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Jurnal Pensil Pendidikan Teknik Sipil

Journal homepage: http://journal.unj.ac.id/unj/index.php/jpensil/index

ARTIFICIAL INTELLIGENCE IN BUILDING CONDITION MONITORING FOR MAINTENANCE AND RESILIENCE ENHANCEMENT: A BIBLIOMETRIC REVIEW OF THE LAST DECADE

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P-ISSN: 2301-8437
E-ISSN: 2623-1085

ARTICLE HISTORY
Accepted:
21 Oktober 2025
Revision:
22 Januari 2026
Published:
31 Januari 2026

ARTICLE DOI:
10.21009/jpensil.v15i1.61201

Abstract

In past years, a variety of methods for monitoring the condition of concrete structures have been researched and widely used, including the application of artificial intelligence (AI). AI is increasingly popular in building monitoring and has shown excellent progress over time. This article provides a detailed bibliometric and scientometric overview of "Artificial Intelligence in Building Condition Monitoring" using data from Scopus over the last decade (2014–2024), supported by VOS Viewer software. This analysis found 222 relevant documents, which were mostly journal articles, with the most publications appearing in 2022. America and China are the countries that contribute the most to this field of research. The visualization results reveal five clusters related to AI applications in building condition monitoring, with the main topics being "condition monitoring" and "machine learning." Research trends show an increasing focus on integrating AI with other advanced technologies to improve monitoring systems and apply these innovations in various types of buildings.

Keywords: Artificial Intelligence, Monitoring Condition, Building, Bibliometric, Vos Viewer

Introduction

Civil structures and infrastructure a key role in economy and support the daily activities of people around the world. However, these assets often deteriorate faster than expected and approach the end of their useful lives (Balageas, *et al.,* 2010). Changing these structures requires enormous costs, significant labor, and exceeds the capacity of available human and financial resources. Therefore, engineers devised various ways to improve safety and maintain the building in good condition (Karballaeezadeh *et al.,* 2019), while minimizing the risk of financial losses and loss of life due to construction failures. namely with the help of monitoring the condition of a structure.

In architecture, the use of artificial intelligence (AI)-based sensors helps create smart and responsive buildings. These buildings are equipped with sensors that can monitor environmental conditions, occupant activity patterns, and energy use. With this technology, buildings can automatically adjust settings to improve energy efficiency and occupant comfort. In addition, AI algorithms use previous data to predict maintenance needs, thereby helping to maintain building durability and reduce operational costs.AI is also changing the way architects work. AI-based generative design technology helps architects create various designs based on certain criteria, simplifying the planning process and encouraging creativity. Connected devices based on AI enable real-time collaboration between architects, engineers, and construction teams, making the design process more efficient. In engineering, AI-based sensors are bringing major changes to project management, structural analysis, and predictive maintenance. Artificial intelligence algorithms can estimate risks, manage resource usage more effectively, and assist in project scheduling. IoT sensors monitor building conditions in real-time, providing critical data for proactive maintenance and preventing unexpected damage. AI also improves the accuracy of structural simulations, allowing designers to design strong and efficient buildings.

AI-based robotics and automation technologies support the construction process by augmenting human capabilities and addressing labor shortages. During a project, AI-based management tools enable real-time site monitoring, tracking progress, and identifying issues. AI-powered sensors embedded in construction equipment and materials provide data for predictive maintenance, increasing the efficiency of resource use. In addition, AI improves construction safety by detecting potential hazards and providing immediate alerts to workers. Drones with AI cameras can be used to display construction sites, providing stakeholders with a bird's eye view and supporting decision-making. Techniques that use artificial intelligence to monitor conditions help companies not only diagnose problems with equipment but also predict potential failures and provide recommendations on how to fix them (Nadakatti, *et al.,* 2008). Interest in monitoring conditions utilizing artificial intelligence (AI) has grown in recent years, leading to the emergence of new software for managing maintenance. Artificial intelligence (AI) in civil engineering is one of the important innovations in the development of intelligent software for the construction sector. AI development focuses on creating systems that are able to imitate human functions, such as troubleshooting and introducing patterns (Zhang & Lu, 2021). Construction projects often face great challenges due to their scale and complexity, so many civil engineering companies are adopting machine learning technology to support the design and construction of infrastructure, such as roads, bridges, and other projects. AI has many potential applications in the construction sector, from optimizing processes to reducing waste (Adewale, *et al.,* 2024). One of its main applications is Smart Construction Design, where AI-based tools enable automatic environmental calculations and analysis, strengthening BIM (Building Information Modeling) technology to produce comprehensive data models that support project simulations (Pan & Zhang, 2021)(Rane, *et al.,* 2023). In addition, Construction Process Orchestration leverages drones and robots for autonomous monitoring of construction sites (Jiang *et al.,* 2024), generating 3D maps and real- time reports that can be shared via the cloud. Furthermore, Construction 3D Printing uses AI to print buildings with calculations for resistance to wind loads, earthquakes, and other environmental factors, while ensuring structural comfort. Previous studies on the use of artificial intelligence in monitoring building conditions have shown that this approach is highly effective, such as the research of Beck who developed a support system for expert systems in industrial automation (Beck, 1990), Ceglarek et al. who used knowledge-based diagnosis to detect failures in the process of installing the car body (Ceglarek, *et al.,* 1994). In addition, Fran Barbera and his team recommend a condition-based maintenance model to achieve the best repair policy, Gabbar et al. designed an integrated RCM system with CMMS to optimize plant maintenance, and John Zeleznikow & Nolan combining software methods of reasoning such as fuzzy logic and artificial neural systems to improve the efficiency of knowledge-based systems (Barbera, *et al.,* 1999; Gabbar, *et al.,* 2003; Zeleznikow & Nolan, 2001). These studies show that artificial intelligence (AI) and knowledge-based systems play an important role in maintaining and improving industrial resilience and building maintenance.

This study aims to identify patterns in research on building condition monitoring using artificial intelligence. The overall objective of this research is to offer latest information on the topic and explore the possibilities for future development, improvement, and application of AI technology. To achieve this objective, this paper presents the results of an in-depth bibliometric analysis of scientific literature related to AI-based building condition monitoring. In recent years, approaches based on bibliometric analysis have proven effective in evaluating trends in large datasets. In the context of scientific studies, bibliometric analysis allows researchers to uncover significant findings through quantitative analysis, including patterns of relationships between researchers, institutions, countries, and keywords relevant to a particular field of study. The results provide a comprehensive evaluation of the existing scientific network and the potential for further collaboration or development in this field.

Research Methods

This study uses a bibliometric approach and scientometric analysis combined with the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) framework. This approach aims to select relevant and high-quality articles to support the research objectives. The steps in this method include:

Data collection for the study was conducted by extracted publications from the Scopus database through a process of identifying relevant literature. Although Google Scholar, Scopus, and Web of Science are databases commonly used for citation indexing and academic literature collection (Ahmed, *et al.,* 2024; Bergman, 2012; Chadegani *et al.*, 2013), Scopus was selected due to its broader bibliometric coverage, wider range of indexed journals, and more efficient indexing procedures (Chadegani *et al.*, 2013; Meho, 2019). The search was conducted using the query TITLE-ABS-KEY (artificial intelligence, monitoring, buildings, conditions) applied to article titles, abstracts, and keywords (Nindhita, *et al.,* 2024; Zhong *et al.,* 2019), with restrictions set to the last decade (2014–2024) and the Engineering field, while no limitations were imposed on document type, language, country, or source. These criteria ensure that the latest research in line with technological developments is included in the analysis. The search yielded 327 documents, which were then screened using the PRISMA guidelines and analyzed using bibliometric and scientometric methods. The reference selection process was carried out based on the PRISMA guidelines (Page *et al.,* 2021; Rethlefsen *et al.,* 2021), which were developed to address inadequate reporting in systematic reviews and meta-analyses (Moher, *et al.,* 2009; Page & Moher, 2017). PRISMA involves several main steps (Rethlefsen *et al.,* 2021; Xie, *et al.,* 2023), beginning with study identification through searches of multiple information sources such as databases, study registries, and online resources, with detailed reporting of the search strategy. The screening process then eliminates duplicate data and selects studies for the title, abstract, and full text ensure eligibility, and in this study, it was applied to publications from the last 10 years. Inclusion and exclusion criteria are determined in order to select appropriate studies and exclude those that are not suitable, while data extraction focused on techniques related to artificial intelligence for building control. The collected data were synthesized and presented in tables or diagrams, followed by a risk of bias assessment to ensure validity. Finally, the overall results were summarized and reported using the PRISMA flow diagram (Figure 1).

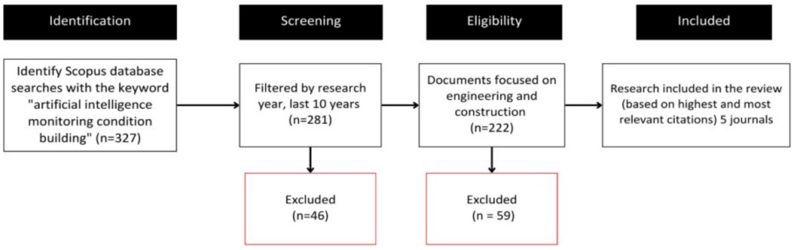


Figure 1. Screening literature with PRISMA

Bibliometrics has become a major trend in academic research, used to determine the results of articles and journals, how researchers collaborate, and the different parts of research (Donthu, *et al.,* 2015; Khan *et al.,* 2021; Passas, 2024). It also helps to study the structure of thinking within a field through existing written works, combining both objective indicators such as citation counts and keyword occurrences with subjective evaluations like thematic analysis (Donthu, *et al.,*2022; Donthu, *et al.,* 2021; Verma & Gustafsson, 2020). By analyzing bibliometrics enables scholars to map cumulative knowledge, identify gaps, and advance research fields in new directions. Closely related terms include "infometrics" (broader) and "scientometrics" (narrower), with bibliometrics popularized by Pritchard in 1969 and scientometrics introduced by Nalimov the same year (Bar-Ilan, 2010; Garfield, 2009; Rousseau, 2014, 2021; Wolfram, 2015). Scientometric analysis applies quantitative methods to study knowledge trends and academic productivity at the level of individuals, institutions, and journals, often through big data tools like citation networks and bibliometric maps (Fayyad, *et al.,* 2024; Ghaleb, *et al.,* 2022; Kazemi, 2023; Mingers & Leydesdorff, 2015). This process maps scientific literature into interactive visualizations that facilitate statistical and network analysis (Olawumi & Chan, 2018). In this study, VOSviewer was used as it is widely recognized for producing clear, meaningful, and interpretable results, while also supporting the visualization of collaboration networks and intellectual landscapes across fields (Ali, *et al.,* 2022; Chou & Pham, 2013; Kazemi, 2023; Oyewola & Dada, 2022).

Bibliometric analysis is not just about visualizing data; it's also a strong way to use numbers to study how a research area is built, how it changes over time, and the main ideas that guide it. This method combines looking at how well research is doing like how many papers are published, how often they are cited, and which authors or universities are most active with tools that help map out the science. These studies help researchers spot the main topics, new areas of study, and where knowledge is missing. Recent studies show that this approach is very good at showing how research trends change and what scholars focus on over time. For instance, (Sunarno & Ningsih, 2022) employed bibliometric analysis to reveal how sustainability accounting research has evolved from a predominantly environmental reporting focus toward more integrated discussions on governance, social accountability, and sustainable finance, highlighting the dynamic nature of the field and the role of interdisciplinary convergence. Similarly, bibliometric mapping has proven valuable in identifying thematic clusters and collaboration patterns within education related research.(Razilu et al., 2025) mapped global research trends in interactive learning media using Scopus indexed publications and found that technological integration, learner centered design, and digital pedagogy emerged as central intellectual structures within the field.

Their analysis demonstrated how keyword co occurrence and co authorship networks can uncover both mature research streams and underexplored areas, thereby guiding future research agendas. In a comparable vein, (Faizal, 2025) utilized bibliometric techniques to map the global landscape of STEM education research, revealing a rapid growth in publications related to computational thinking, interdisciplinary STEM integration, and technology enhanced learning environments. These findings underscore the capacity of bibliometric analysis to illuminate how scientific discourse responds to technological advancement and policy driven educational reforms. Bibliometric analysis also plays a critical role in contextualizing national research output within the global scholarly ecosystem. (Tupan, 2025), in a bibliometric study of archival research publications in Indonesia indexed in Scopus, demonstrated how national research productivity, international collaboration, and citation impact can be systematically assessed using bibliometric indicators. The study found that even though more papers are being published, international teamwork in research is still not very widespread, which shows there are chances to improve global science cooperation. These findings show that using bibliometric analysis is not just helpful for describing research trends, but also for making decisions about research policies and how institutions grow. Additionally, big bibliometric studies that look at many years give a clear picture of how ideas develop and how fields of study change over time, especially in areas that involve multiple disciplines. (Febryanti, 2025), through an extensive bibliometric analysis of health and communication research from 1995 to 2025, identified significant transitions from traditional health communication models toward digital health, social media based interventions, and participatory communication frameworks.

By employing citation analysis, keyword evolution, and collaboration mapping, the study illustrates how bibliometric methods can capture both historical continuity and transformative change within a research domain. Collectively, these studies affirm that bibliometric analysis supported by visualization tools such as VOSviewer offers a rigorous and systematic means of synthesizing large volumes of scientific literature. It enables researchers to move beyond narrative reviews by providing empirical evidence of research patterns, intellectual structures, and collaborative dynamics. Consequently, bibliometric analysis is increasingly recognized as a high-impact methodological approach for establishing a comprehensive research overview, informing future research directions, and strengthening the theoretical and empirical foundations of scholarly inquiry across disciplines.

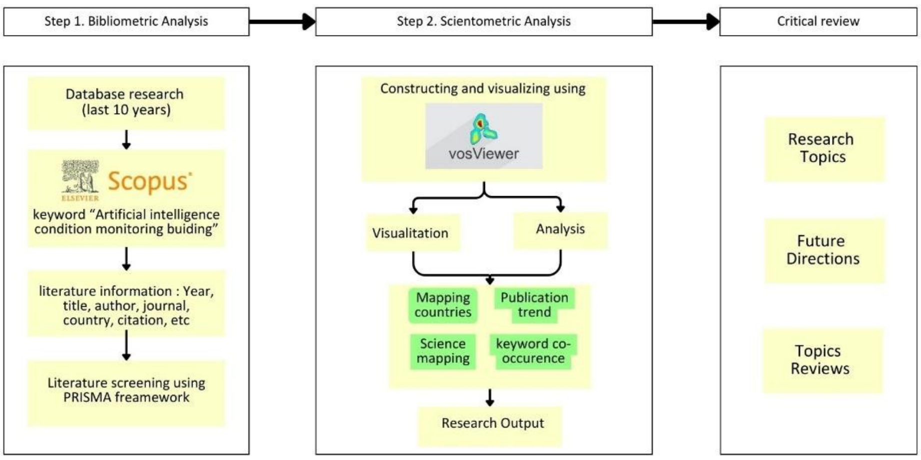


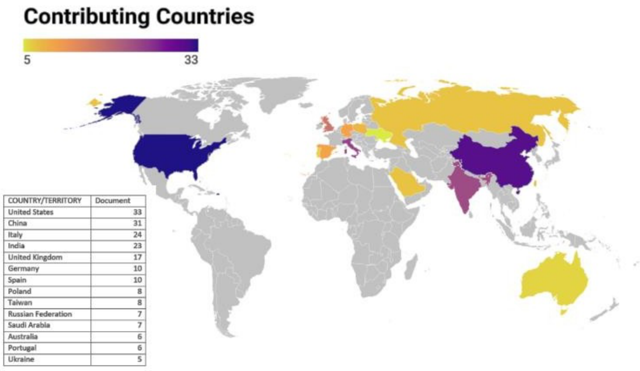
Figure 2. Research Method Diagram

Research Results and Discussion

Research and publications on AI research in building condition monitoring show significant developments from year to year. Based on the Scopus baseline data search of 327 documents, only 222 documents were deemed relevant and appropriate. From these 222 documents, scientific discussions can be conducted covering number of documents per annual period, kind of document, country of origin of the author, and frequency of keywords.. Analysis of co-authorship also provides an overview of patterns of cooperation between countries and institutions. The aspects analyzed include: (3.1) Annual publication trends; (3.2) Distribution of document types and subjects; (3.3) Regional network analysis; (3.4) Authors with the most contributions in collaboration; (3.5) Documents and affiliations with the most contributions; and (3.6) Clustering, hotspot keywords, and visualization analysis.

Based on data extraction from the Scopus database, 222 documents were identified discussing artificial intelligence in monitoring building conditions from 2014 to 2024. The results show that publications in 2014 were relatively low and remained stagnant until 2020, but began to rise in 2021, with a sharp increase in 2022. By the end of 2024, publications peaked at 52 documents, marking the highest number within the observed period. This trend indicates a growing interest in artificial intelligence applications for building condition monitoring over the last decade, likely driven by rapid technological advancements (Alaloul, *et al.,* 2021) and tasks prioritized by artificial intelligence (AI) in simplifying human tasks and being widely adopted across various fields, particularly engineering (Brynjolfsson & McAfee, 2017). Based on Scopus data regarding crack monitoring in concrete structures, six types of documents were identified: articles, conference papers, reviews, conference reviews, book chapters, and books. Articles dominate with 46.3% (103 documents), followed by conference papers at 37.4% (83 documents), reviews at 7.6% (17 documents), conference reviews at 5% (11 documents), book chapters at 2.7% (6 documents), and books at 1% (2 documents). These findings suggest that authors prefer to publish in journal articles, as bibliometric analysis consistently shows that this format is most common in studies of artificial intelligence for building condition monitoring. Articles dominate because much of the research involves field testing with specific tools, where processed data provides conclusions on building conditions. Conference papers, the second largest type, often present field studies with new methods or case-specific findings, while reviews, book chapters, and conference reviews typically cover theories, formula development, or summaries of AI evolution in monitoring. Subject analysis further revealed five main domains: Engineering (163 documents), Computer Science (131), Mathematics (38), Materials Science (20), and Decision Science (18), with Engineering emerging as the most productive field.

The trend of state participation describes how and to what extent countries are involved in various activities, initiatives, or issues of a global nature (Chanief Rahita, *et al.,* 2024). In this research, it is essential to identify the countries that contribute the most. Figure 6 displays a geographic map of the authors' countries of origin in the same field, which illustrates how contributions are distributed and helps readers identify the countries that are most active in publishing and developing research in this field.



COUNTRY/TERRITORY	Document
United States	33
China	31
Italy	24
India	23
United Kingdom	17
Germany	10
Spain	10
Poland	8
Taiwan	8
Russian Federation	7
Saudi Arabia	7
Australia	6
Portugal	6
Ukraine	5

Figure 3. Countries with The Most Contribution to Publication

The trend of country participation highlights how different nations contribute to advancing science and technology in artificial intelligence for building condition monitoring. Based on Figure 3, the United States leads with 33 documents (15% of total publications), followed by China, India, the United Kingdom, and Germany. The U.S. dominance reflects its advanced research infrastructure, strong international collaboration, and significant investment in AI technology. Meanwhile, China and India demonstrate growing focus on innovation in construction and monitoring, while the U.K. and Germany show solid commitment to research and AI application in structural monitoring. Collaboration networks reveal close ties between the U.S., China, India, and Italy, indicating that leading countries not only dominate in publication output but also actively engage in cross-border cooperation. Despite these strong ties, opportunities remain to expand international networks by involving more countries in collaborative efforts. Broader participation would foster knowledge exchange, encourage innovation, and accelerate the development of AI-based building monitoring technologies, ultimately enhancing global construction and infrastructure practices.

Studying the relationships between authors and co-authors provides important information about the main research groups in a particular field. The influence of a researcher on a topic is assessed by how often their work is cited by other researchers (Van Eck & Waltman, 2010). The five most relevant articles to AI research in building condition monitoring cover a range of important topics. The first article discusses the design of a smart home system based on multisensor data fusion, while the second uses image recognition sensors to monitor office building occupancy. The third article proposes a predictive maintenance framework for smart environments, and the fourth model indoor temperatures in tropical climates using outdoor environmental data. Finally, the fifth article focuses on AI- Monitoring equipment conditions using digital twins and Industry 4.0 technology. These studies explain how artificial intelligence (AI) can be used in various aspects of building management to improve efficiency, comfort, and sustainability.

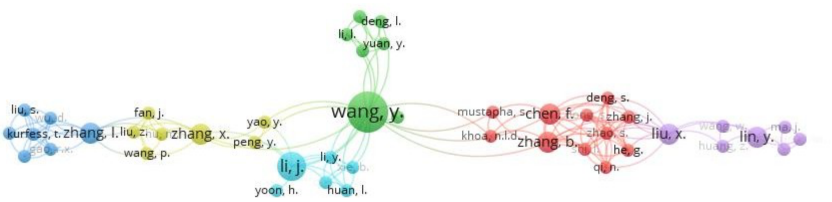


Figure 4. Visualization of Atuhor Contribution

Identifying the research sources with the greatest contributions through affiliations is Analyzing institutional affiliations is an important step in understanding the collective impact of universities, organizations, or research groups in shaping knowledge in the field (Chanief Rahita *et al.,* 2024). Such analysis helps evaluate the role and influence of affiliations in developing thematic focuses, intellectual strands, and collaborative networks that define current research trends. As shown in Table 4, Southeast University (China) emerges as the leading contributor with 5 documents on artificial intelligence for building condition monitoring over the past decade. Drexel University (United States) and Consiglio Nazionale delle Ricerche (Italy) follow with 4 documents each, alongside The University of Texas at San Antonio (United States) and Silesian University of Technology (Poland), which also produced 4 documents each. These findings highlight the institutions most instrumental in advancing this research domain, offering insights into potential collaboration opportunities, identifying centers of research excellence, and assessing the influence of academic contributions on the future development of AI-based building monitoring.

Table 1. Top Affiliation with The Most Publication

Affiliation	Number of Document	Country
Southeast University	5	China
Drexel University	4	United State
Consiglio Nazionale delle Ricerche	4	Italy
The University of Texas at San Antonio	3	United State
Silesian University of Technology	3	Poland
Politechnika Wrocławska	3	Poland
Università della Calabria	3	Italy
Politecnico di Milano	3	Italy
Politecnico di Bari	3	Italy
Margie and Bill Klesse College of Engineering and Integrated Design	3	United State
Universidad Autónoma de Yucatán	2	Chile
Pennsylvania State University	2	United State

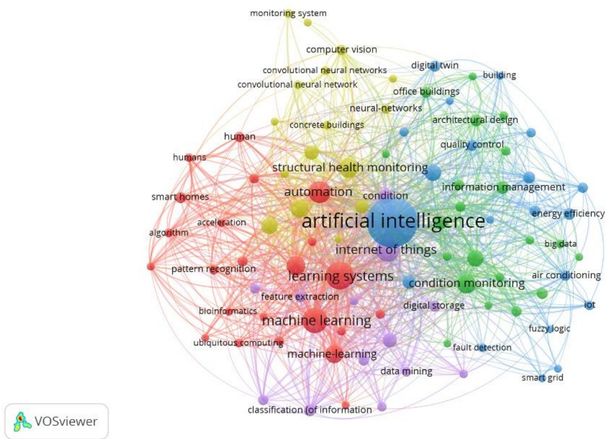


Figure 5. Visualization Representation of the Co-Occurrence of Keywords

The keyword analysis using VOSviewer from 222 documents identified five main clusters in research on artificial intelligence (AI) for building condition monitoring, each reflecting different thematic focuses. The blue cluster focuses on information management systems and building condition monitoring. The green cluster emphasizes the Internet of Things (IoT) and smart networks so that data can be managed more efficiently. The red cluster handles the development from an algorithm for machine learning. The yellow cluster involves monitors the health of the structure, damage detection, and the use of neural networks. Meanwhile, the purple cluster centers on advanced data processing such as data mining, feature extraction, and classification. These clusters are interconnected, showing that AI research in building monitoring integrates various methods and technologies to generate actionable insights and improve infrastructure resilience.

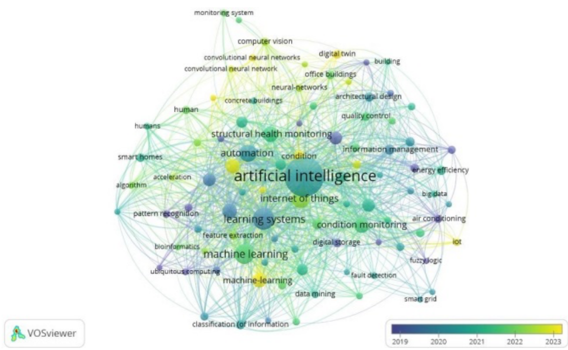


Figure 6. Overlay Visualization

The latest visualization trends show a shift from early research focused on the basic development of artificial intelligence (AI) towards current research involving applied Technologies such as the Internet of Things (IoT), machine learning, deep learning, and digital twins. Keywords like "machine learning," "condition monitoring," and "digital twin" emerge as dominant in recent years, marked in yellow, indicating their growing significance. While AI applications are largely concentrated on office buildings due to commercial demands, research on campus buildings remains limited, possibly due to budget and priority constraints in educational institutions. Density visualization also highlights potential research opportunities in underexplored areas such as computer vision, neural networks, smart homes, and fuzzy logic, suggesting promising directions for future development in AI-based building condition monitoring.

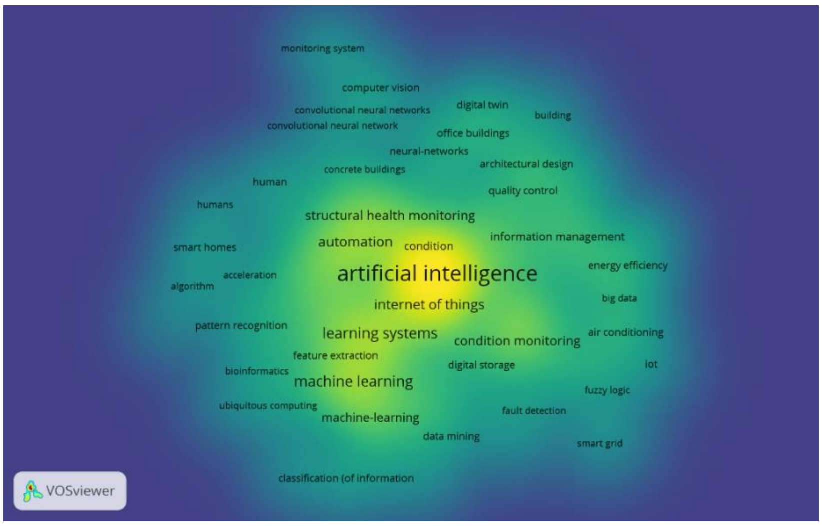


Figure 7. Density Visualization

Conclusion

Based on the results of the study, this research emphasizes that the use of artificial intelligence (AI) plays an important role, in building condition monitoring still holds extensive potential for development, both in terms of methodology and practical implementation. The bibliometric analysis reveals a significant increase in publications since 2020, peaking in 2022, with a dominance of articles in the engineering field and major contributions from the United States, China, India, and Europe. Future research trends are directed toward strengthening information management systems, advancing IoT and smart sensors, utilizing deep learning for complex data analysis, and integrating digital twin technology as a tool for simulation and predictive maintenance. Issues of security, privacy, sustainability, and specific applications in campus buildings are also gaining importance. Therefore, future studies should focus on optimizing keyword mapping, expanding case studies across different types of buildings, and emphasizing energy efficiency and sustainability so that the innovations produced are not only technologically relevant but also responsive to the real needs of society and the environment.

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