**SINERGI** Vol. 29, No. 2, June 2025: 317-330
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2025.2.005

# Bibliometric analysis of research trends in rigid pavement over the last decade

**Sri Wiwoho Mudjanarko[1*], Paikun[2], Basil David Daniel[3]**
[1]Department of Civil Engineering, Narotama University, Indonesia
[2]Department of Civil Engineering, Faculty of Engineering, Computer and Design, Nusa Putra University, Indonesia
[3]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Malaysia

***Abstract***
*This study presents a bibliometric analysis of research trends in rigid pavement over the last decade, aiming to identify publication trends, research output distribution, main themes, citation patterns, and research gaps. The PRISMA method was employed, and statistical analysis was conducted using bibliometric software. By collecting bibliographic data from academic publications, this research reveals a significant growth in rigid pavement publications, reflecting increased global interest in this field. Major research themes include pavement design, material characterization, construction techniques, maintenance, and performance evaluation. Citation pattern analysis is used to identify influential works in this field. However, this study has limitations in data coverage and is susceptible to biases inherent in bibliometric analysis. Nevertheless, it contributes significantly to understanding the research landscape of rigid pavement, providing valuable insights for researchers, practitioners, and policymakers. Future research could deepen qualitative analysis, track the evolution of research themes, and explore interdisciplinary frameworks to enrich our understanding of rigid pavements.*



***Keywords:***
*Bibliometric analysis;*
*International collaboration*
*Research distribution;*
*Research trends;*
*Rigid pavement;*

***Article History:***
*Received: June 9, 2024*
*Revised: September 30, 2024*
*Accepted: December 31, 2024*
*Published: May 1, 2025*

***Corresponding Author:***
*Sri Wiwoho Mudjanarko*
*Department of Civil Engineering*
*Narotama University, Surabaya, Indonesia*
*Email:*
*sri.wiwoho@narotama.ac.id*

## INTRODUCTION

Rigid pavement, a road structure consisting of Portland Cement Concrete (PCC) slabs, has been widely used in transportation infrastructure due to its durability, strength, and relatively low maintenance requirements [1, 2, 3]. Over the past decade, the field of rigid pavement research has made significant advancements, driven by increasing demand for sustainable and long-lasting transportation networks [4, 5, 6]. Researchers and practitioners have investigated various aspects of pavement design, materials, construction techniques, maintenance practices, and performance evaluation methodologies to enhance its efficiency, lifespan, and cost-effectiveness [7, 8, 9, 10, 11].

Despite significant progress in rigid pavement research, there is still a need for systematic analysis of trends and patterns in the literature to identify key focus areas, knowledge gaps, and emerging research directions [12][13]. Such analysis is crucial to provide input for future research agendas, facilitate knowledge dissemination, and promote collaboration among researchers and practitioners in the pavement engineering field [14].

Based on this background, this study formulates the following research questions:

1. What are the trends in publication trends in rigid pavement research over the past decade, in terms of authors, institutional affiliations, and geographical distribution?

2. How is the distribution of research output among various types of publications, and what are its implications for knowledge dissemination and accessibility?
3. What are the main thematic research areas in the rigid pavement literature, and how have they evolved over time?
4. What are the citation patterns in the rigid pavement literature, and which publications have significant influence in the field?
5. What are the key research gaps and emerging trends in rigid pavement engineering, and how can they shape the future research agenda?

The main objective of this paper is to conduct a comprehensive bibliometric analysis of research trends related to rigid pavement over the last decade (2013-2023). Specifically, this paper aims to:

1. Identify the most productive authors, institutions, and countries in the rigid pavement literature.
2. Analyze the distribution of research output across various types of publications, including journal articles, conference papers, and technical reports.
3. Investigate the thematic focus of rigid pavement research, covering topics such as pavement design, material characterization, construction techniques, maintenance strategies, and performance evaluation.
4. Analyze citation patterns in the rigid pavement literature to determine the impact and influence of key works and emerging trends.
5. Identify potential research gaps and opportunities for future investigation in the field of rigid pavement engineering.

The next section provides an overview of the methodology used for bibliometric analysis, including data collection, pre-processing, and analysis techniques [15]. Subsequently, the analysis findings are presented and discussed in detail, emphasizing trends, patterns, and key insights obtained from the data. The paper concludes with a summary of the main findings, implications for research and practice, and suggestions for future research directions in the field of rigid pavement engineering [16].

## METHOD

This study utilizes a bibliometric approach to explore and analyze literature related to rigid pavement [17]. This approach leverages a combination of bibliometric analysis tools and techniques, using the Bibliometrix software within the R programming environment [18][19].

Biblioshiny, as the web interface of the Bibliometric package, is employed to simplify bibliometric analysis without requiring deep programming skills [20]. Its comprehensive graphical user interface makes it accessible to both novice and experienced users, allowing the import of bibliographic data from various sources such as Scopus [21].

The data used in this research were obtained from the Scopus database and exported in a suitable format for analysis, namely BibTeX [22]. This dataset includes essential bibliographic information such as titles, authors, keywords, abstracts, citations, and publication details [23]. Bibliometrics processes this data to conduct various types of studies, including calculating metrics like the h-index, analyzing trends over time, mapping co-authorship and citation networks, and identifying main themes and research clusters [24].

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method is also applied in this bibliometric analysis to enhance the credibility and transparency of the study [25]. Adapted PRISMA principles for bibliometric analysis ensure that the bibliometric review is conducted systematically, transparently, and reproducibly [26]. These steps include identifying relevant literature, screening articles based on inclusion and exclusion criteria, and synthesizing results using bibliometric tools and software [27]. The flow of the PRISMA method is illustrated in Figure 1.

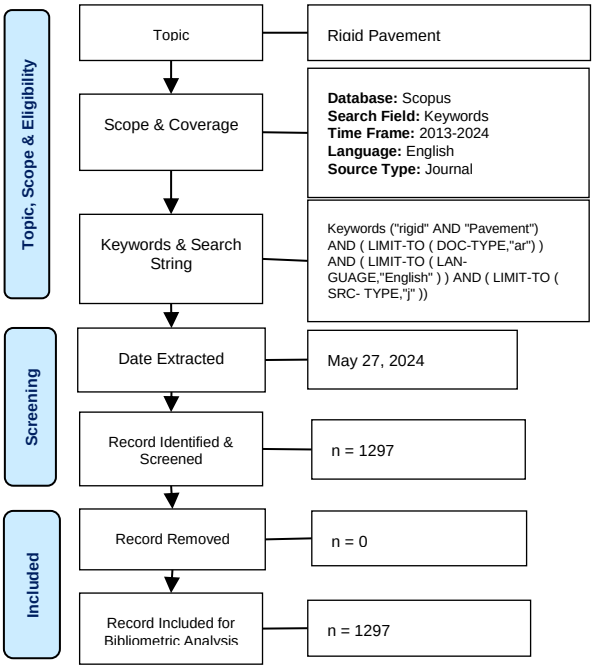


Figure 1. Flow diagram of the search strategy

Figure 1 depicts a systematic process for searching and screening literature for a bibliometric analysis on the topic of "Rigid Pavement." The process begins with defining the topic and search scope, including the database (Scopus), search field (keywords), time frame (all), language (English), and source type (journal). The search is conducted using the keywords "rigid" and "pavement" with additional filters to ensure that only relevant scientific articles are included. On May 27, 2024, this search identified 1297 records, all of which passed the initial screening stage without any being removed. Ultimately, all 1297 articles were included in the bibliometric analysis, demonstrating that the search and screening process employed was both efficient and comprehensive, ensuring extensive coverage of the literature in this field.

## RESULTS AND DISCUSSION

### Main Information

A comprehensive study on research trends in the field of rigid pavement has been conducted using bibliometric analysis. Utilizing the Bibliometric-BiblioShiny application, data covering the period from 2013 to 2023 were analyzed to identify significant patterns in the related literature. Before presenting the analysis results, it is essential to introduce key information about the data to be analyzed. This includes the study period, the number of data sources used, the number of documents analyzed, and other important statistics [28]. Key information about the publication data of research results discussing rigid pavement is presented in Figure 2.

From the analysis results using the Bibliometric-BiblioShiny application, several key findings have been identified [29]. First, the high annual growth rate of documents at 11.79% indicates a continuous increase in interest in research on rigid pavement during the study period. This underscores the importance of this topic in the academic and industrial communities.


Figure 2. Main Data Information

Furthermore, the relatively young average age of documents at 4.9 years indicates that the majority of analyzed research is recent, affirming the topic's relevance to the changing times.

Moreover, the high average citation per document, with a value of 7.739, indicates that research on rigid pavement has significant influence in scholarly literature. This suggests that this topic is a major focus in the field of civil engineering and transportation. However, despite an international collaboration rate of 16.5%, the relatively low number of co-authors per document, namely 3.58, indicates that collaboration among authors from different countries is still limited. This highlights the potential for enhancing cross-border cooperation in research on rigid pavement. This is based on Scopus publication data from 2013-2023 with publication types as shown in Table 1.

Data from Scopus shows that from the period of 2013 to 2023, there were 1,297 publications on rigid pavement analyzed. The majority, approximately 64.61%, were journal articles, indicating that journal articles are the primary source of information in the literature on rigid pavement. Furthermore, about 34.39% were conference papers, which also made a significant contribution to research on rigid pavement. Although fewer in number, other types of publications also made meaningful contributions in complementing the literature on rigid pavement. This analysis provides valuable insights into the distribution and contribution of various types of publications in research on rigid pavement, which can offer a better understanding for researchers and practitioners in this field.

### Annual Scientific Production

In order to understand the annual scientific production trends in the field of rigid pavement, bibliometric analysis was conducted using historical data from 2013 to 2023 [30]. An overview of the scientific production in the field of rigid pavement during the studied period is presented in Figure 3.

Table 1. Source Type

| Source Type | Total Publications (TP) | Percentage (%) |
|---|---|---|
| article | 838 | 64.61% |
| Scopus and WoS articles | 5 | 0.39% |
| article conference paper | 3 | 0.23% |
| conference paper | 446 | 34.39% |
| conference paper article | 3 | 0.23% |
| conference paper | 2 | 0.15% |
| **Total** | **1297** | **100.00%** |

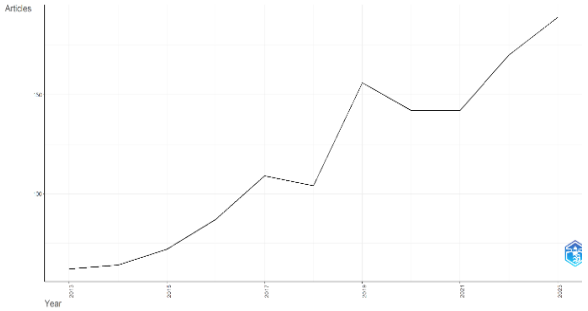


Figure 3. Annual scientific production

The collected data reveals interesting trends in scientific production on rigid pavement during the period of 2013-2023. Starting from 62 articles in 2013, scientific production consistently increased, reaching its peak in 2023 with 189 articles. This indicates a continuously growing interest in research on rigid pavement throughout the study period. These trends may also reflect the development of new technologies and methodologies that stimulate research growth in this field. The significant increase from year to year, especially after 2017, may reflect a growing focus from the academic and industry communities on improving the quality, sustainability, and efficiency of road infrastructure. Thus, this analysis provides valuable insights into the dynamics of scientific production in the field of rigid pavement, which can help determine the direction of future research and identify emerging trends in the foreseeable future.

Citations per year from scientific publications on rigid pavement from 2013 to 2023, providing an overview of the trend of citations per year from those publications, are presented in Table 2.

The citation data per year shows significant variation during the study period [31]. Initially, there was a stable or slightly increasing trend from year to year, reaching its peak in 2017 with 14.59 citations per article, reflecting an increased interest in research on rigid pavement.

Table 2. Citations per Year

| Year | Mean TCperArt | N | MeanTCper Year | Citable Years |
|---|---|---|---|---|
| 2013 | 9.50 | 62 | 0.79 | 12 |
| 2014 | 9.12 | 64 | 0.83 | 11 |
| 2015 | 8.08 | 72 | 0.81 | 10 |
| 2016 | 8.57 | 87 | 0.95 | 9 |
| 2017 | 14.59 | 109 | 1.82 | 8 |
| 2018 | 9.02 | 104 | 1.29 | 7 |
| 2019 | 7.60 | 156 | 1.27 | 6 |
| 2020 | 9.85 | 142 | 1.97 | 5 |
| 2021 | 8.01 | 142 | 2.00 | 4 |
| 2022 | 5.54 | 170 | 1.85 | 3 |
| 2023 | 1.82 | 189 | 0.91 | 2 |

However, after 2017, there was a significant decrease, reaching its lowest point in 2023 with only 1.82 citations per article. This reflects a declining interest in the topic or a lack of innovative research receiving further attention. Additionally, the number of citable years also decreased from year to year, indicating that newer publications may receive less attention over a longer period.

## Most Relevant Sources

Bibliometric analysis has identified the most relevant sources in the literature on rigid pavement [32]. An overview of the sources that are the focus of this study is presented in Figure 4.

From the analysis results, it can be seen that several sources emerge as the most relevant in the literature on rigid pavement. These sources include "Construction and Building Materials" with 98 articles, "International Journal of Pavement Engineering" with 64 articles, and "IOP Conference Series: Materials Science and Engineering" with 46 articles. These sources may serve as primary outlets for researchers to seek information, publish research findings, or stay updated on the latest developments in the field of rigid pavement. Additionally, the presence of sources such as "Transportation Research Record," "Road Materials and Pavement Design," and "Journal of Transportation Engineering Part B: Pavements" also indicates significant contributions to the literature on rigid pavement. By identifying the most relevant sources, this analysis can assist researchers and practitioners in navigating the extensive literature and finding the most valuable sources in this field.

## Core Sources by Bradford's Law

Core Sources by Bradford's Law aim to identify the most significant sources in their contribution to the literature in the field of rigid pavement [33]. The data generated will provide insights into the most important sources for understanding and advancing knowledge in this field, as shown in Figure 5.

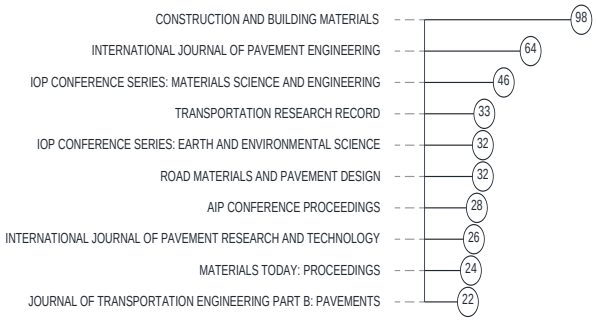


Figure 4. Most relevant sources

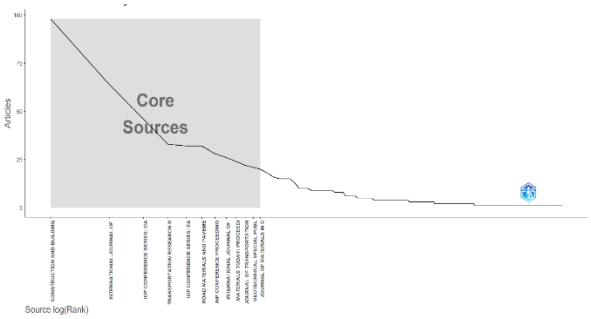


Figure 5. Core Sources by Bradford's Law

From the bibliometric analysis data, it can be observed that key sources in the literature on rigid pavement, such as "Construction and Building Materials," "International Journal of Pavement Engineering," and "IOP Conference Series: Materials Science and Engineering," dominate the top ranks in the list. These sources, along with several others, constitute the core or primary focus of the literature in this field, reflecting the importance of their contributions to knowledge development and research. On the other hand, there are also sources that appear in lower zones, indicating their lower contributions to the literature or their more specific focus on particular topics within the field of rigid pavement.

## Sources' Local Impact

Sources' Local Impact aims to identify the influence or contribution of specific sources in the development of knowledge and research in the field of rigid pavement. The results of the analysis are shown in Figure 6.

This bibliometric analysis data provides an overview of the local impact of various publication sources in the literature on rigid pavement. Sources such as "Construction and Building Materials," "International Journal of Pavement Engineering," and "Road Materials and Pavement Design" demonstrate significant impact, with high h-index and substantial citation numbers.

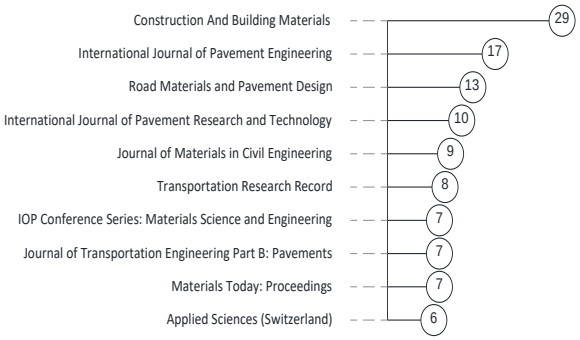


Figure 6. Sources' Local Impact by H index

On the other hand, some other sources have lower impact, which may reflect their more limited contributions to the literature or a more specific focus on particular topics within the field of rigid pavement. Additionally, there is a trend of increasing local impact for some sources, such as "Sustainability" and "Materials Today: Proceedings," indicating growing recognition or acknowledgment from the scholarly community for their contributions.

## Sources' Production over Time

The analysis of Sources' Production over Time aims to identify how the contribution of publication sources changes from year to year, whether there is an increase or decrease in production, and to understand the factors that may influence these production patterns [34]. This information can help in understanding the dynamics of literature development, identifying research trends, and understanding changes in focus or interest in specific study areas over time. The results of the Sources' Production over Time analysis are presented in Figure 7.

This bibliometric analysis data reveals interesting publication production patterns from several key sources in the literature on rigid pavement over the studied period. Sources such as "Construction and Building Materials" and "International Journal of Pavement Engineering" show a stable increasing production trend from year to year, indicating their significant role in supporting literature in this field.

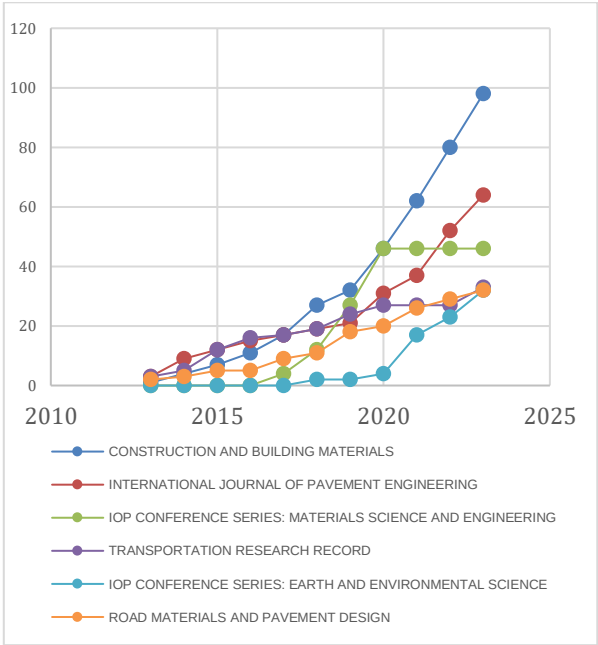


Figure 7. Sources' Production over Time

On the other hand, sources like "IOP Conference Series: Materials Science and Engineering" and "Transportation Research Record" exhibit variations in their production, but with a general tendency of increasing over time.

## Most Relevant Authors

The Most Relevant Authors aim to identify and highlight authors who have the most significant or relevant contributions in a field of study or specific topic [35]. This analysis aims to identify thought leaders, experts, or major contributors in the field based on criteria such as the number of publications, citations, or the impact of their research. The results of the analysis are presented in Figure 8.

The bibliometric analysis data indicates that several authors have played significant roles in the literature on rigid pavement. Authors such as Halil Ceylan, SungHwan Kim, and Kasthurirangan Gopalakrishnan stand out with a high number of articles and significant fractional count of articles. This indicates substantial contributions in this field. Authors like Syed Waqar Haider, Lijun Sun, and Xingyu Gu also have significant contributions in the literature.

## Authors' Production over Time

The analysis of Authors' Production over Time aims to understand the patterns and trends in publication production by authors in a field of study or specific topic over time [36]. By analyzing authors' publication output over a certain period, we can identify changes in authors' productivity, collaboration trends, as well as changes in the focus or research interests of these authors. The results of the Authors' Production over Time analysis are shown in Figure 9.

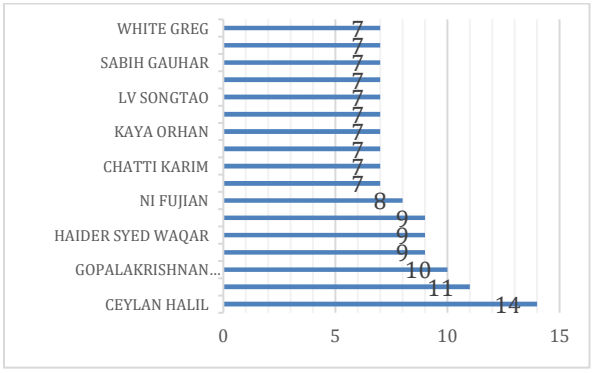


Figure 8. Most relevant authors

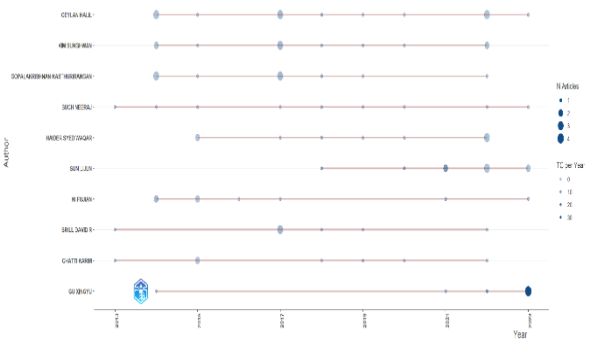


Figure 9. Authors' Production over Time

The data shows the contributions of key authors in the literature on rigid pavement. David R. Brill, Halil Ceylan, and Karim Chatti stand out with high publication frequencies and significant citation counts from year to year. Other authors such as SungHwan Kim, Kasthurirangan Gopalakrishnan, and Fujian Ni also have consistent and significant contributions in the literature.

## Author Productivity through Lotka's Law

Lotka's Law is used to describe the distribution of author productivity by grouping authors based on the number of documents they write [37]. The results of this analysis are presented in Figure 10 and Table 3.

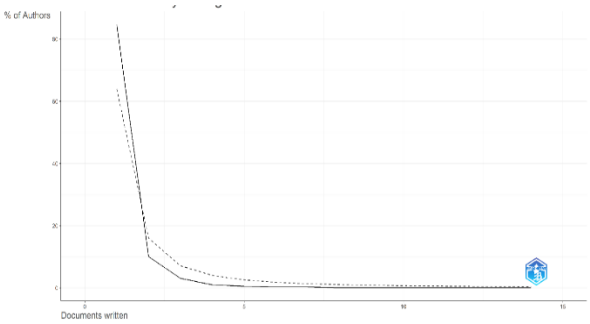


Figure 10. Author Productivity through Lotka's Law

Table 3. Author Productivity through Lotka's Law

| Documents written | No. of Authors | Proportion of Authors |
|---|---|---|
| 1 | 3117 | 0.847 |
| 2 | 369 | 0.1 |
| 3 | 113 | 0.031 |
| 4 | 35 | 0.01 |
| 5 | 19 | 0.005 |
| 6 | 11 | 0.003 |
| 7 | 11 | 0.003 |
| 8 | 1 | 0 |
| 9 | 3 | 0.001 |
| 10 | 1 | 0 |
| 11 | 1 | 0 |
| 14 | 1 | 0 |

The data shows a pattern consistent with Lotka's Law, where a small number of authors are highly productive while the majority of authors have only a few contributions. The majority of authors (84.7%) write only one document, while a small fraction of authors (0.1%) are very productive, writing two documents. As the number of documents written increases, the number of authors decreases, indicating that only a few authors are consistently productive in the field. This analysis provides a strong insight into the distribution of scientific author productivity, which is an important characteristic of the rigid pavement field of study over the past 10 years.

## Authors' Local Impact

Bibliometric analysis was conducted to understand the local impact of scientific authors in the literature on rigid pavement. It is important to note that elements such as h-index, g-index, and m-index are used to measure the relative impact of authors in scientific literature, taking into account the number of citations (TC), number of publications (NP), and the year of first publication (PY_start) of their works [38], as presented in Figure 11.

The data shows the local impact of several authors in the literature on rigid pavement. Some authors, such as Xingyu Gu, Zhen Liu, and Songtao Lv, stand out with relatively high impact indices, as indicated by their h-index, g-index, and m-index. Meanwhile, other authors, such as David R. Brill and Halil Ceylan, have significant impacts despite having fewer publications. This analysis provides insights into the contributions and impact of specific authors in the development of literature on rigid pavement, which can help understand the relevance and quality of their works in an academic context.

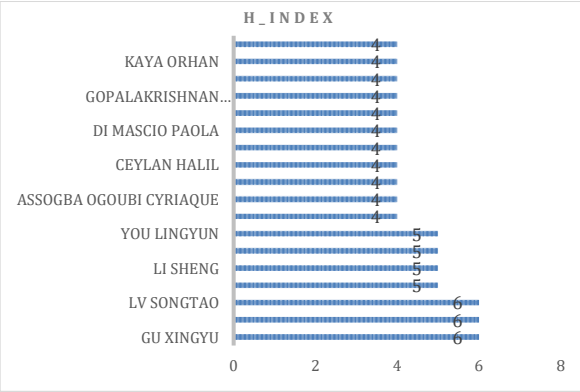


Figure 11. Authors' Local Impact

## Most Relevant Affiliations

Most Relevant Affiliations refer to the institutions or affiliations that are most relevant or significant in the scientific literature on rigid pavement [39]. In bibliometric analysis, the identification of Most Relevant Affiliations is presented in Figure 12.

The data on Most Relevant Affiliations in bibliometric analysis shows the affiliations or institutions that contribute most to the related scientific literature. From this data, several institutions such as Tongji University, Southeast University, and Chang'an University emerge as the most relevant with a significant number of articles. This indicates that these institutions play a crucial role in the development of knowledge in the field of study. Additionally, some institutions outside of China also appear, such as Iowa State University, Michigan State University, and the Indian Institute of Technology, showing geographical diversity in research contributions

.

## Affiliations' Production over Time

To track the contributions of specific institutions in generating knowledge in the field of rigid pavement studies, a bibliometric analysis of Affiliations' Production over Time is necessary [40], and the results are presented in Figure 13.

The data on Affiliations' Production over Time shows the number of articles produced by several affiliations over a certain period. Major affiliations such as Chang'an University, School of Transportation Science and Engineering, Changsha University of Science and Technology, Iowa State University, Southeast University, and Tongji University show a trend of increasing article production from year to year. For example, Chang'an University has a stable increasing trend from 2013 to 2023, while Tongji University demonstrates a significant increase from 2013 to 2023.

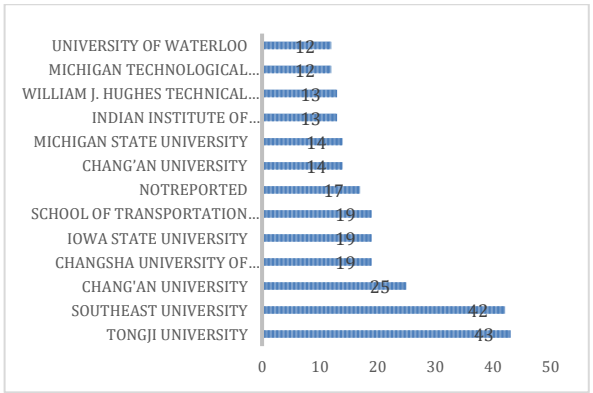


Figure 12. Most Relevant Affiliations

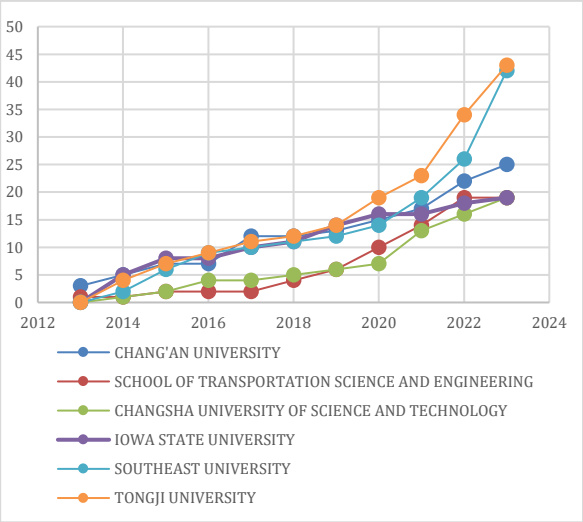


Figure 13. Affiliations' Production over Time

This indicates the contributions of these affiliations to research and scholarly publications in relevant fields of study. Additionally, the consistent increase from year to year also reflects the potential growth of resources and research focus in each affiliation.

## Corresponding Author's Countries

Corresponding Author's Countries indicate the distribution of the number of articles written by corresponding authors from various countries in bibliometric analysis [41]. China dominates in terms of the number of articles, followed by the United States and India. The MCP (Multiple Corresponding Authors) Ratio proportion, which is the ratio of the number of articles with more than one corresponding author compared to the total articles, varies from country to country. Countries like Australia, Canada, and the United Kingdom show relatively high MCP Ratios, indicating the potential for strong international collaboration in research and scholarly publications among corresponding authors from these countries. Meanwhile, the MCP Ratio of countries like Egypt, Nigeria, and Brazil shows lower proportions, which may indicate more localized research focus or a lack of international collaboration in their research, as shown in Figure 14.

The analysis results show that China has a very strong growth trend in scientific production, with the number of articles continuously increasing from year to year. India also shows a significant growth trend in scientific production, although not as strong as China.

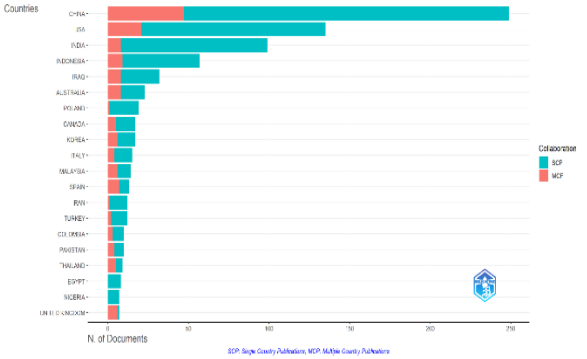


Figure 14. Corresponding Author's Countries

Meanwhile, the United States maintains its position as one of the world's leading scientific producers, although its growth trend is not as fast as China and India. Indonesia also shows a significant increase in scientific production, although still far behind China, India, and the United States. On the other hand, Iraq shows a fairly stable increase in its scientific production, although still at a lower level compared to the other countries listed in the data.

It is noted that China dominates in the total number of citations, followed by the United States and India. However, when viewed from the average citations per article perspective, some countries like Senegal, the Netherlands, and Iran stand out with high averages. China and the United States remain leaders in terms of the total number of citations, indicating significant contributions to global scientific literature. However, this does not always reflect the quality of articles, as some countries with fewer articles may have higher average citations per article.

## Most Frequent Words

Most Frequent Words serve to identify the main topics or focuses of the analyzed research [42]. In this example, words like "pavements", "rigid pavements", "concretes", and "asphalt" appear as some of the most frequently encountered words in the studied literature as shown in Figure 15.

Data analysis indicates that topics related to road infrastructure, such as "pavements", "rigid pavements", "asphalt", "concrete pavements", and "asphalt pavements", dominate in the Most relevant word and WordCloud. Additionally, there are words related to technical aspects such as "compressive strength", "finite element method", "cracks", and "pavement overlays". These findings suggest that the analyzed literature has a strong focus on construction and materials related to road infrastructure, as well as technical aspects in its design and maintenance.

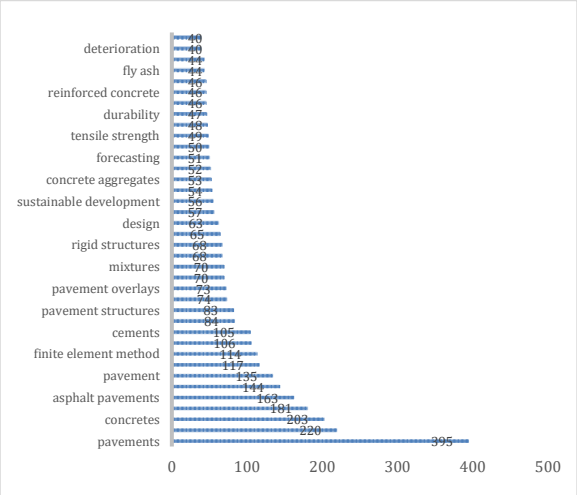


Figure 15. Most relevant word

## Trend Topics

Trend Topics provide information about the frequency of occurrence of several research topics in the literature based on quarterly years (year_q1, year_med, year_q3) [43]. The data covers various topics relevant to road infrastructure such as continuum mechanics, civil engineering, load transfer, cement, speed, vibration, bitumen material, transportation departments, road design based on mechanistic-empirical guidelines, trucks, cracks, road overlays, design, concrete, reinforced concrete, finite element methods, and others, as shown in Figure 16.

Data analysis indicates that there are several topics showing an increasing trend in research interest over time. For example, topics related to road infrastructure such as "pavements", "rigid pavements", "asphalt", and "asphalt pavements" show a steady increase in their frequency of occurrence from year to year.

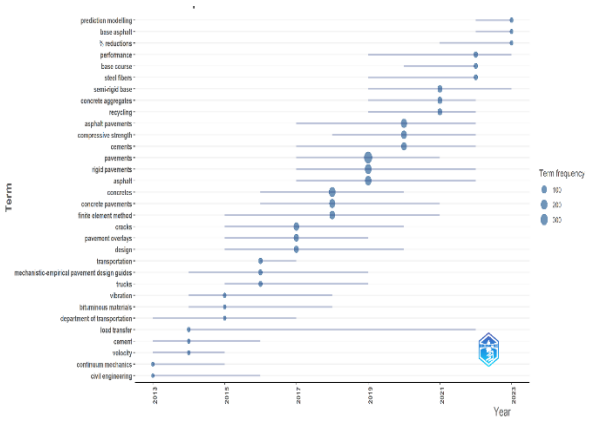


Figure 16. Trend Topics

## Co-occurrence Network

The Co-occurrence Network data provides an overview of the relationships between various concepts in the field of road infrastructure based on their co-occurrence in scientific research [44], as shown in Figure 17.

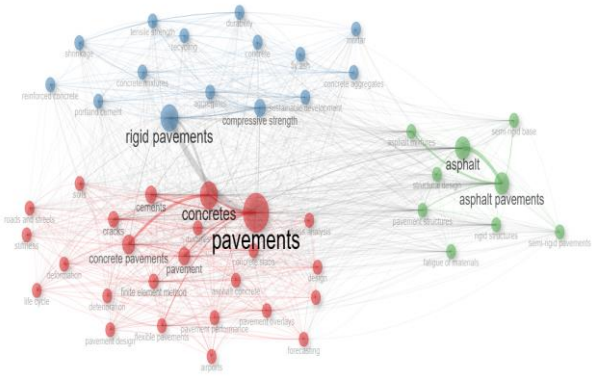


Figure 17. Co-occurrence Network

Table 4. Ranking and proximity between cluster nodes

| Node | Cluster | Betweenness | Closeness | Page Rank |
|---|---|---|---|---|
| pavements | 1 | 85.373 | 0.021 | 0.07 |
| concretes | 1 | 34.793 | 0.021 | 0.053 |
| concrete pavements | 1 | 16.736 | 0.02 | 0.034 |
| pavement | 1 | 15.682 | 0.021 | 0.031 |
| finite element method | 1 | 6.097 | 0.018 | 0.025 |
| cracks | 1 | 8.475 | 0.02 | 0.029 |
| cements | 1 | 11.226 | 0.02 | 0.033 |
| pavement overlays | 1 | 3.919 | 0.017 | 0.019 |
| flexible pavements | 1 | 2.261 | 0.017 | 0.018 |
| mixtures | 1 | 5.598 | 0.019 | 0.024 |
| concrete slabs | 1 | 2.409 | 0.017 | 0.018 |
| design | 1 | 1.782 | 0.016 | 0.017 |
| rigid pavements | 2 | 29.71 | 0.02 | 0.05 |
| compressive strength | 2 | 8.446 | 0.018 | 0.031 |
| aggregates | 2 | 4.878 | 0.018 | 0.024 |
| sustainable development | 2 | 1.631 | 0.016 | 0.015 |
| concrete mixtures | 2 | 1.412 | 0.016 | 0.018 |
| concrete aggregates | 2 | 1.402 | 0.015 | 0.018 |
| portland cement | 2 | 2.174 | 0.017 | 0.016 |
| asphalt | 3 | 20.237 | 0.02 | 0.043 |
| asphalt pavements | 3 | 18.334 | 0.02 | 0.041 |
| asphalt mixtures | 3 | 3.692 | 0.018 | 0.023 |
| pavement structures | 3 | 4.289 | 0.018 | 0.023 |
| rigid structures | 3 | 3.211 | 0.018 | 0.02 |
| fatigue of materials | 3 | 1.855 | 0.017 | 0.016 |

Nodes such as "pavements," "concretes," "finite element method," and "cracks" exhibit high interconnectedness, as indicated by significant values of closeness, betweenness, and PageRank. In Cluster 2, which focuses on "rigid pavements" and "compressive strength," these concepts show strong contextual linkages, as detailed in Table 4.

The bibliometric analysis reveals a co-occurrence network of terms in pavement and concrete research, grouped into three main clusters. The first cluster centers on concrete pavement, incorporating finite element methods and cracking, with "pavements" as a key connecting term. The second cluster emphasizes rigid pavements and mechanical properties such as compressive strength, where "rigid pavements" play a central role. The third cluster relates to asphalt pavement and asphalt mixtures, with "asphalt" as the core term.

The next steps in rigid pavement research involve identifying specific areas that require further exploration based on this analysis. Researchers can focus on enhancing compressive strength and material durability by testing various concrete mixtures and sustainable additives. Additionally, research can be directed towards more advanced analytical methods, such as finite element analysis, to predict and mitigate cracking in rigid pavements. Integrating sustainability aspects, such as the use of recycled materials and the development of eco-friendly concrete, is also crucial for addressing environmental challenges in rigid pavement construction. Collaborating with experts from other clusters, such as flexible pavements and asphalt mixtures, can provide new perspectives and innovative solutions to the challenges faced in rigid pavement research and development.

Furthermore, the Thematic Map serves as a visual representation of the data, showing patterns or thematic clusters within an information network or scientific literature. In the context of bibliometric analysis, the Thematic Map depicts the relationships between frequently occurring topics or concepts in a collection of scientific publications, as explained in Figure 16 and detailed in Table 5.

It is noted that there are five main clusters: "compressive strength", "nondestructive examination", "asphalt", "pavements", and "maintenance". The "pavements" cluster stands out with high values of Callon Centrality and Cluster Frequency, indicating that this topic frequently appears and has strong connections with other topics in the network. The "compressive strength" and "asphalt" clusters also stand out with significant values in several metrics, demonstrating the importance of these two topics in the context of this bibliometric analysis.

## Countries' Collaboration World Map

The frequency of collaboration among countries involved in scientific research encompasses several different country pairs with varying collaboration frequencies [45]. Countries such as China, the United States, and Malaysia appear to have high collaboration frequencies with various other countries as shown in Figure 18.

Analysis of the data indicates that collaboration among countries in scientific research is a significant and widespread phenomenon [46]. Countries such as the United States, China, and Malaysia stand out in international collaboration, demonstrating their important role in facilitating cross-border knowledge exchange. Furthermore, the collaboration patterns observed depict a complex and dynamic network among research institutions in various countries [47]. This highlights the importance of cross-border cooperation in advancing research and development in various fields of science.

## Discussion

Analyzing the publication trends in rigid pavement research over the past decade, it was found that the number of publications produced by authors in this field has significantly increased.

Table 5. Thematic Map of research on rigid pavements

| Cluster | Callon Centrality | Callon Density | Rank Centrality | Rank Density | Cluster Frequency |
|---|---|---|---|---|---|
| Compressive strength | 3.303 | 15.203 | 3 | 5 | 1345 |
| Nondestructive examination | 0.846 | 13.845 | 1 | 3 | 203 |
| Asphalt | 5.299 | 12.62 | 4 | 2 | 2180 |
| Pavements | 7.847 | 10.913 | 5 | 1 | 2870 |
| Maintenance | 0.936 | 14.422 | 2 | 4 | 318 |

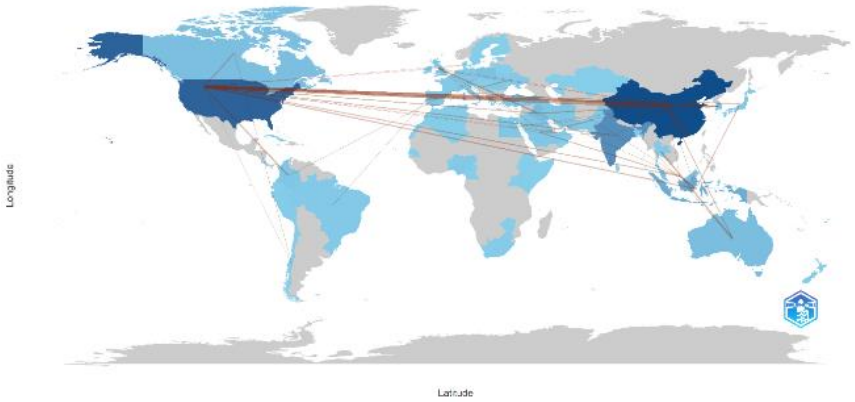


Figure 18. Countries' Collaboration World Map

Based on the data, some authors stand out with high productivity, while there are also a large number of authors who contribute on a smaller scale. Institutionally, several institutions have proven to be productive research hubs in rigid pavement research. The geographic distribution of authors and institutions also shows interesting patterns, with cross-border collaboration and publications on the rise, indicating the international nature of this discipline.

In examining the distribution of research output, it was found that research findings are widely disseminated across various types of publications, including journal articles, conference papers, and technical reports. The implications are increased accessibility and dissemination of knowledge about rigid pavements, as the scientific community can access this information through various platforms. However, it is important to ensure that the quality of publications is maintained across all types of documents to ensure the accuracy and validity of the information conveyed.

The main thematic areas in rigid pavement literature include pavement design, material characterization, construction techniques, maintenance, and performance evaluation. The evolution over time indicates a shift in focus from traditional technical aspects to an emphasis on sustainability and efficiency. This reflects the research adaptation to evolving challenges and needs in transportation infrastructure.

Analysis of citation patterns provides insights into publications that have a significant influence in rigid pavement literature. These important works play a role in shaping the direction of research and influencing thinking within the academic community. Identifying the most influential publications can help researchers prioritize relevant literature and keep up with trends in the field.

Despite significant progress, there are still some research gaps that need to be addressed in the future. Future research opportunities include further exploration of innovative technologies, enhanced sustainability, and the development of more sophisticated predictive models. By identifying and addressing these gaps, a more comprehensive and relevant research agenda can be formed to meet the needs of future transportation infrastructure.

## CONCLUSION

This bibliometric analysis provides a comprehensive understanding of trends, topics, collaboration networks, and thematic maps in rigid pavement research. It reveals the evolution of research themes, international collaboration patterns, and focal areas. The analysis identifies key trends, significant research topics, and collaboration networks, serving as a valuable resource for researchers, policymakers, and practitioners in transportation engineering and infrastructure development.

The research shows a significant increase in rigid pavement publications over the past decade, with more authors, institutional affiliations, and global participation. Research outputs are disseminated across various publications, indicating diversity and increased accessibility in the field. Key research themes include pavement design, material characterization, construction techniques, maintenance strategies, and performance evaluation, with a shift towards sustainability and efficiency. Citation pattern analysis identifies influential publications shaping research directions. Despite progress, research gaps remain, with opportunities for exploring innovative technologies, sustainability, and predictive models.

This analysis has limitations, relying solely on bibliographic data and subject to biases such as language and publication biases. Future research should include in-depth qualitative analysis, longitudinal studies tracking research theme evolution, and interdisciplinary research integrating insights from materials science and data analytics to advance understanding of rigid pavement design, performance, and maintenance.

## ACKNOWLEDGMENT

This research was supported/partially supported by Universiti Tun Hussein Onn Malaysia. In addition, we thank our colleagues from Nusa Putra University and Narotama University who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

## REFERENCES

[1] Z. Liu, S. Yu, Y. Huang, L. Liu, and Y. Pan, "A systematic review of rigid-flexible composite pavement," *Journal of Road Engineering*, May 2024, doi: 10.1016/J.JRENG.2024.02.001.

[2] N. D. Beskou, "Review on dynamic response of road pavements to moving vehicle loads; part 1: Rigid pavements," *Soil Dynamics and Earthquake Engineering*, vol. 175, 2023, doi: 10.1016/j.soildyn.2023.108249.

[3] H. B. Tran and V. T. A. Phan, "Potential usage of fly ash and nano silica in high-strength concrete: Laboratory experiment and application in rigid pavement," *Case Studies in Construction Materials*, vol. 20, p. e02856, Jul. 2024, doi: 10.1016/J.CSCM.2024.E02856.

[4] M. C. Cavalli *et al.*, "Review of advanced road materials, structures, equipment, and detection technologies," *Journal of Road Engineering*, vol. 3, no. 4, pp. 370–468, Dec. 2023, doi: 10.1016/J.JRENG.2023.12.001.

[5] M. K. D. Rout, S. K. Sahdeo, S. Biswas, K. Roy, and A. K. Sinha, "Feasibility Study of Reclaimed Asphalt Pavements (RAP) as Recycled Aggregates Used in Rigid Pavement Construction," *Materials (Basel).*, vol. 16, no. 4, 2023, doi: 10.3390/ma16041504.

[6] L. A. A. Al-Hindawi, A. M. Al-Dahawi, and A. S. J. Al-Zuheriy, "Use of Waste Materials for Sustainable Development of Rigid Pavement," *International Journal of Engineering, Transactions A: Basics*, vol. 36, no. 10, pp. 1919 – 1931, 2023, doi: 10.5829/ije.2023.36.10a.16.

[7] H. Yin and D. R. Brill, "Concrete Pavement Overload Test at the FAA's National Airport Pavement Test Facility," in *Airfield and Highway Pavements 2017: Airfield Pavement Technology and Safety - Proceedings of the International Conference on Highway Pavements and Airfield Technology 2017*, V.-V. E.M., M. S., A.-Q. I.L., and O. H., Eds., American Society of Civil Engineers (ASCE), 2017, pp. 127 – 151, doi: 10.1061/9780784480953.012.

[8] S. K. Yadav and V. Srivastava, "Non-conventional materials in rigid pavement: Effect on mechanical properties," *International Journal of Civil Engineering and Technology*, vol. 8, no. 4, pp. 1888 – 1896, 2017, doi: 09766308

[9] D. G. Mapa, M. Gunaratne, K. A. Riding, and A. Zayed, "Evaluating early-age stresses in jointed plain concrete pavement repair slabs," *ACI Materials Journal* vol. 117, no. 4, pp. 119 – 132, 2020, Doi: 10.14359/51725780.

[10] W. Wibowo, A. Setyawan, Y. M. Purwana, and B. Setiawan, "Critical Stress Evaluation Of Rigid Pavement Due To The Presence Of Water In Expansive Soil Subgrade," *EUREKA: Physics and Engineering*, vol. 2023, no. 2, pp. 174 – 183, 2023,Doi: 10.21303/2461-4262.2023.002810.

[11] L. Sadik, S. Khoshnevisan, and M. Faraz Athar, "Reliability-Based Robust Design Framework for Rigid Pavements," in *Geotechnical Special Publication*, R. E., M. B.M., and W. M.H., Eds., American Society of Civil Engineers (ASCE), 2023, pp. 388 – 396, doi: 10.1061/9780784484708.036.

[12] Q. Yang *et al.*, "Impacts of climate change on environmental and economic sustainability of flexible pavements across China," *Resources, Conservation and Recycling*, vol. 206, p. 107589, Jul. 2024, doi: 10.1016/J.RESCONREC.2024.107589.

[13] B. H. Nam, "In-situ super accelerated pavement test for the fatigue evaluation of in-service airfield rigid pavement – A case study at Mecham Airport," *Construction and Building Materials.*, vol. 353, p. 129115, 2022, doi: 10.1016/j.conbuildmat.2022.129115.

[14] A. D. Nataadmadja and A. Ricky, "The usage of marginal aggregate as wearing course layer," *AIP Conference Proceedings*, vol. 3026, no. 1, pp. 183–190, 2024, doi: 10.1063/5.0199796.

[15] H. B. Tambunan, "A Bibliometric Study of Solar Photovoltaic," *2022 International Conference on Technology and Policy in Energy and Electric Power (ICT-PEP)*, Jakarta, Indonesia, 2022, pp. 180-185, doi: 10.1109/ICT-PEP57242.2022.9988834.

[16] D. Essen and A. Hidayat, "Acid Effect Sulphate Against Strong Concrete Press Containing Lime As Substitutions of Cement and Glass As Substitution of Coarse Aggregate," in *Journal of World Conference*, vol. 3, no. 1, pp. 48-55, 2021.

[17] T. Rahman, M. Z. Irawan, A. N. Tajudin, M. R. F. Amrozi, and I. Widyatmoko, "Knowledge mapping of cool pavement technologies for urban heat island Mitigation: A Systematic bibliometric analysis," *Energy and Buildings*, p. 113133, 2023, doi: 10.1016/j.enbuild.2023.113133

[18] B. A. Prata, L. R. Abreu, and M. S. Nagano, "Applications of constraint programming in production scheduling problems: A descriptive bibliometric analysis," *Results in Control and Optimization.*, vol. 14, p. 100350, Mar. 2024, doi:

10.1016/J.RICO.2023.100350.
[19] H. B. Tambunan, N. W. Priambodo, J. Hartono, I. A. Aditya, M. Triani, and Rasgianti, "Research trends on microgrid systems: a bibliometric network analysis," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 3, pp. 2529–2545, 2023, doi: 10.11591/ijece.v13i3.pp2529-2545.
[20] T. O. Omotehinwa, "Examining the developments in scheduling algorithms research: A bibliometric approach," *Heliyon*, vol. 8, no. 5, p. e09510, May 2022, Doi: 10.1016/J.HELIYON.2022.E09510.
[21] R. Harder, "Using Scopus and OpenAlex APIs to retrieve bibliographic data for evidence synthesis. A procedure based on Bash and SQL," *MethodsX*, vol. 12, p. 102601, Jun. 2024, doi: 10.1016/J.MEX.2024.102601.
[22] J. Homolak, I. Kodvanj, and D. Virag, "Preliminary analysis of COVID-19 academic information patterns: a call for open science in the times of closed borders," *Scientometrics*, vol. 124, pp. 2687–2701, 2020, doi: 10.1007/s11192-020-03587-2
[23] R. Zakaria, A. Ahmi, A. H. Ahmad, and Z. Othman, "Worldwide melatonin research: a bibliometric analysis of the published literature between 2015 and 2019," *Chronobiology International*, vol. 38, no. 1, pp. 27–37, 2021, doi: 10.1080/07420528.2020.1838534
[24] V. Z. Pessin, L. H. Yamane, and R. R. Siman, "Smart bibliometrics: an integrated method of science mapping and bibliometric analysis," *Scientometrics*, vol. 127, no. 6, pp. 3695–3718, 2022, doi: 10.1007/s11192-022-04406-6
[25] S. Galletta, S. Mazzù, V. Naciti, and A. Paltrinieri, "A PRISMA systematic review of greenwashing in the banking industry: A call for action," *Research in International Business and Finance*, vol. 69, p. 102262, Apr. 2024, doi: 10.1016/J.RIBAF.2024.102262.
[26] Z. Liu, J. Moon, B. Kim, and C.-P. Dai, "Integrating adaptivity in educational games: A combined bibliometric analysis and meta-analysis review," *Educational Technology Research and Development*, vol. 68, pp. 1931–1959, 2020, doi: 10.1007/s11423-020-09791-4
[27] M. A. Rojas-Sánchez, P. R. Palos-Sánchez, and J. A. Folgado-Fernández, "Systematic literature review and bibliometric analysis on virtual reality and education," *Education and Information Technologies*, vol. 28, no. 1, pp. 155–192, 2023, doi: 10.1007/s10639-022-11167-5
[28] N. Donthu, S. Kumar, N. Pandey, and P. Gupta, "Forty years of the International Journal of Information Management: A bibliometric analysis," *International Journal of Information Management*, vol. 57, p. 102307, 2021, doi: 10.1016/j.ijinfomgt.2020.102307
[29] V. Singh, H. Singh, B. Dhiman, N. Kumar, and T. Singh, "Analyzing bibliometric and thematic patterns in the transition to sustainable transportation: Uncovering the influences on electric vehicle adoption," *Research in Transportation Business & Management*, vol. 50, p. 101033, Oct. 2023, doi: 10.1016/J.RTBM.2023.101033.
[30] M. Abdullah *et al.*, "Neurosurgery and Social Media: A Bibliometric Analysis of Scientific Production from 2004 to 2023," *World Neurosurgery*, vol. 188, pp. 45–54, Aug. 2024, doi: 10.1016/J.WNEU.2024.04.128.
[31] B. S. Lancho Barrantes, S. Dalton, and D. Andre, "Bibliometrics Methods in Detecting Citations to Questionable Journals," *Journal of Academic Librarianship*, vol. 49, no. 4, p. 102749, Jul. 2023, doi: 10.1016/J.ACALIB.2023.102749.
[32] N. Ellili *et al.*, "The applications of big data in the insurance industry: A bibliometric and systematic review of relevant literature," *Journal of Finance and Data Science*, vol. 9, p. 100102, Nov. 2023, doi: 10.1016/J.JFDS.2023.100102.
[33] D. J. Borgohain, M. K. Verma, M. Nazim, and M. Sarkar, "Application of Bradford's law of scattering and Leimkuhler model to information science literature," *COLLNET Journal of Scientometrics and Information Management*, vol. 15, no. 1, pp. 197–212, 2021, doi: 10.1080/09737766.2021.1943041
[34] D. Verano-Tacoronte, S. Flores-Ureba, M. Mesa-Mendoza, and V. Llorente-Muñoz, "Evolution of scientific production on urban passenger transport: A bibliometric analysis," *European Journal of Management and Business Economics*, vol. 30, no. 1, p. 100239, Jan. 2024, doi: 10.1016/J.IEDEEN.2023.100239.
[35] I. Danvila-del-Valle, C. Estévez-Mendoza, and F. J. Lara, "Human resources training: A bibliometric analysis," *Journal of Business Research*, vol. 101, pp. 627–636, 2019, doi: 10.1016/j.jbusres.2019.02.026
[36] C. Forliano, P. De Bernardi, and D. Yahiaoui, "Entrepreneurial universities: A bibliometric analysis within the business and management domains," *Technological Forecasting and Social Change*, vol. 165, p. 120522, 2021, doi: 10.1016/j.techfore.2020.120522
[37] N. Kushairi and A. Ahmi, "Flipped classroom in the second decade of the Millenia: a Bibliometrics analysis with Lotka's law," *Education and Information Technologies*, vol. 26, no. 4, pp. 4401–4431, 2021, doi: 10.1007/s10639-021-10457-8
[38] A. Ullah and K. Ameen, "Relating research growth, authorship patterns and publishing outlets: a bibliometric study of LIS articles produced by Pakistani authors," *Scientometrics*, vol. 126, no. 9, pp. 8029–8047, 2021, doi: 10.1007/s11192-021-04081-z
[39] I. Sverdlichenko, S. Xie, and E. Margolin, "Impact of institutional affiliation bias on editorial publication decisions: A bibliometric analysis of three ophthalmology journals," *Ethics, Medicine and Public Health*, vol. 21, p. 100758, Apr. 2022, doi: 10.1016/J.JEMEP.2022.100758.
[40] F. Lorusso, F. Inchingolo, and A. Scarano,

"Scientific production in dentistry: The national panorama through a bibliometric study of Italian academies," *BioMed Research International*, vol. 2020, no. 1, p. 3468303, 2020, doi: 10.1155/2020/3468303

[41] K. Garg, B. Chaurasia, A. J. Gienapp, B. Splavski, and K. I. Arnautovic, "Bibliometric analysis of publications from 2011–2020 in 6 Major Neurosurgical Journals (Part 1): Geographic, demographic, and article type trends," *World Neurosurgery*, vol. 157, pp. 125–134, 2022, doi: 10.1016/j.wneu.2021.10.091

[42] M. Mafruchati, S. Musta'ina, and A. K. Wardhana, "Research trends of Moringa oleifera Lam as Remedy toward Cattle's embryo according to the frequently used words in content of papers and citations," *Heliyon*, vol. 10, no. 11, p. e31522, Jun. 2024, doi: 10.1016/J.HELIYON.2024.E31522.

[43] X. Hou *et al.*, "Exploring the topic structure and abuse trends of new psychoactive Substance since the 21st century from a bibliometric perspective," *Saudi Pharmaceutical Journal* vol. 32, no. 4, p. 101991, Apr. 2024, doi: 10.1016/J.JSPS.2024.101991.

[44] M. J. Dino *et al.*, "Charting the uncharted: Mapping scientific publications on online disinhibition effect in the digital space via bibliometrics and network analyses," *Computers in Human Behavior Report*, vol. 12, p. 100336, Dec. 2023, doi: 10.1016/J.CHBR.2023.100336.

[45] C. Dini, M. M. A. Pereira, J. G. S. Souza, E. D. de Avila, and V. A. R. Barão, "Mapping the trends and impact of research collaboration between countries in oral implantology publications: A bibliometric analysis from 1999 to 2019," *Journal of Prosthetic Dentistry*, Nov. 2022, doi: 10.1016/J.PROSDENT.2022.10.009.

[46] L. O. Agashua, C. Arum, B. D. Oluyemi-Ayibiowu, and C. M. Ikumapayi, "A systematic review of geopolymer materials: innovations, prevailing constraints and resolutions," *Sinergi (Indonesia)*, vol. 28, no. 3, pp. 473–488, 2024, doi: 10.22441/sinergi.2024.3.004.

[47] R. P. Youlia, D. Utami, D. Romahadi, and Y. Xiawei, "A review towards Friction Stir Welding technique: working principle and process parameters," *Sinergi (Indonesia)*, vol. 27, no. 3, pp. 289–308, 2023, doi: 10.22441/sinergi.2023.3.001.