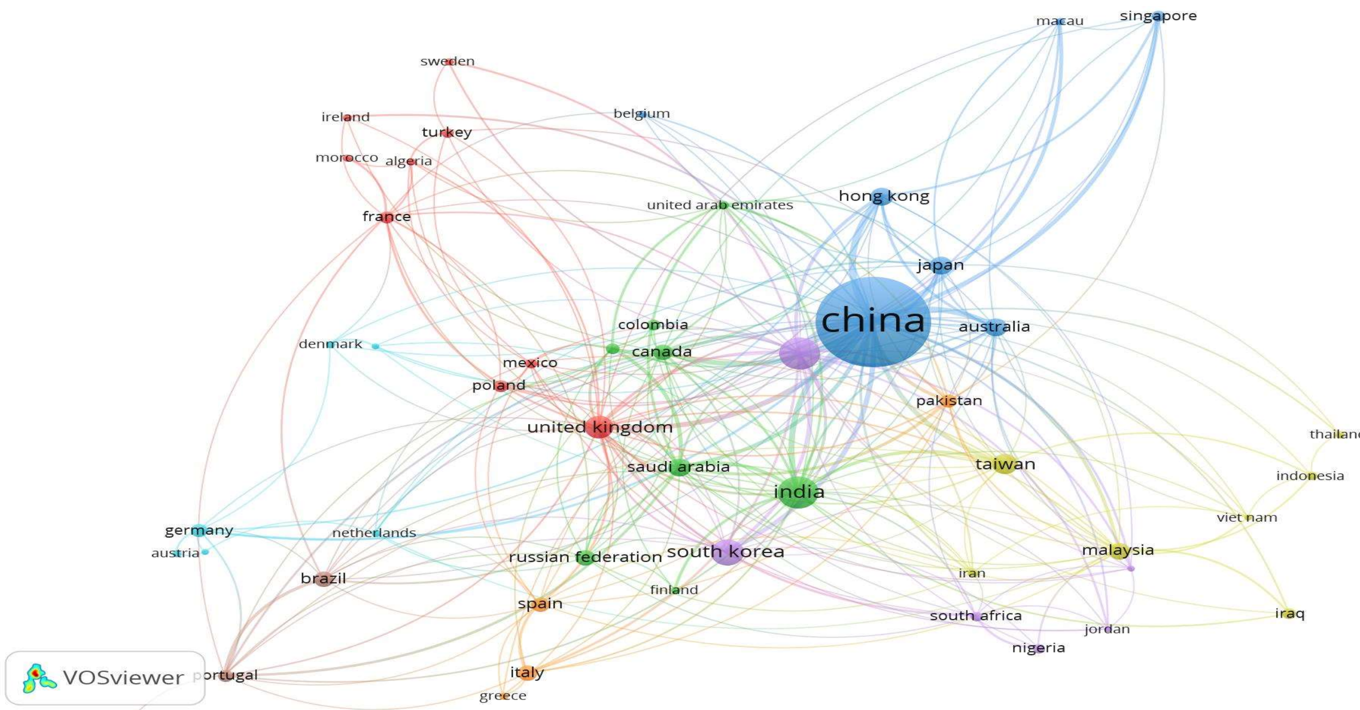

Figure 4. A snapshot of the network-based bibliometric map created using co-authorship data from various nations.

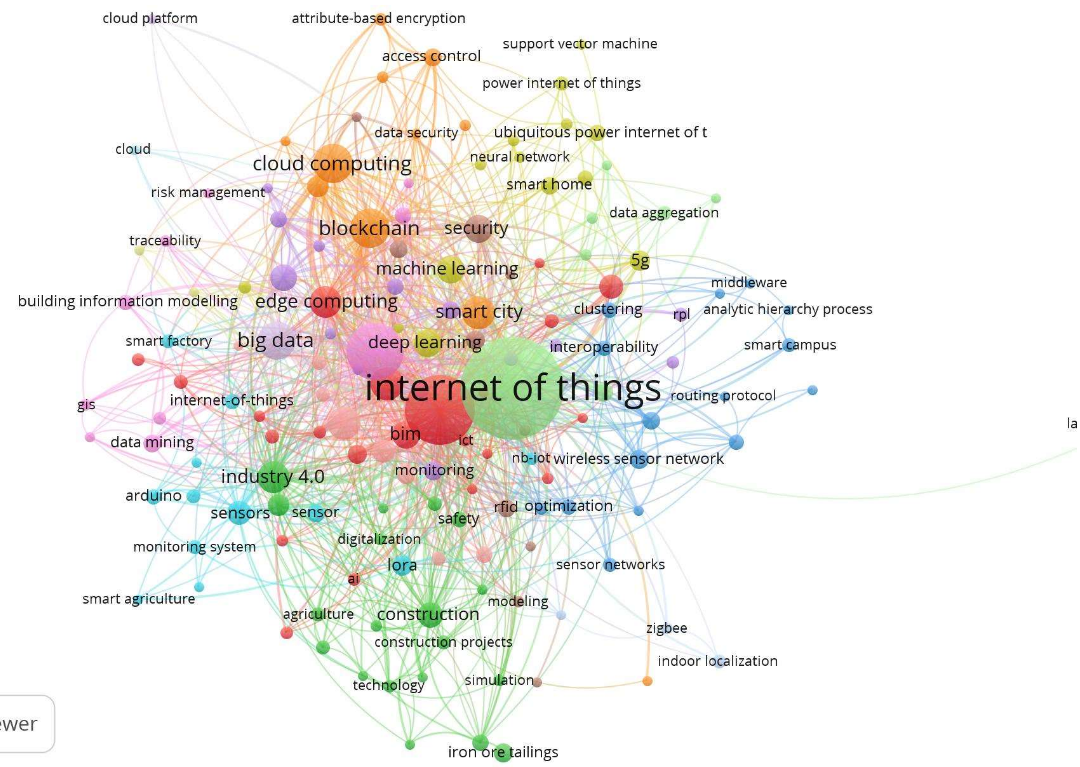

Figure 5. An examination of the co-occurring author keywords produced a bibliometric map that is represented visually here. In a specific subject of study, the map aids in locating the most popular and connected keywords.

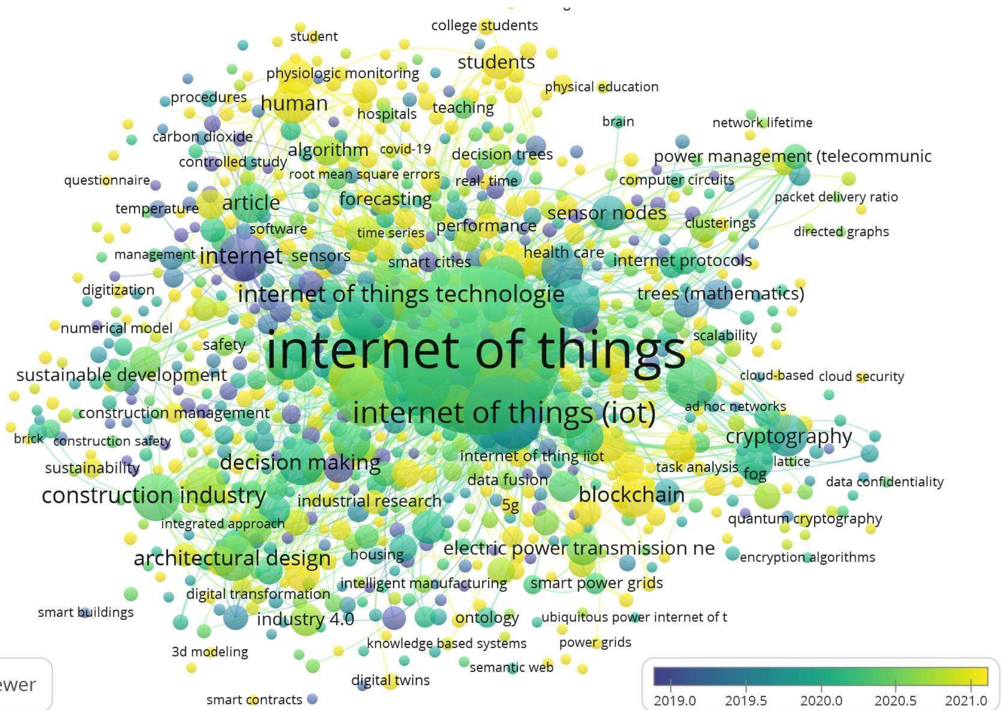

Figure 6. This is a snapshot of the bibliometric map generated through author keyword co-occurrence analysis, using the overlay visualization mode. The map displays the relationships between keywords based on their co-occurrence in publications. To be included in the map, a keyword must occur at least five times in the analyzed literature.

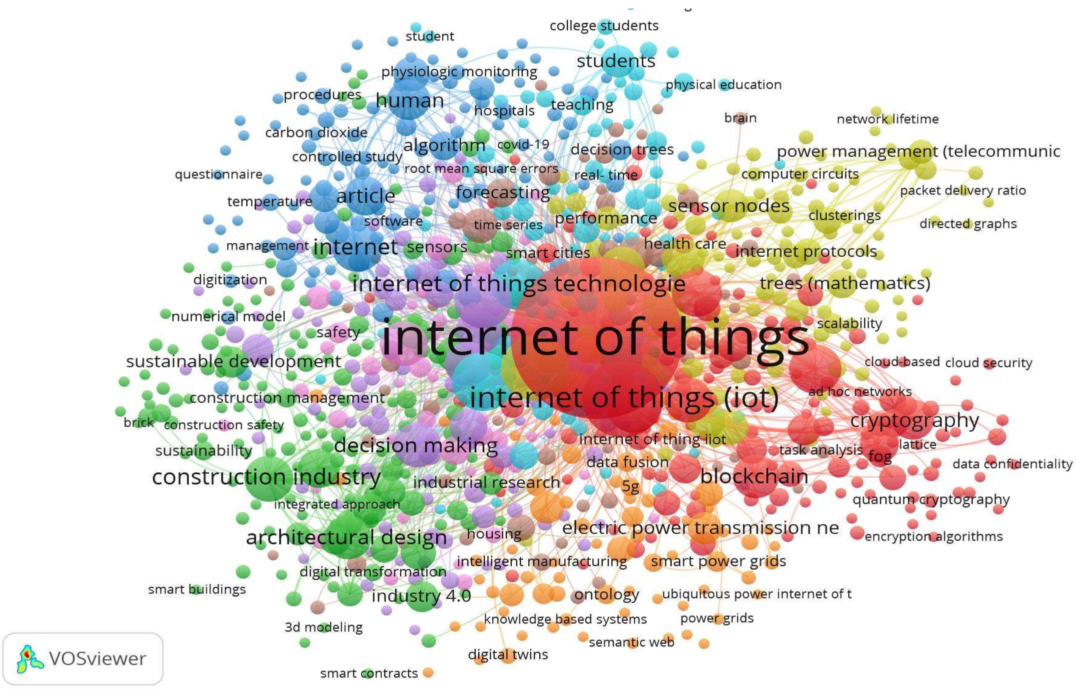

Figure 7. A snapshot of the bibliometric map generated through the analysis of all keywords' co-occurrence.

4.2. Leading authors

The 10 most prolific journals conducting research on the Internet of Things (IoT) in the construction industry are listed in **Table 1**. These journals are ranked based on the number of times their papers have been cited, with notable contributions from IEEE Access, IEEE Internet of Things Journal, and Wireless Communications and Mobile Computing. The most cited article from each journal is also highlighted, showcasing the breadth of research in this field.

Table 2 lists the 15 authors with the most publications related to IoT in construction research. The authors represent a range of countries, including China, Hong Kong, India, Portugal, Sweden, the United Arab Emirates, Nigeria, and the United States. The first works of these authors date from 1989 to 2020, with various positions held by the authors such as first author, co-author, and last author, which often denotes seniority or a supervisory role. Guizani, Mohsen, with 1,285 articles and an h-index of 82, leads the list, followed by Rodrigues, Joel J.P.C., and Kumar, N. It should be noted that the authors mentioned in **Table 2** may differ from those associated with the most cited papers in **Table 1**.

Table 1. The top 10 journals that have conducted the most research on the Internet of Things (IoT) in the construction industry are listed in the list below. The most cited article for each journal is listed, and these journals are ranked according to how many times their papers have been cited.

Journal	TP	TC	CiteScore 2022	The most cited article(reference)	Times cited	Publisher
IEEE Access	54,382	479,740	8.8	A Metaverse: Taxonomy, Components, Applications, and Open Challenges	160	IEEE
IEEE Internet of Things Journal	5079	86,450	17	Secure Artificial Intelligence of Things for Implicit Group Recommendations	106	IEEE
Wireless Communications and Mobile Computing	4309	9338	2.2	Deep Reinforcement Learning-Based Path Control and Optimization for Unmanned Ships	48	HINDAWI
Mobile Information Systems	2594	3406	1.3	Ambient Assistive Living for Monitoring the Physical Activity of Diabetic Adults through Body Area Networks	17	HINDAWI
Sensors Switzerland	30,875	206,342	6.7	Comparing YOLOv3, YOLOv4 and YOLOv5 for Autonomous Landing Spot Detection in Faulty UAVs	104	Multidisciplinary Digital Publishing Institute (MDPI)
Computational Intelligence and Neuroscience	4168	7660	1.8	Applying Dynamic Systems to Social Media by Using Controlling Stability	37	HINDAWI
Automation in Construction	1657	27,221	16.4	Pavement distress detection using convolutional neural networks with images captured via UAV	48	ELSEVIER
Sustainability Switzerland	48,515	276,102	5.7	The Impact of Financial Development and FDI on Renewable Energy in the UAE: A Path towards Sustainable Development	67	Multidisciplinary Digital Publishing Institute (MDPI)
Sensors	30,875	206,342	6.7	Comparing YOLOv3, YOLOv4 and YOLOv5 for Autonomous Landing Spot Detection in Faulty UAVs	104	Multidisciplinary Digital Publishing Institute (MDPI)
Security and Communication Networks	2492	6248	2.5	Computational Technique Based on Machine Learning and Image Processing for Medical Image Analysis of Breast Cancer Diagnosis	18	HINDAWI

TP: Total Publications; TC: Total Citation.

Table 2. The 15 authors with the most publications in the subject of Internet of Things in Construction research are listed below.

Sr No.	Author	Scopus Author ID	Year of 1st Publication*	TP	h-index	TC	Current affiliation	Country
1	Rodrigues, Joel J. P. C.	25930566300	2002**	1114	79	20,307	Instituto de Telecomunicacoes, Lisboa	Portugal
2	Xue, Fan	56720069500	2006***	85	28	1862	The University of Hong Kong, Pokfulam	Hong Kong
3	Lu, Weisheng Wilson	24173836000	2003***	238	49	5104	The University of Hong Kong, Pokfulam	Hong Kong
4	Lv, Zhihan	55925162500	2011*	437	60	7880	Uppsala Universitet, Uppsala	Sweden
5	Kumar, N.	57206866080	1994***	896	88	17,507	Shri Ramswaroop Memorial University, Barabanki	India
6	Liu, Zhansheng	57191688199	2010***	76	11	328	Beijing University of Technology, Beijing	China
7	Gehlot, Anita	57709976000	2015*	205	12	636	Uttaranchal University, Dehradun	India
8	Guizani, Mohsen	7004750176	1989**	1285	82	31,645	Mohamed Bin Zayed University of Artificial Intelligence, Abu Dhabi	United Arab Emirates
9	Li, Clyde Zhengdao	57188592789	2014*	51	27	2136	Shenzhen University, Shenzhen	China
10	Li, Heng	8692514900	1992***	605	75	14,519	Hong Kong Polytechnic University, Kowloon	Hong Kong
11	Singh, Rajesh	57610169600	2002***	238	13	836	Uttaranchal University, Dehradun	India
12	Zhang, Mingwu	22636534500	1993**	227	23	1585	Hubei University of Technology, Wuhan	China
13	Zhang, Yang	35346173600	2005*	90	11	371	Beijing University of Posts and Telecommunications, Beijing	China
14	Arowoiya, Victor Adetunji	57215611010	2020*	10	5	57	Federal University of Technology, Akure	Nigeria
15	Du, Xiaojiang	8371278000	2002*	623	59	11,082	Stevens Institute of Technology, Hoboken	United States

*First Author, ** Co- Author, ***Last Author.

4.3. Author keywords

The authors used co-authorship, co-occurrence with countries, and all keywords as units of analysis with the full counting method to identify significant authors, countries, and keywords in the field of Internet of Things in construction. For co-authorship with authors, they applied certain thresholds, such as a maximum of 25 authors per document and a minimum of 5 documents for an author, and 221 authors met these criteria. They calculated the total strength of the co-authorship links for each of these 221 authors and selected the ones with the highest link strength. This resulted in the creation of 11 clusters, each containing a different number of items.

Similarly, for co-occurrence with countries, they set a maximum of 25 countries per document and a minimum of 5 documents for a country, and 50 countries met these criteria. They calculated the total strength of the co-authorship links for each of these 50 countries and selected the ones with the highest link strength.

The researchers selected a minimum threshold of five occurrences for each keyword in order to carry out a co-occurrence analysis of both author keywords and keyword co-occurrences. As a result, 152 author keywords and 919 related keywords for keywords were found. Then, only the keywords with the strongest connections were kept after the researchers evaluated the overall strength of each keyword's co-occurrence links. Ultimately, this process led to the formation of 10 clusters for all keywords and 152 keywords for author keywords.

4.4. Discussion

A) Integration of IoT with blockchain

The integration of blockchain technology with IoT can significantly enhance the construction industry by improving data security, transparency, and reliability. Here's how:

- Data integrity and security: Blockchain's decentralized ledger system can secure IoT data by providing an immutable record of all transactions. In construction, this means that data from IoT devices, such as sensor readings and equipment logs, can be recorded in a way that prevents tampering and fraud. This ensures that the data used for decision-making is accurate and trustworthy.
- Smart contracts: Blockchain can facilitate the use of smart contracts—self-executing contracts with the terms directly written into code. In construction projects, smart contracts can automate various processes, such as payments and compliance checks, based on data collected from IoT devices. For instance, a smart contract could automatically release payments to subcontractors once IoT sensors confirm that specific milestones are met.
- Enhanced traceability: Blockchain can provide a transparent and traceable record of all IoT-generated data, which is particularly valuable in managing complex construction projects with multiple stakeholders. This traceability can help in verifying the authenticity of materials, monitoring construction progress, and ensuring compliance with regulatory standards.

B) Integration of IoT with Artificial Intelligence (AI)

Integrating AI with IoT can further revolutionize the construction industry by enabling predictive analytics, automation, and enhanced decision-making.

- Predictive maintenance: AI algorithms can analyse data from IoT sensors to predict when equipment or infrastructure will need maintenance. This proactive approach can prevent costly breakdowns and extend the lifespan of machinery and materials. For example, AI can analyse vibration patterns from IoT sensors to predict potential failures in construction equipment.
- Automated construction processes: AI-powered systems can use IoT data to automate various construction processes. For instance, AI can control robotic systems for tasks such as bricklaying or concrete pouring based on real-time data from IoT sensors, improving efficiency and precision in construction.
- Improved decision-making: AI can analyze vast amounts of IoT data to provide actionable insights and recommendations for construction management. By processing data on building conditions, energy usage, and worker productivity, AI can help project managers make informed decisions, optimize resource allocation, and enhance overall project performance.
- Risk management: AI algorithms can assess risks by analysing data from IoT devices and historical records. For example, AI can predict potential safety hazards by analysing environmental conditions and worker behaviour data, enabling better risk management and enhancing site safety.

C) Combined impact of IoT, blockchain, and AI

The combined integration of IoT, blockchain, and AI can lead to several transformative impacts in the construction industry:

- Increased efficiency: The synergy between these technologies can streamline construction processes by automating routine tasks, optimizing resource use, and reducing manual errors. This leads to faster project completion times and lower costs.
- Enhanced data utilization: By integrating AI with IoT data recorded on a blockchain, construction firms can leverage rich, real-time insights to drive decision-making. This integrated approach allows for better forecasting, resource management, and overall project planning.
- Strengthened collaboration: Blockchain's transparency combined with AI's analytical capabilities can foster greater collaboration among stakeholders. All parties can access accurate, real-time information, leading to better coordination and reduced conflicts.
- Greater compliance and accountability: The integration ensures that all processes are documented, automated, and auditable, which strengthens compliance with industry standards and regulations. Blockchain's immutable ledger and AI's monitoring capabilities enhance accountability throughout the project lifecycle.

5. Challenges and future directions

While the integration of these technologies offers numerous benefits, there are challenges to address:

- Technical Complexity: Integrating blockchain and AI with IoT requires advanced technical expertise and infrastructure. Construction firms may face challenges in implementing and maintaining these systems.

- Data Privacy and Security: Ensuring data privacy and security is critical when combining these technologies. It is essential to address potential vulnerabilities and ensure compliance with data protection regulations.
- Cost and Scalability: The initial investment and ongoing costs associated with deploying and maintaining these technologies can be significant. Scalability considerations need to be addressed to ensure these solutions are cost-effective for different project sizes.

Future research should focus on developing scalable and cost-effective solutions for integrating IoT, blockchain, and AI, addressing technical and regulatory challenges, and exploring new applications and use cases in the construction industry.

6. Conclusion

The study analyzed the research trends, characteristics, and future directions of IoT in the construction industry through a bibliometric analysis of 2070 publications in the Scopus database from 2004 to 2022. The analysis revealed a rapid increase in publications on IoT in the construction industry, with China, India, the United States, and the United Kingdom being the leading countries in terms of publications. Smart buildings, building energy management, and construction automation were identified as the most researched topics, and sensors and wireless networks were the most frequently used technologies. The study suggested potential research directions for the future, such as the integration of AI and blockchain with IoT applications in the construction industry. Overall, the findings of the study provide insights into the current research trends, gaps, and future directions in IoT applications in the construction industry.

Conflict of interest: The author declares no conflict of interest.

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