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A Bibliometric Analysis of Scaffolding Safety: Challenges, Trends, and Solutions in Construction Projects

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Abstract

Scaffolding plays a critical role in construction, offering essential support for workers at various heights for the smooth functioning of various construction activities. However, it poses significant safety risks stemming from poor design, material deficiencies, environmental factors, and inadequate worker training. This study explores scaffolding safety challenges and proposes strategies to mitigate risks and improve efficiency. By employing bibliometric analysis of Scopus data and tools like VOS viewer, it visualizes research trends, identifies critical safety issues, and highlights advancements in protocols. Key findings emphasize the necessity of certified materials, advanced design technologies, supervised assembly processes, and robust training programs. Emerging global research trends highlight interdisciplinary collaboration and the integration of technologies like automation and deep learning to address scaffolding challenges. The study offers actionable recommendations for industry stakeholders, advocating for innovation and improved safety practices to enhance project outcomes. These insights aim to foster safer, more efficient construction environments through the adoption of advanced tools and best practices.

Keywords: Scaffolding, Construction, Bibliometric Analysis

1. Introduction

Scaffolding is one of the important part of the construction projects which act as an temporary structure to support the workers to perform any kind of work at different heights and elevations [1, 2]. It has a key role in every aspect of the building projects including from initial phases to the maintenance repairs [3]. There are different types of scaffolding and the mostly used in the construction sector with ease are tube-coupler systems, modular scaffolding [4, 5]. The type of scaffolding is selected based upon the project requirements. The planning must be done effectively in order to make a safe environment for the scaffold design and dismantling. Though the scaffolding is installed with greater care and planning but accidents occur due to lack of training, installation issues that could leads towards a disaster for the life of on-site workers [6]. Due to the negligence is safety protocols, fall from the height may occur [7]. In order to avoid some tragic accident scaffolding can be done using the strict regulations so that the chance of any unforeseen happen is reduced [8]. A study proposed semi-autonomous drone system that integrates computer vision techniques to enhance safety protocols in suspension scaffolds which utilizes YOLO-based object detection [9]. In contrast, this study takes a broader approach by examining the challenges and trends to improve efficiency across scaffolding operations as a whole. In most of the cases there are budget problems in the project which make concerns regarding safety as contractors try to reduce to cost of the projects by taking safety at stake [10]. However, if the advanced solutions are taken into

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account then the probability of the unforeseen incidents may decreased, which includes automated modeling, sensor based modeling [11-14]. These advanced technologies not only play a key role in improving safety but make a lot in the productivity of the project. By keeping a tough focus on safety the construction industry can mitigate risks by following the international standards and providing the safer workplace for everyone [15].

Construction projects always need the scaffolding as there is need to do work on the elevations and it cannot be done without temporary structures [16]. It is one of the difficult and riskier part of the project in which any unforeseen event can be happen if the guidelines and proper monitoring was not done from time to time. Risk issues on construction sites are unexpected and difficult to control, making them dynamic situations. Injuries or even fatalities may result from certain scaffold collapses, falls, or collisions with objects that frequently occur in the construction business [17]. These accidents highlight the need for improved planning and execution procedures as well as training programs for a safe workplace. Furthermore, the increasing complexity of today's building projects indicates that a new component is needed to guarantee scaffolding's efficiency and safety, particularly in design [18].

The situation of scaffolding safety in the building sector is the main topic of this review paper. In order to accomplish this, the writers integrate the extant research with an analysis of specific patterns, obstacles, and prospects that could potentially enhance scaffold safety in the building sector. By doing bibliometric analyses based on the Scopus data, the goal is to guarantee that the research is quantitative and methodical. The authors describe other important facets of the discipline, including the visualization of co-authorship networks and keyword occurrence maps, among others, using the visualization program VOS viewer. These topics help to provide a more comprehensive view of the current academic discussion about scaffolding safety, the gaps that still exist among researchers, and potential fixes and recommendations. In order to improve scaffolding tool safety and innovation on construction sites, the authors of this study offer policy and practice recommendations to a range of stakeholders.

2. Methodology

By providing a useful framework for bibliometrically examining scaffolding safety in the construction sector, the methodology used in this study fills in the existing void. Since it contains a vast amount of peer-reviewed journal articles, conference proceedings, and review papers, it begins by identifying Scopus as the primary database. In addition to providing a comprehensive dataset for analysis, Scopus also applies a number of filters to help focus the search. The inclusion range is stated as the years 2000–2025, with the documents being of the journal article, conference paper, or review article type, and the language being English. In this manner, the dataset includes the most recent and relevant advancements related to the addressable domain. Following database selection, a CSV report is exported from Scopus to facilitate data retrieval. This file contains important data that could be exported, such as abstracts, keywords, bibliographic information, and citation information. Finding trends, patterns, and insights in the field is made possible by this metadata, which also acts as the foundation for additional analysis. VOS viewer version 1.6.20 is chosen as an analyzing tool following data extraction. One of the most popular tools for visualizing bibliometrics is VOS viewer, which makes it possible to create co-authorship networks, keyword co-occurrence maps, and other bibliometric analysis visualizations. It imports a CSV file into the tool to start the real analysis.

A keyword co-occurrence analysis, which considers keywords that appear at least 10 times, is one of the main investigations that follow in order to determine the most talked-about subjects and new themes in scaffolding safety research. A co-authorship analysis that maps the networks of collaboration among authors who have contributed at least one document comes next. By highlighting significant contributors, this aids in understanding the composition of the research community. The evolution of research effort over time is then demonstrated by analyzing temporal trends by looking at the number of documents released annually between 2000 and 2025.The quantity of documents produced by each nation is taken into consideration while analyzing the geographical contribution, and countries that provide at least 10 papers are cut off. This illustrates the main countries in scaffolding safety studies and shows how the research effort is distributed globally. In order to identify the major dominating journals and conference proceedings in the subject, it also examines the number of documents published for each source. All subject areas and document types will be analyzed, with a concentration on journal articles, conference papers, and reviews for their applicability to the study's goals.

Among other types of representation that serve as the foundation for the results section, the results are further examined for visualizations such as co-authorship networks and keyword maps. These will significantly aid in identifying important research gaps, collaborative possibilities, and emerging trends, providing academics, practitioners, and policymakers with a useful viewpoint in their efforts to enhance scaffolding safety in the construction sector. This study's systematic methodology guarantees thorough coverage of the scholarly literature on scaffolding safety.

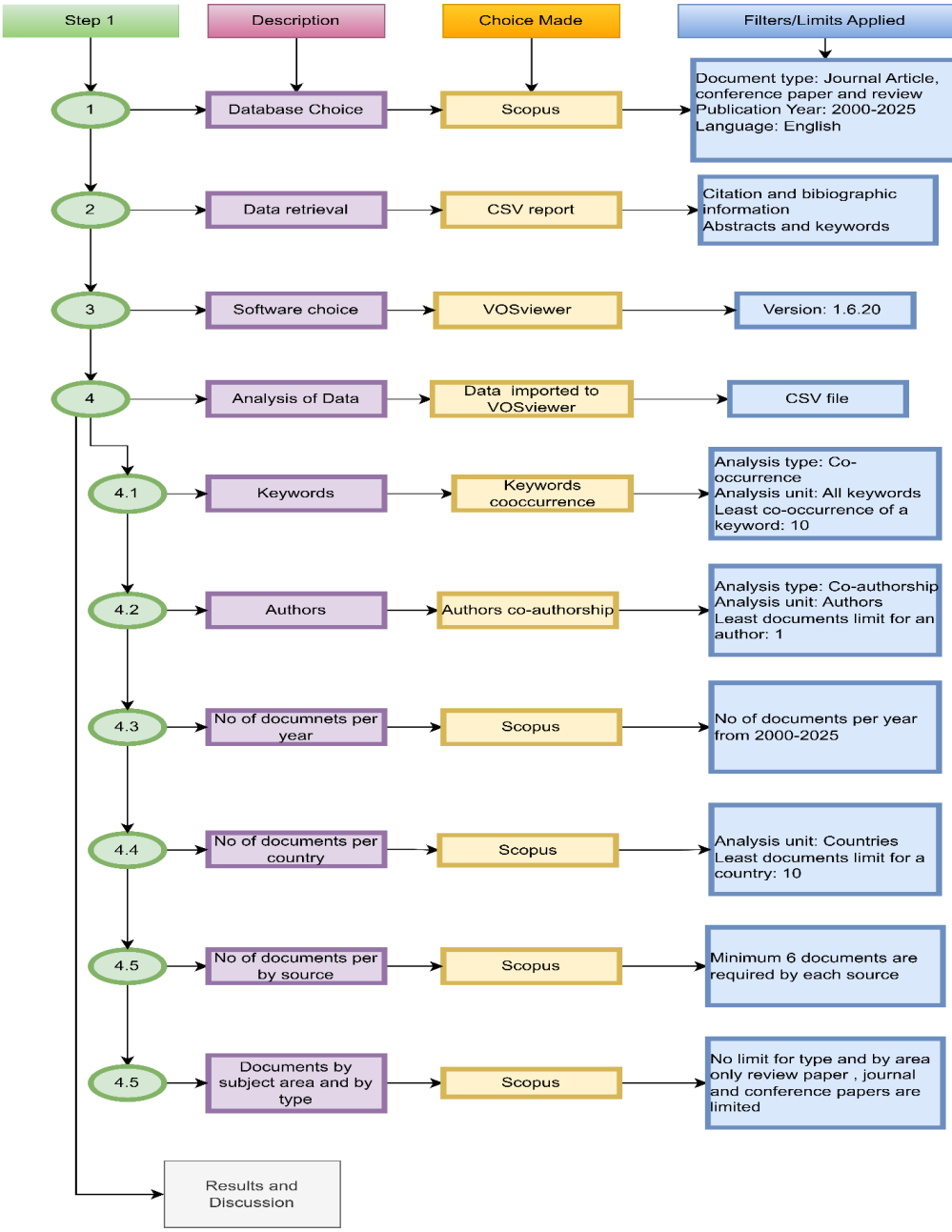

Figure 1. Methodological Framework for Bibliometric Analysis of Scaffolding Safety

3. Results and Discussion

3.1. Challenges in Scaffolding Design and Material Selection

Table 1 explains the challenges and the concerns that are closely related to scaffolding in construction sector. There are five major identified challenges that represents the durability and safety of scaffolding. The challenges tackled with a methodological manner will result in safer and efficient scaffolding. The design and material used for the scaffolding shows the stability of the structure. The faulty design and poor material usage can lead towards the mishaps and unforeseen events making the work environment uncomfortable [19]. This problem is crucial since the scaffolding must frequently support heavy loads during the operation and may experience a variety of strains. Table 1 highlights how employing approved materials and contemporary design tools greatly lowers these hazards. Increased structural integrity and dependability are guaranteed by contemporary engineering techniques [20]. The topic of safety compliance is usually always brought up, and non-compliance with any safety standard conditions is also the primary source of issues. In addition to endangering personnel, problems including inadequate anchoring systems and missing rail guards may have repercussions for construction companies, as they may be subject to legal, financial, or reputational repercussions. The training for the workers and monitoring is the key for prevention in both of scenarios. For the prevention of the incidents such measures aid in providing a safer culture and environment for the workers so that the work is done without any interruption [21].

Overloading and the use of poor assembly system is the main cause of instability for the scaffolding system failure which is the big area concern [22, 23]. These typically result from a shortage of supervising staff and skilled labour, which leads to project delays and structural collapse. The Table 1 emphasizes careful planning and execution in scaffolding erection, recommending supervised assembly and load monitoring to prevent it [24]. This focus on precision and supervision aligns with the industry's growing recognition of the need to lower risk and improve operational excellence. The scaffolding system also faces significant environmental problems, such as exposure to wind, rain, and adverse weather conditions, which can cause temperature changes that might lead to corrosion [25]. Such corrosion will shorten the scaffolding materials' lifespan and lead to structural failure. For the improvement in performance and safety the scaffolding systems must used the weather resistant materials and repellent coatings to get maximum outputs and minimal incidents [26].

The lack of training of the workers play a key role in the cause of scaffolding related difficulties. Inadequate training results in incorrect scaffolding assembly and use, which could have major repercussions for worker safety and project timeline. Comprehensive training programs that would provide the employees with the necessary knowledge and abilities would come next. Workers will be fully informed about scaffolding safety procedures thanks to this training, which is crucial in averting potential mishaps during construction [27].

Table 1 lists the various scaffolding-related issues in the construction sector and, concurrently, suggests workable solutions for each. The comprehensive approach to scaffolding system enhancement is highlighted, even as design elements, adherence to safety features, erection procedures, environmental considerations, and worker training are prioritized. This discussion makes it abundantly evident that technical know-how, regulatory compliance, and worker education funding are all desperately needed for safer and more effective construction methods.

Table 1. Challenges, Impacts, and Solutions for Scaffolding in Construction

Category	Key Issues	Challenges	Impact on Construction	Possible Solutions	References
Design & Materials	Inadequate design and use of substandard materials	Structural instability and reduced durability	Increased risk of collapse and accidents	Use certified materials and advanced design tools	[19]
Safety Compliance	Non-adherence to safety standards	Lack of guardrails and proper anchoring	Increased injuries and fatalities	Regular inspections and worker training	[21]
Erection Process	Improper assembly and overloading	Incorrect joining and instability	Structural failure and project delays	Supervised assembly and load monitoring	[24]
Environmental Factors	Extreme weather exposure	Corrosion and instability	Reduced lifespan and structural damage	Weather-resistant materials and coatings	[26]
Worker Training	Insufficient training	Errors in assembly and usage	Higher accident rates and inefficiency	Comprehensive training programs	[27]

3.2. Trends in Scaffolding Safety Research Output

The publication patterns pertaining to scaffolding and safety concerns in the construction sector from 2000 to 2025 are depicted in Fig. 2. The graph's line of trend indicates that scientific activity in the examined field has generally increased, indicating that industry and academia are interested in addressing scaffolding's safety issues. The output was somewhat modest over the 2000–2010 decade, with only 5–10 publications year. Perhaps as a result of isolated instances or regional issues within the building industry, this era marks the beginning of research interest in scaffolding and safety. The number of articles suddenly increases from 2010 onwards, and the graph shows upward trend beyond 2015. It is explained by growing concern for scaffold-related risks, advancements in efficient construction equipment, and heightened knowledge of workplace safety. The surge in papers around 2020 indicates that research has been concentrated during this time, most likely due to increased worldwide construction and more stringent occupational safety regulations.

There is a notable drop in 2025, though, which might be the result of either a recent change in the priorities of research or insufficient data for the year. Overall, the data shows the growing focus on scaffolding safety, indicating a greater understanding of its significance in guaranteeing worker safety and enhancing project effectiveness. These patterns suggest that further research is required to capitalize on new opportunities and address outstanding issues with scaffolding safety procedures.

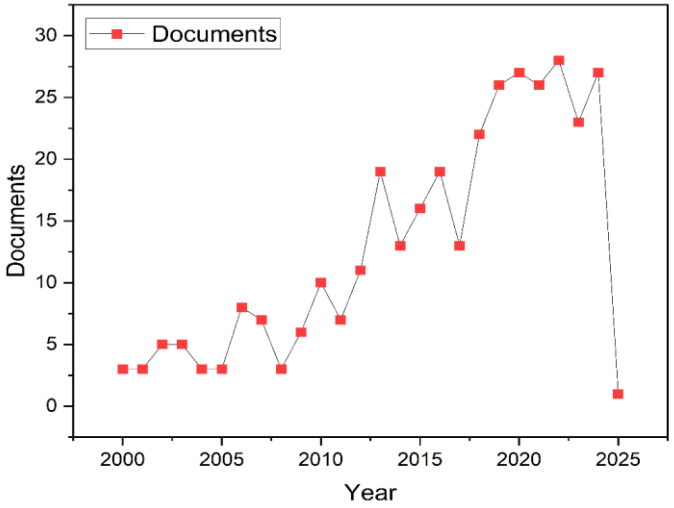

Figure 2. Publication Trends in Scaffolding and Safety Research (2000–2025)

3.3. Trends in Scaffolding Safety by Journals

The distribution of research articles on scaffolding and safety concerns across journals is shown in the Fig. 3 with a minimum criterion of six. The overview shows which sources are most active in scaffolding and safety research because journals are rated for this purpose based on the quantity of contributing articles. With around twelve articles published in this field, "Automation in Construction" is the top journal. This illustrates the increasing focus on incorporating automation and cutting-edge technologies to solve scaffolding-related construction issues. Second in rank, the "Journal of Construction Engineering and Management" has also made significant contributions, demonstrating its emphasis on engineering techniques and management tactics that raise safety standards. In the meantime, "Buildings" and "Safety Science" journals have about equal participation in the publishing contribution. These publications show a well-rounded emphasis on methods with reference to safety procedures and architectural issues. Contributing a moderate number of articles, the publications in "Advances in Intelligent Systems and Computing" emphasize the function of intelligent and computational systems in scaffolding and construction safety.

Lastly, by offering details on structural elements and how they affect scaffolding safety, "Engineering Structures" adds to the body of literature. The interdisciplinary character of scaffolding research is depicted in the figure, which spans engineering, automation, safety science, and construction management. This distribution emphasizes how important it is for these disciplines to work together to increase safety in the construction sector.

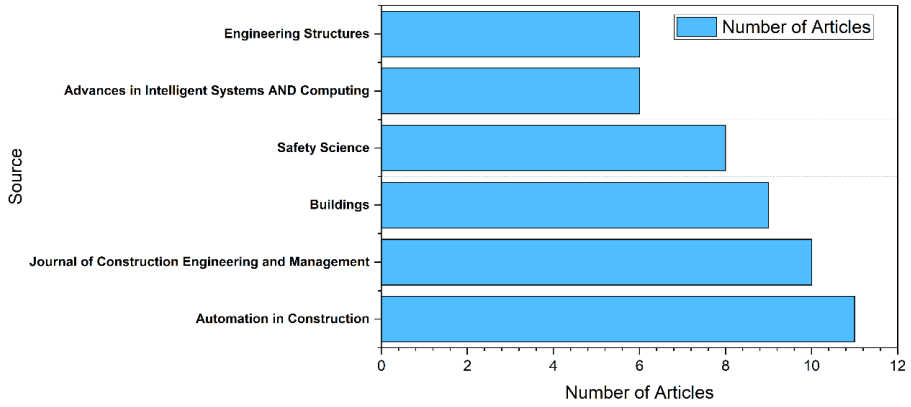

Figure 3. Distribution of Research Outputs by Journals

3.4 Global Contributions to Scaffolding Research

The study output on scaffolding and related issues in building across different nations is also highlighted in Fig. 4. It shows a great deal of variance in research output, which is indicative of academic focus, construction industry priorities, and economic advancement. The United States is at the forefront of construction-related research, as evidenced by its 78 annual publications. Well-established academic institutions and significant research funding, as well as an industry that prioritizes innovation and safety, have made this feasible. Next up is China, whose experts have published 51 publications in the relevant journals. The country's large development projects and fast urbanization demand exceptional work. Their high rankings are a reflection of their significant investments in worker safety and building technologies. Spain and Italy contribute 12 and 10, respectively, indicating moderate activity in the scaffolding industry; Poland provides 26, perhaps as a result of the country's focus on enhancing scaffolding standards and safety. Even though building has a long history throughout Europe, certain nations, like Italy, produce relatively little, which may indicate that more work in this area may be done with greater industry-academia collaboration. South Korea and Taiwan, two countries in the Asia-Pacific area, contribute 23 and 16, respectively, demonstrating their strong interest in technology advancement and construction safety. With 11 publications annually, Japan and Hong Kong demonstrate their steady scholarly contributions to fields including dense urban infrastructure and earthquake-resistant building. With ten publications, Australia comes in second, demonstrating its interest in sustainable building practices and workplace safety. The information also highlights the under-represented regions, which include sections of the Middle East, Africa, and South America, where there has been little documented research on scaffolding and construction-related difficulties. This might be the result of smaller building industry, a lack of funding for study, or a lack of emphasis on this topic among academics. These disparities suggest that in order to address the issues of safety and efficiency in building, international cooperation and information exchange are required.

Overall, the Fig. 4 shows how research output is related to economic development and the size of the construction industry, emphasizing the potential for established research nations to start working with under-represented regions while promoting global advancements in scaffolding safety, technology, and innovation.

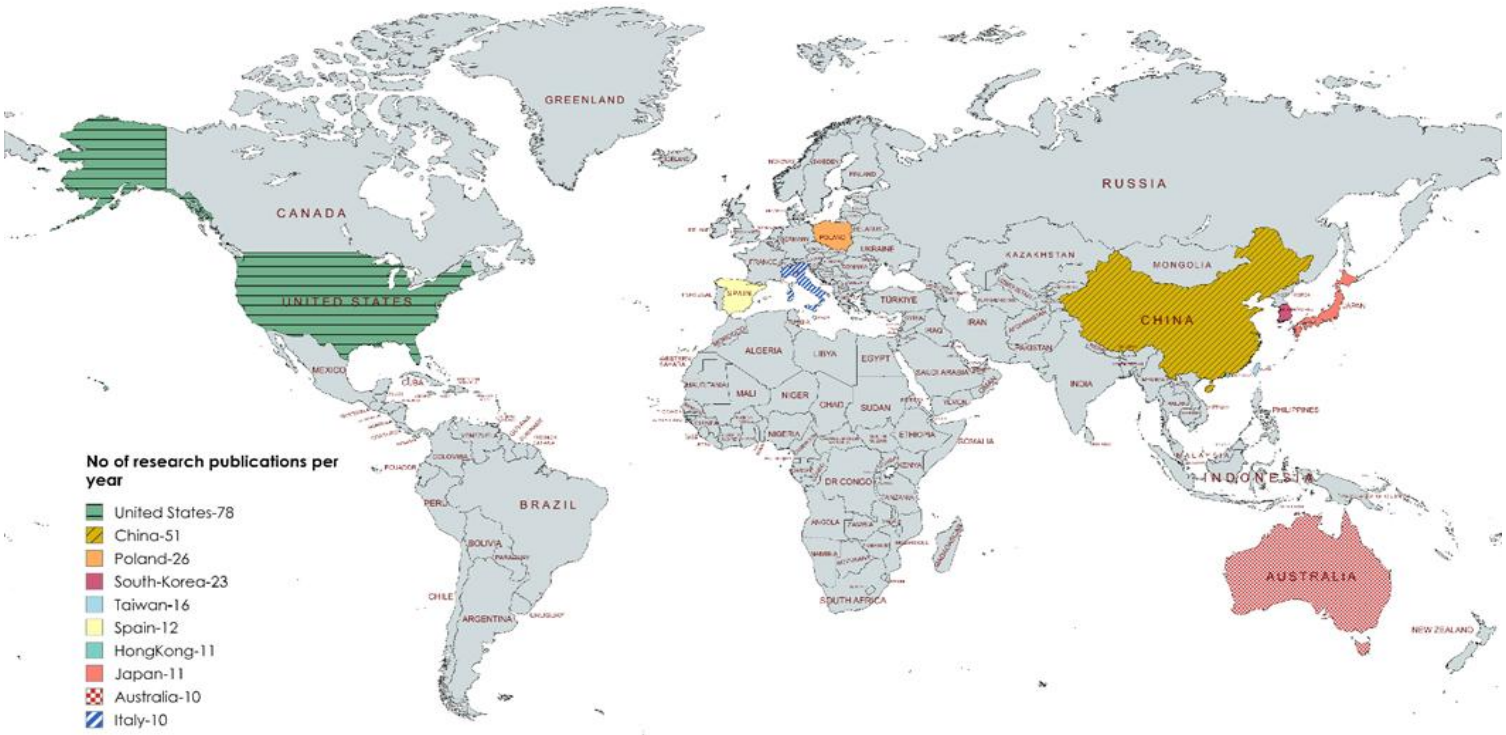

Figure 4. Geographical Distribution of Research Outputs on Scaffolding Safety (2000–2025)

3.5 Visualization of Keywords by VOS viewer

The VOS viewer-generated map illustrates the co-occurrence network of keywords [28, 29]. The keywords are related to scaffolding in the construction sector, highlighting significant themes and their connections are shown in Fig. 5. The visualization that follows highlights the interwoven nature of the themes and identifies a few thematic clusters, each of which represents a specific focal area in scaffolding research. Since the node is the largest in size and the keyword "scaffolds" is at the center of the network, it serves as the fundamental component of the subject being studied. This results in the emergence of several conceptual clusters, each representing a distinct but complementary field of inquiry. The red cluster has various technological components. The components encompass "design," "temporary structures," "inspection," and "finite element method." The fundamental objective of this research is to enhance the engineering performance and structural integrity of scaffolding systems to ensure their safe and effective use on building sites.

The green cluster prioritizes risk management and precautionary measures. This article employs terms such as "accident prevention," "occupational hazards," and "construction sector." This cluster underscores the inherent dangers associated with construction, emphasizing the critical importance of scaffolding for overall safety. The continuous use of these phrases indicates that accident prevention and occupational health remain critical research domains within the profession. This category encompasses several ideas, including "human," "procedures," and "article." These phrases pertain to research examining the influence of human factors on scaffolding usage. For the mitigation of threats this section explains how the training and compliance with the regulations can help to get the maximum output results. "Occupational Safety", "Industry Building", and "Occupational accident", these are the terms which are connected with each other in the yellow cluster. The standards implementation and the reduction of the accidents becomes the main focus of the interconnectivity of these terms. The purple cluster presents various themes in this study. The most famous words which have connectivity are "robotics," "hazards," and "architectural design." For the enhancement of scaffolding and systems the integration of robotics mainly play a key role which increases the productivity of the project. For the forecasting in the building the "deep learning"

integration also play a key role in terms of productivity. Scaffolding Research is extensive, and much of this could be seen in the structural connections among the concepts in each cluster. It applies human-centered methodologies together with technology to safety standards. This reveals a need for collaborative cross-domain research projects and integrated studies toward addressing many of today's emerging challenges facing construction.

As a result, important topics and priorities have come to light as scaffolding research has improved. The figure highlights some upcoming technological innovation potential while presenting structural improvements and enhancements in safety and human considerations. The usefulness and contribution of scaffolding research in construction can be further expanded by investigating more under-represented areas, such as sustainability and cross-regional practices.

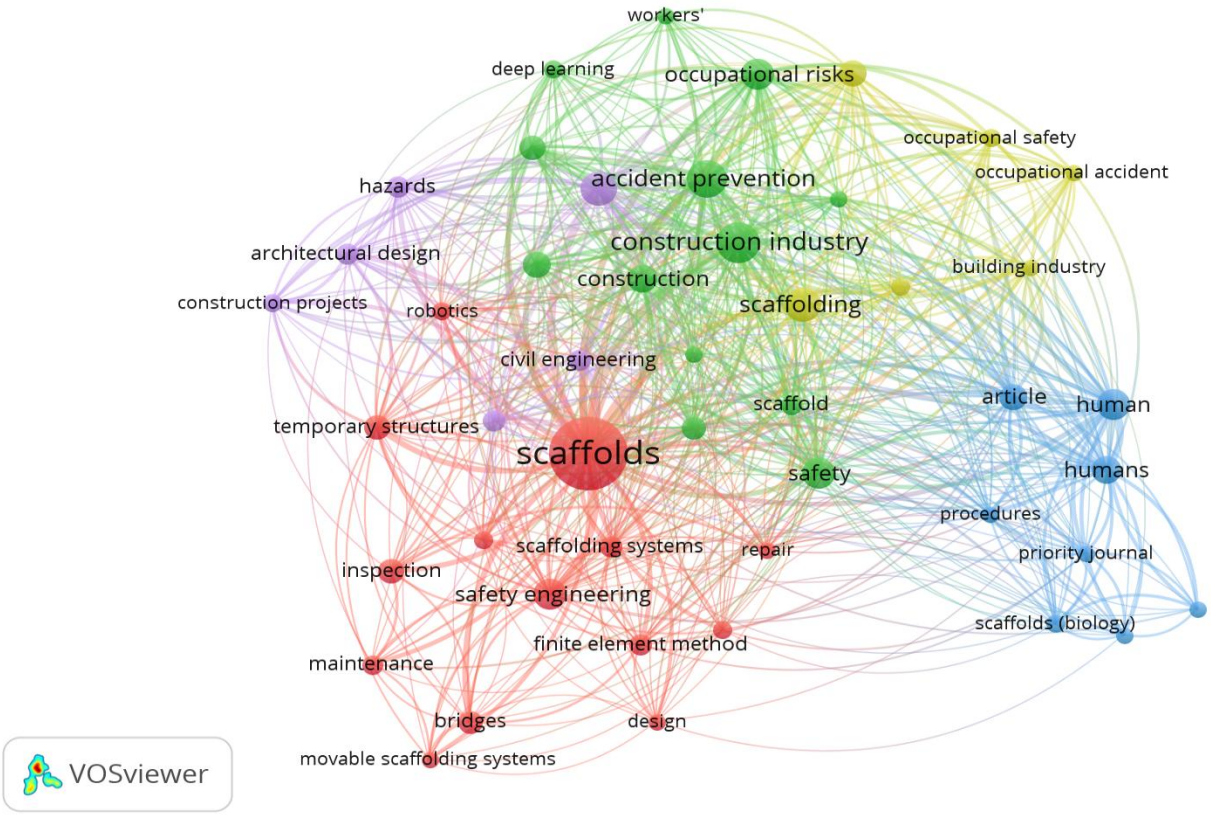

Figure 5. Keyword Co-Occurrence Network in Scaffolding Research

3.6 Visualization of Co-Authorship Networks by VOS viewer

The latter network, which was created using VOSviewer's co-authorship analysis, depicts a wide range of established linkages that occur in cooperative activity pertaining to scaffolding and safety on building sites. Among other things, Fig. 6 illustrates the structure of research networks and key participants in this type of activity by displaying a variety of clusterings from extremely cohesive groups of writers working together. The size of the "Park, Chansik" network core node and its wide range of connections demonstrate a significant degree of cooperation. As a result, this could identify Park, Chansik as one of the key players in the scaffolding and safety space, serving as a liaison between several researchers. Other players near the primary node include "Khan, Muhammad" and "Anjum, Sharjeel," whose close ties to Park, Chansik indicate an ongoing partnership on certain studies or publications. Color clusters represent groups of several collaborators. Assuming that "Lan, Bao Quy," "Baek, Chanwoo," and "Lee, Dongmin" form a cluster, they are most likely working together on the specifics of scaffolding and the safety component of building sites.

Examples of international collaboration include "Skibniewski, Miroslaw J." working with "Ding, Lieyun"; such findings elevate the voices of academics who are likely from different institutions and geographically distant, in addition to other local and occasionally peripheral voices regarding construction-site safety. It highlights the connections between research groups, or inter-cluster links. These connections show multidisciplinary efforts to address some challenging scaffolding problems, which may involve fusing engineering with cutting-edge technologies and safety procedures. For instance, the connection between "Park, Chansik" and "Khan, Numan" may indicate a shared interest in scaffolding's safety and technical aspects in building construction.

The network of co-authors generally demonstrates cooperation in studies pertaining to scaffolding and safety concerns. In addition to leading the hunt for new areas to advance the science, some central investigators, like Park and Chansik, have the responsibility of encouraging collaborations. The existence of multiple clusters within the network indicates differences in areas of expertise, which are connected to pledge to address all facets of difficult scaffolding by pooling safety knowledge. In addition to highlighting the industry leaders today, this network analysis suggests future interdisciplinary partnerships that could improve research results even more.

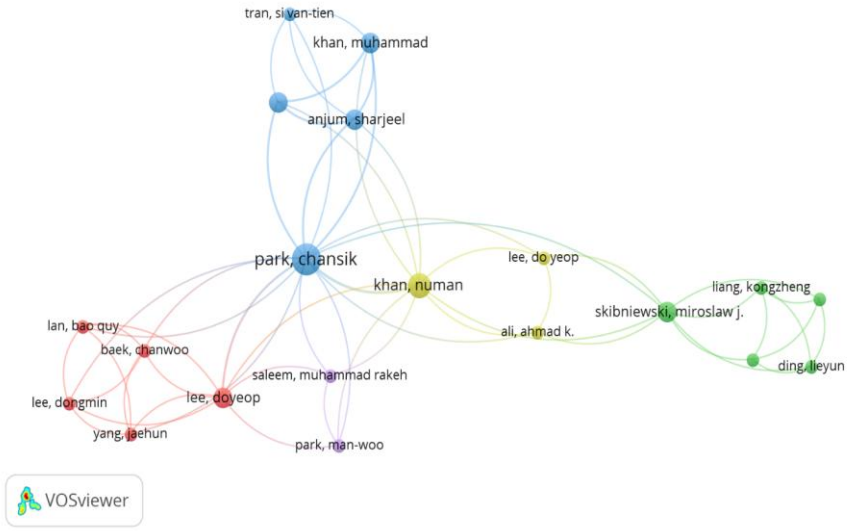

Figure 6. Co-Authorship Network in Scaffolding Safety Research

3.7 Distribution of Research Output by Publication Types

The distribution of research outputs from 2000 to 2025 that are linked to the keyword combination "scaffolding" AND "safety issues" in the Scopus database is shown in the Fig. 7. Only English-language publications in the fields of engineering and environmental science which are divided into articles, conference papers, and reviews are the subject of the analysis. Journal papers make up the largest portion, accounting for half of the overall outputs. This dominance highlights their legitimacy and the academic rigor they offer to the field, as half of the research in this area has been disseminated through conventional peer-reviewed scholarly journals.

With 42.8% of the research, conference papers are the second-largest category. This substantial proportion demonstrates the topic's dynamic nature, as researchers frequently present their discoveries at conferences for discussion, cooperation, and critique before they are turned into journal papers. Conferences' immediacy fits in nicely with real-world difficulties and developments in scaffolding safety. Reviews make up the smallest percentage of publications (7.2%). Their minimal presence may indicate a smaller body of literature or a stronger emphasis on original studies and technical publications in these areas, even though they play a part in summarizing prior research.

Overall, the data emphasizes the importance of journal articles and conference papers as the main channels for sharing scaffolding safety research, highlighting the field's practical value as well as its depth of academic study.

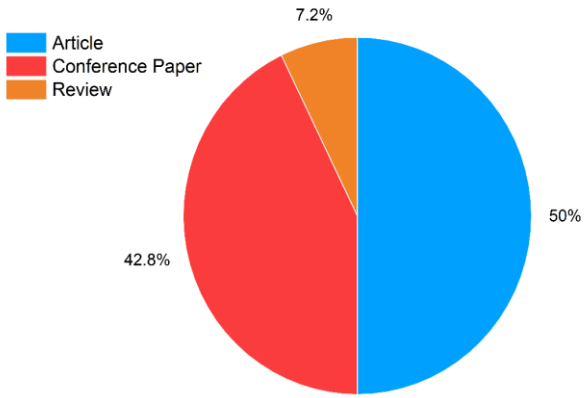

Figure 7. Distribution of Publication Types on Scaffolding and Safety Issues

3.8 Subject Area Contributions to Scaffolding Safety Research

The Fig. 8 shows the general distribution of articles from the Scopus database from 2000 to 2025 that describe the keywords "scaffolding" AND "safety issues" across various subject areas. Since the dataset in this instance has been filtered inside the English language and is not subject-area-specific, it can display a wide range of disciplines that use these terms. As a result, with 51.1% of all articles, engineering is now the most popular topic area. Given that engineering is directly in charge of scaffolding design, installation, and maintenance, this abnormally large share may explain why engineering is actually the primary discipline that deals with scaffolding and safety issues. Engineering research is the primary contribution to this area since it likely focusses on materials, safety procedures, and structural stability. Environmental sciences make up the second-highest percentage (10.7%). This demonstrates the growing consciousness of sustainability and environmental issues in scaffolding. Most of the time, researchers in this field would talk about the safety concerns associated with scaffolding's interaction with natural ecosystems as well as the ecological effects of scaffolding materials and techniques. The corresponding percentage for mathematics is 6.9%, which may indicate that it has done modelling and simulation work related to scaffolding safety. It would also cover risk analysis, scaffolding design optimization for safety, and computational techniques for forecasting structural integrity.

Smaller but significant contributions are made by other fields like energy (4.4%), biochemistry, genetics, and molecular biology (4.4%), and chemical engineering (4.5%). These disciplines probably explore specialized subjects like the development of novel scaffolding materials, bioengineering solutions for safety issues, or the building of scaffolding systems that use less energy. Similar to this, fields that concentrate on the organizational, sociological, and material facets of scaffolding safety include business, management, and accounting (4%), social sciences (2.7%), and materials science (2.4%).Other fields make up 2.3% of the total, including physics, astronomy, and computer science. Technological developments like the use of artificial intelligence or physics-based simulations for scaffolding safety assessments may lead to their involvement. These contributions demonstrate the broad scope of research addressing scaffolding and safety issues, despite having smaller shares.

Overall, the Fig. 8 highlights engineering's dominance in this field while displaying contributions from a variety of disciplines. This illustrates how several viewpoints from technological advancements to societal and environmental effects are used to address these issues, highlighting the complex nature of scaffolding and safety problems.

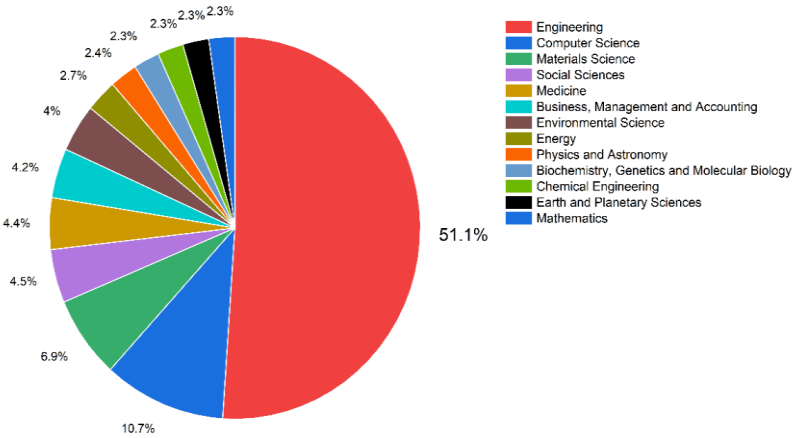

Figure 8. Subject Area Distribution of Scaffolding and Safety Research

4. Conclusions

The efficiency of construction is decided by the two parameters which are safety and stability of scaffold making the construction risk free. Assurance of safety measures, physical conditions of scaffolding, and proper supervision during assembly installation must taken into account. Assuring material certificated, applied advanced engineering tools, required inspections, and supervision of assembling are useful strategies to enhance the structure strength and overcome the accidental events. Ensuing that the workers are well trained acts as key steps in promoting safety consciousness as well as reducing the accidents. In light of these findings, future developments in scaffolding technologies and safety could be and should be sourced from robotics and sensor-based systems. Over half of the experts stated that automatic design or redesign of scaffolding and using techniques like deep learning could enhance the determination of risks and the exactness of performance. Interdisciplinary research is appropriate when it comes to addressing scaffolding difficulties in their entirety as well as encouraging innovation.

5. Recommendations

Stakeholders need to ensure they meet standards or look for those that are higher than these standards, invest in these modern technologies, and work on training programs. Also, progress towards providing more safer scaffolding solutions and means can work to underrepresented areas improved through shared international learning. Construction professionals, project managers, designers and manufacturers can work together and come up with better scaffolding systems through collaborations such as technical knowledge, regulatory changes, and workers training to reduce risks and progress in the construction industry safely.

Data Availability Statement: Data will be available on request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DL Deep Learning

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