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RESEARCH ARTICLE

A bibliometric analysis of fiber cement board research: Trends, development and future direction

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ABSTRACT

Over the past decade, research on fiber cement board (FCB) materials has experienced significant growth, driven by the demand for sustainable and high-performance construction materials. This bibliometric analysis examines global research trends in FCB studies from 2021 to 2025 by systematically retrieving publications from Scopus using predefined search strings related to fiber cement boards. The study applied filters for peer-reviewed articles published in English and utilized the bibliometric tools VOSviewer to analyze citation networks, co-authorship patterns, keyword co-occurrence, and thematic evolution. This approach enabled the identification of influential publications and authors, as well as the detection of emerging areas of interest. A comprehensive database search revealed a growing focus on incorporating various fiber reinforcements, including synthetic and natural fibers, to enhance mechanical, thermal, and durable properties. Notably, research on hybrid fiber reinforcement and alternative binders has gained prominence due to their potential to improve sustainability and structural performance. The study revealed a rising publication trend, peaking at nearly 650 articles in 2024, with China leading in output (854 publications) and citations (10,373), while Australia demonstrated the highest impact (19.9 citations per paper). Highly cited authors such as Zaid, O. (691 citations) and Kaplan, G. (471 citations) have made significant contributions, with Construction and Building Materials emerging as the dominant journal. These quantified insights highlight key contributors, research influence, and thematic shifts toward AI integration, sustainability, and fiber innovation in FCB studies. The results highlight the importance of material innovation, emphasizing the role of fiber-modified cement composites in advancing environmentally friendly and resilient construction practices. This study serves as a crucial reference for shaping future research and industrial applications in sustainable building materials.

1.0 INTRODUCTION

Fiber cement boards (FCBs) have emerged as a pivotal innovation in modern construction, offering durable, lightweight, and environmentally friendly alternatives to traditional building materials such as wood, gypsum, and concrete (Jonnala et al., 2024). These composite materials, primarily composed of cement, cellulose fibers, and other reinforcements, are widely utilized due to their superior fire resistance, moisture resistance, and termite resistance, as well as their structural integrity. Over the past few decades, research on FCBs has expanded significantly, driven by advancements in material science, improvements in manufacturing technologies, and the increasing demand for sustainable construction solutions. As the construction industry faces mounting pressure to adopt energy-efficient and environmentally responsible materials, it is crucial to examine the research trends, developments, and future directions of FCB technology.

To achieve this, bibliometric analysis serves as a valuable tool for assessing the evolution of scientific knowledge in this domain. By analyzing key bibliometric indicators such as publication characteristics, citation networks, keyword co-occurrence, the most productive countries and institutions, and top-cited authors—this study aims to map the intellectual structure of FCB research, identify influential contributions and trace emerging themes in the field that require further exploration.

The development of fiber cement materials can be historically traced back to the late 19th century, particularly through Ludwig Hatschek's invention of asbestos-cement composites (Lopes & Salles, 2014). Initially, asbestos fibers were widely used as reinforcements due to their high tensile

strength, durability, and fire resistance. However, the discovery of severe health hazards associated with asbestos exposure led to a global shift toward alternative, safer fiber reinforcements such as cellulose, polyvinyl alcohol, and polypropylene fibers (Gualtieri et al., 2022). This transition marked a significant turning point in fiber cement research, prompting researchers and manufacturers to explore new reinforcement techniques and to improve material formulations.

Since the late 20th century, FCB research has diversified into several key areas, including durability enhancement, mechanical performance optimization, and sustainability. The introduction of nanotechnology and bio-based reinforcements has further expanded the scope of FCB research, leading to the development of high-performance, environmentally friendly composite materials. Additionally, advancements in industrial automation and digital fabrication techniques have revolutionized FCB manufacturing, enabling greater efficiency, precision, and design flexibility.

As the global demand for sustainable, durable, and high-performance building materials continues to rise, FCB research is expected to advance significantly. This study provides a comprehensive bibliometric analysis of FCB research from 2021 to 2025, highlighting key trends and developments in the field. Using quantitative bibliometric analysis, the study examines publication patterns and offers a detailed overview of the research landscape, intellectual trajectory, and key areas of interest. By identifying influential studies, emerging trends, and research gaps, this work contributes to a deeper understanding of fiber cement technology and serves as a valuable resource for researchers, industry professionals, and policymakers in shaping the future of sustainable construction materials.

2.0 MATERIALS AND METHODS

2.1. Bibliometric Approach

Bibliometric analysis is a systematic approach to collecting, managing, and analyzing bibliographic data from scholarly publications to evaluate research trends, intellectual structures, and knowledge development within a specific field (Verbeek et al. 2002; Assyakur & Rosa 2022; Alves et al. 2021). This study employs bibliometric methods to explore the landscape of FCB, focusing on identifying key research themes, influential publications, prominent author, collaboration networks, and emerging trends shaping the field's development. A combination of general descriptive statistics and advanced bibliometric techniques, including document co-citation analysis and keyword co-occurrence mapping are utilized to provide a comprehensive overview of the field (Wu & Wu, 2017).

To ensure robust data collection, the study relies on the Elsevier Scopus database, noted for its extensive coverage of high-quality peer-reviewed literature and effectiveness in bibliometric studies (di Stefano et al. 2010; Khiste & Paithankar 2017; Al-Khoury et al. 2022). The search query is designed to capture relevant research on fiber cement boards, fiber-reinforced cement, and sustainable cement materials. To maintain the integrity of the dataset, only articles from peer-reviewed journals are included in the analysis, while conference papers, books, book chapters, and lecture notes are excluded (Gu et al., 2019).

The study covers a publication period from 2021 to 2025, ensuring that only recent advancements in FCB research are captured. The extracted data include publication details (authors, affiliations, and sources), citation metrics, keyword distribution, and co-citation networks. Bibliometric tools such as VOSviewer are utilized to perform network visualization and trend analyses.

2.2. Data Search Strategy

The data search strategy began with an initial query in the Scopus database using the string "TITLE-ABS-KEY ('fiber cement board' OR 'fiber-reinforced cement' OR 'sustainable cement board')" to capture a comprehensive dataset on FCB research. This broad search retrieved a substantial number of publications, encompassing various aspects of FCB technology. To refine the dataset and ensure its relevance, additional filters were applied. The study focused on articles published between 2021 and 2025, enabling an analysis of recent advancements in the field. Only peer-reviewed journal articles were included, ensuring that the dataset were derived from rigorously vetted research. Conference papers, book chapters, and technical notes were excluded to maintain dataset integrity. Additionally, only publications in their final publication stage were considered to ensure consistency, while the language was restricted to English to enhance accessibility and comparability. The search was further refined to ensure a focus on high-impact journal studies.

After applying these criteria, the refined dataset comprised 2,437 articles relevant to the study. This dataset was then exported in BibTeX and CSV formats for bibliometric analysis. To examine research trends and patterns, bibliometric tools such as VOSviewer were employed for co-authorship analysis, citation network mapping, and keyword co-occurrence analyses. Additionally, a manual screening process was conducted to remove duplicate records, irrelevant articles, and papers with incomplete metadata, to retain only high-quality studies in the final analysis.

Figure 1 provides a detailed flowchart illustrating the data screening and selection process. This refined dataset serves as the foundation for the bibliometric analysis, offering valuable insights into the intellectual structure, dominant research themes, and emerging trends in FCB research.

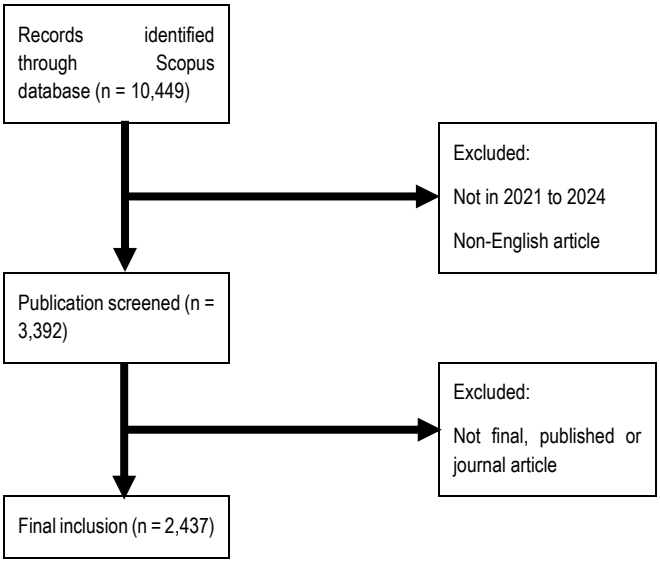


Figure 1: Data screening and excluding.

2.3. Data Analysis

For this study, VOSviewer, a widely used bibliometric analysis software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (van Eck & Waltman, 2010a, 2017), was employed to analyze the research landscape of FCB studies. VOSviewer is particularly effective for network visualizations, clustering related research items, and generating density maps, making it an ideal tool for mapping co-authorship networks, co-citation patterns, and keyword co-occurrence. Its advanced algorithms enable graph-based visualization of bibliometric data, allowing researchers to identify relationships between publications, authors, and research themes. Its continuous updates ensure efficient processing and visualization of large datasets, making it a valuable tool for this bibliometric study.

To perform the analysis, datasets extracted from Scopus were formatted in CSV and BibTeX formats, covering publications from 2021 to 2025. The extracted bibliometric metadata included publication year, title, authors, journals, citation counts, keywords, and institutional affiliations. VOSviewer (version 1.6.19) was utilized to conduct clustering and mapping techniques, highlighting dominant research themes and collaborations in FCB research. In comparison with traditional Multidimensional Scaling (MDS) techniques, VOSviewer optimizes the spatial representation of bibliometric relationships in low-dimensional space, ensuring an accurate depiction of research linkages (van Eck & Waltman, 2010b).

For network analysis, VOSviewer employed the association strength (ASij) normalization method to balance the frequency of co-occurrences between items, ensuring a more accurate visualization of research connections (Van Eck & Waltman, 2007). Three primary analytical approaches were applied:

1. Citation and co-citation analysis – Determined the most influential papers in the field by recognizing highly cited studies and their intellectual linkages.
2. Co-authorship network analysis – Highlighted collaborative research networks, showcasing key researchers, institutions, and international partnerships shaping the field.
3. Keyword co-occurrence analysis – Identified emerging research trends and dominant themes in FCB studies by mapping frequently occurring terms.

By visualizing these relationships, the analysis provides a structured overview of the intellectual development in FCB research, revealing core areas of study, research gaps, and potential directions for future investigations. The findings offer valuable insights for academicians, industry professionals, and policymakers, supporting further advancements in sustainable fiber cement materials.

3.0 RESULT

3.1 Characteristics of Publication

Based on the trends depicted in Figures 2 and 3, publication activity in FCB research has exhibited notable variations in recent years. Figure 3 illustrates the annual publication output alongside citation trends from 2021 to 2025. The number of published articles has steadily increased from 2021 to 2024, peaking at nearly 650 articles in 2024. This upward trend suggests a growing interest and investment in FCB research. Although the data for 2025 currently shows a lower number of publications, this is likely due to the fact that it is still the first quarter of the year. Publication numbers are expected to rise as the year progresses.

In contrast, citation trends exhibit an inverse pattern. While the number of articles has been rising, citations have steadily decreased over the years. The highest citation count was recorded in 2021, followed by a continuous decline, reaching its lowest in 2025. This suggests that earlier publications have had a more significant impact on the field, whereas more recent studies may not have had sufficient time to accumulate citations or might be focusing on niche topics with limited reach. The decreasing citation trend may also reflect a shift in the research landscape, with newer studies possibly exploring incremental advancements rather than groundbreaking innovations.

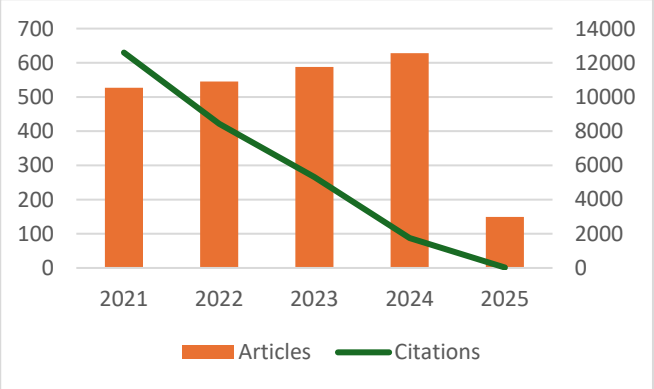


Figure 2: The number articles published and the number of citations received over the years 2021 – 2025.

Meanwhile, Figure 3 presents the distribution of publications across major journals in the field. The journal Construction and Building Materials has consistently been the leading outlet for FCB research, exhibiting significant fluctuations in publication activity. This dominance is attributed to the journal's scope, which focuses on construction and building materials, including cement, concrete reinforcement, brick and mortar, additives and non-conventional building materials, all of which are highly relevant to FCB research. After a peak in 2021, the number of articles decreased in 2022, rebounded in 2023, and reached its highest point in 2024. However, similar to the overall trend in Figure 2(a), the number of publications in this journal appears lower in 2025, likely due to incomplete data for the year. Since publication activity typically increases throughout the year, the final count for 2025 is expected to rise.

The Journal of Building Engineering (JOBE) and Case Studies in Construction Materials (CSCM) followed similar growth patterns, with publication peaks in 2024, highlighting their increasing role in disseminating FCB research. Unlike Construction and Building Materials, which focuses on materials science, JOBE and CSCM emphasize aspects such as design phases, construction processes, operational performance, and real case studies involving actual construction projects.

Other journals, such as Materials, Journal of Materials in Civil Engineering, Cement and Concrete Composites, and Structures, have shown stable publication trends, reflecting their continuous contribution to the field. These journals primarily focus on material research, including FCB advancements. Meanwhile, the presence of FCB research in Engineering Structures, Buildings, and Polymers underscores the interdisciplinary nature of FCB research, bridging materials science, structural engineering, and sustainable construction.

Understanding the top journals publishing FCB research provides valuable insights for researchers, helping them identify reputable sources of information and select suitable publication outlets. Construction and Building Materials remains the most influential journal in the field, while researchers developing new FCBs may find JOBE more suitable, and those interested in real-world applications may find CSCM more relevant. Journals such as Materials, Journal of Materials in Civil Engineering, Cement and Concrete Composites, and Structures serve as foundational platforms for material research in FCB, while Engineering Structures, Buildings, and Polymers highlight innovative reinforcement techniques and emerging developments in FCB technology.

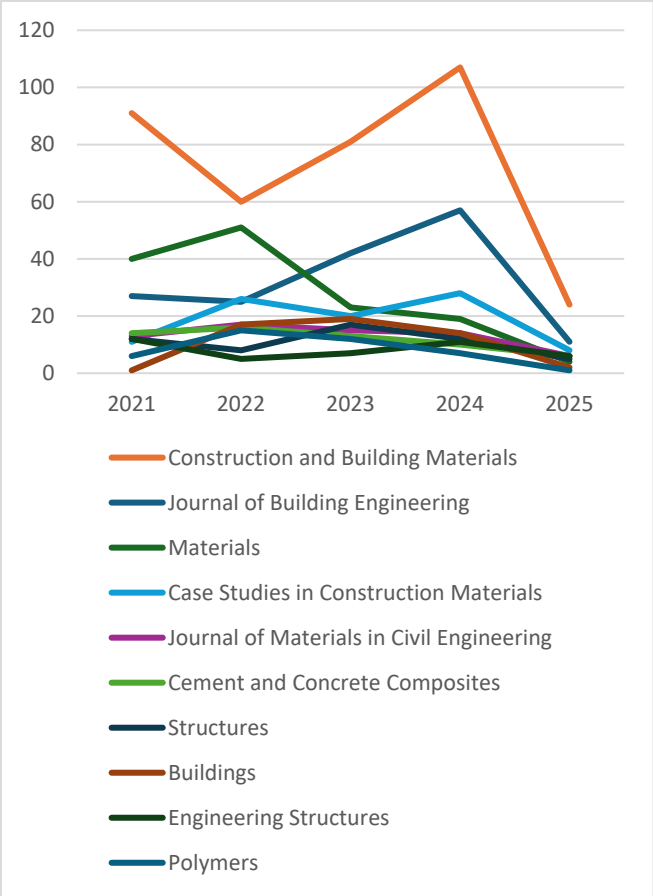


Figure 3: Articles published by various top journals in the field.

3.2 Most Cited Authors

Figure 4 presents an analysis of the most prominent authors in FCB research. In Figure 4, the color spectrum serves as a density indicator, where yellow represents a higher density of cited articles for a given author, while blue indicates a lower citation density. These authors include Zaid, O., Kaplan, G., Raza, A., Mechtcherine, V., Zhang, B., Elchalakani, M., Zhu, H., Hao, H., Garoushi, S., and Valandro, L.F. received a higher citation density compared to others, reflecting the significance and impact of their contributions to the field.

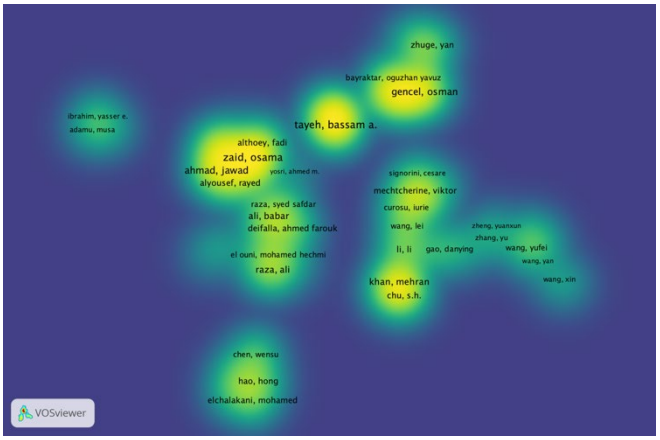


Figure 4: Co-citation density for the most prominent authors in FCB research.

Figure 5 further analyzes the citation received by each author. Among the leading researchers, Zaid, O. from National University of Sciences and Technology, Islamabad, Pakistan, stands out as the most highly cited author, with 691 citations from 19 published articles, demonstrating the substantial influence of his contributions. Closely following, Kaplan, G. from Atatürk Üniversitesi, Erzurum, Türkiye, has received 471 citations from 13 publications, further highlighting their influence on FCB studies.

Raza, A. and Mechtcherine, V. have also made notable contributions, publishing 22 and 19 articles, with citation counts of 344 and 306 respectively, underscoring the reach and relevance of their research. Additionally, Zhang, B., Elchalakani, M., and Zhu, H. have each contributed 13 - 14 articles, with citations ranging from 241 to 250, demonstrating consistent academic engagement in the field.

Further down the list, Hao, H., Garoushi, S., and Valandro, L.F. have each published 13 to 14 articles, though their citation counts vary widely. Notably, Valandro, L.F. has received the lowest citation count (44 citations) despite contributing 13 articles, suggesting a relatively recent or emerging presence in the research landscape.

While most authors primarily focus on mechanical properties such as compressive strength, tensile strength, bonding strength, Garoushi, S., and Valandro, L.F. specialize in material composition and microstructure analysis. This distinction highlights that mechanical strength remains one of the most critical aspects of FCB research, as it directly impacts structural performance and durability.

3.3 The Most Productive Countries

The research landscape in FCB is shaped by several leading countries, each demonstrating significant contributions to scientific advancements in this field. As depicted in Figure 6(a) and (b), these nations have actively invested in research and development, driving innovation in sustainable construction materials. Meanwhile, the distribution of total journal publications and citation impact, summarized in Table 1, highlights the key players in this domain.

China dominates the field with 854 publications, accounting for 40.1% of total journal output. The country has amassed 10,373 citations, with an average of 12.1 citations per publication, ranking 9th in citation efficiency. China's extensive research efforts solidify its role as a global leader in FCB advancements, contributing to both industrial applications and academic knowledge.

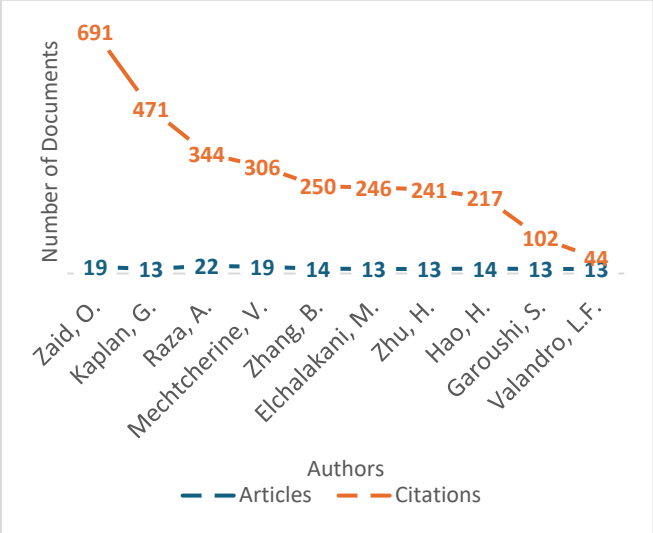


Figure 5: Visualization of highly cited authors in the field of FCB research.

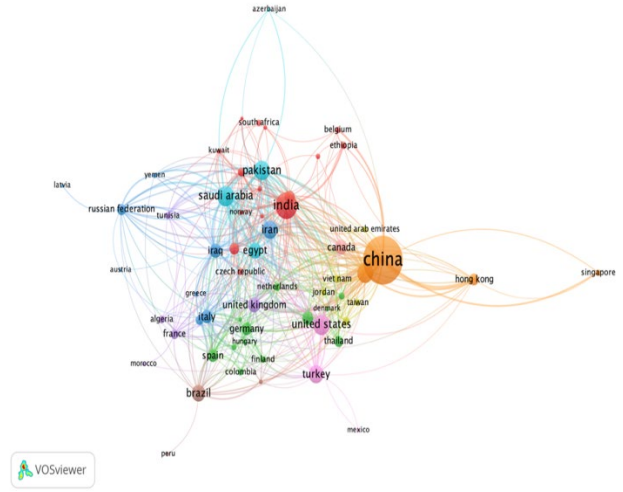
India follows as the second most productive country, publishing 266 articles (12.5% of the total). However, its 2,121 citations result in a lower citation-per-publication ratio of 8.0, placing it 10th in citation efficiency. Despite this, India's research contributions continue to expand, with significant progress in sustainable building materials and construction technologies. The strong research presence of both China and India is linked to their large populations and growing housing demands, with FCB offering an efficient and cost-effective material for residential and industrial applications (Srivastava & Kumar, 2018).

Saudi Arabia and the United States have demonstrated strong citation influence, ranking 3rd and 4th in citation efficiency. Saudi Arabia, with 156 publications (7.3% of total output), has accumulated 2,711 citations, achieving a citation-per-publication ratio of 17.4. Similarly, the United States has produced 148 publications, garnering 2,387 citations, with a citation impact of 16.1. The widespread referencing of research from these countries reflects the high quality and relevance of their contributions to FCB technology.

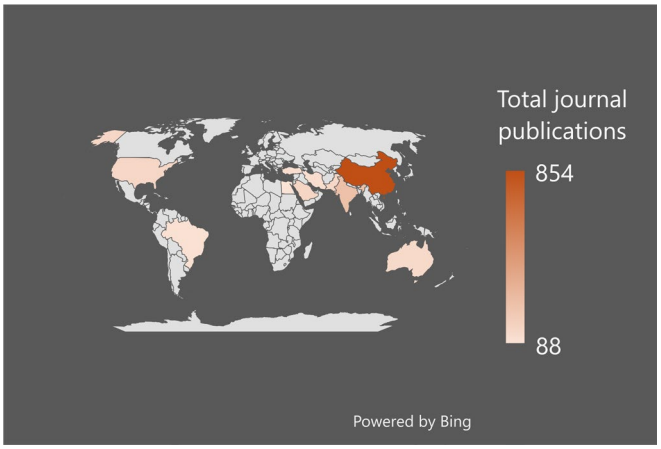
Pakistan and Australia contribute a moderate number of publications; however, their research exhibits the highest citation efficiency. Pakistan, with 146 publications, has accumulated 2,622 citations, achieving a citation-per-

publication ratio of 18.0, ranking 2nd overall. Meanwhile, Australia, despite producing only 137 publications (6.4% of total output), leads in citation impact with 2,731 citations and an average of 19.9 citations per paper, ranking first in citation efficiency.

Several countries are emerging as influential contributors to FCB research, including Turkey (120 publications), Iran (115), Brazil (100), and Egypt (88). These nations show citation-per-publication ratios of 12.7 to 15.6, reflecting growing global influence. Turkey (15.6) and Iran (14.4) rank 5th and 6th, while Brazil and Egypt share the 7th rank (12.7 citations per paper). Their contributions are crucial in expanding the scope of research in fiber-reinforced cementitious materials, reinforcing the global significance of FCB technology.



(a)



(b)

Figure 6: The data on the most productive countries in FCB research (2021 – 2025) using; a) Overlay visualization of co-authorship countries, b) Geographical distribution of publication.

3.3 The Most Productive Institutions

The provided data offers a comprehensive overview of the leading institutions contributing to FCB research. Table 2 presents the ten institutions with the most journal publications, highlighting their pivotal role in advancing this research domain. The geographic distribution of these institutions further underscores the dominance of research in China, followed by Bangladesh, Saudi Arabia, Pakistan, and Hong Kong.

The Ministry of Education of the People's Republic of China leads the rankings with an impressive 128 publications, accounting for 25.5% of the total research output. This substantial contribution underscores China's strong commitment to FCB research, driven by national policies and academic initiatives.

Zhengzhou University (46 publications, 9.2%), Shenzhen University (36 publications, 7.2%), Tongji University (36 publications, 7.2%), and Harbin Institute of Technology (31 publications, 6.2%) strengthen China's dominant research presence. Ongoing innovation and substantial research funding from Chinese institutions reinforce the country's leadership in FCB studies.

According to Xie et al., (2024), one of the key motivations for FCB research in China is the large volume of industrial waste generated, which poses a significant environmental threat. To address this issue, these waste materials can be recycled into supplementary cementitious materials, thereby enhancing sustainability and increasing research interest in FCB technology.

Southeast University, Bangladesh, follows with 59 publications, representing 11.8% of total output. This institution has emerged as a major contributor, reflecting the growing interest in sustainable construction materials in South Asia.

Prince Sattam Bin Abdulaziz University, Saudi Arabia, ranks third with 55 publications (11.0% of total output), highlighting the institution's dedication to materials science and its contributions to cementitious composites research. Similarly, King Khalid University (43 publications, 8.6%) continues to play a significant role in the field.

The University of Engineering and Technology Taxila, Pakistan, has contributed 38 publications (7.6%), marking a notable research presence in South Asia. This reflects an increasing academic focus on fiber-reinforced cement materials in the region.

The Hong Kong Polytechnic University completes the top ten, with 30 publications (6.0% of total output). This institution's contributions reflect Hong Kong's engagement in high-impact research, particularly in sustainable building materials.

Table 1: Top ten of the country publications and citations for the FCB.

Countries	Total journal publications	Percent Total Journal Publications	Citations	Citations/Total Journal Publications	Citations/Total Journal Publications (Rank)
China	854	40.1	10373	12.1	9
India	266	12.5	2121	8.0	10
Saudi Arabia	156	7.3	2711	17.4	3
United States	148	6.9	2387	16.1	4
Pakistan	146	6.9	2622	18.0	2
Australia	137	6.4	2731	19.9	1
Turkey	120	5.6	1876	15.6	5
Iran	115	5.4	1655	14.4	6
Brazil	100	4.7	1273	12.7	7
Egypt	88	4.1	1118	12.7	7

Table 2: Top ten of the most relevant institutional affiliations (2021 – 2025) for the FCB.

Affiliation	Total journal publications	Percent Total Journal Publications	Country
Ministry of Education of the People's Republic of China	128	25.5	China
Southeast University	59	11.8	Bangladesh
Prince Sattam Bin Abdulaziz University	55	11.0	Saudi Arabia
Zhengzhou University	46	9.2	China
King Khalid University	43	8.6	China
University of Engineering and Technology Taxila	38	7.6	Pakistan
Shenzehen University	36	7.2	China
Tongji University	36	7.2	China
Harbin Institute of Technology	31	6.2	China
The Hong Kong Polytechnic University	30	6.0	Hong Kong

3.4 Top Cited Authors

The contributions of leading researchers in the field of FCB research have significantly advanced the understanding of material properties, durability, and sustainability. The top ten highly cited articles from 2021 to 2025 are listed in Table 3. Kang et al. (2021) leads the list with 277 citations for their work on machine learning-based prediction of compressive and flexural strengths of steel fiber-reinforced concrete, published in Construction and Building Materials (2021). Their study underscores the pivotal role of artificial intelligence (AI) in optimizing concrete mix designs and predicting mechanical performance, enhancing efficiency in structural applications.

Following closely, Mehrabi et al. (2021) amassed 227 citations for their research on the effect of pumice powder and nano-clay on strength and permeability in fiber-reinforced pervious concrete with recycled concrete aggregate, also published in Construction and Building Materials. Their findings contribute to the ongoing shift toward eco-friendly construction materials, demonstrating the feasibility of sustainable alternatives in concrete production.

Emad et al. (2022) garnered 196 citations for their study on predicting compressive strength of concrete materials using surrogate models, published in Structures. Their work integrates computational modeling to refine concrete strength estimation, reducing reliance on extensive experimental testing.

In the domain of natural fiber-reinforced cementitious composites, de Azevedo et al. (2021) explored the technological performance of açaí fiber-reinforced cement-based mortars (Journal of Building Engineering) and accumulated 181 citations. Their study highlights the mechanical advantages of biogenic fibers in cementitious applications, reinforcing the role of natural reinforcements in modern construction.

Similarly, Arif et al. (2022) contributed to the development of biopolymeric sustainable materials and their emerging applications, published in Journal of Environmental Chemical Engineering, with 179 citations. Their research presents a transformative perspective on the integration of biopolymers in cementitious systems, emphasizing material circularity and environmental benefits.

Ganesh and Muthukannan (2021) investigated high-performance, optimized, fiber-reinforced geopolymer concrete and its compressive strength prediction, accumulating 168 citations (Journal of Cleaner Production). Their findings bridge the gap between geopolymer chemistry and fiber reinforcement, offering durable and eco-friendly alternatives to conventional concrete.

The impact of fiber additives on physicomechanical,

durability, and thermal properties has been further examined by Yavuz Bayraktar et al. (2021) in their study on basalt fiber-reinforced foamed concrete containing waste marble powder and slag (Construction and Building Materials), receiving 133 citations. Their work aligns with the industry's increasing focus on reducing carbon emissions and utilizing industrial waste in concrete production.

CT scanning and microstructural analysis have also played a crucial role in FCB research. Cao et al. (2021) studied the internal crack mechanisms and strength behavior of cement-fiber-tailings matrix composites (Cement and Concrete Composites), receiving 126 citations. Their research provides critical insights into material integrity and crack propagation in fiber-reinforced cementitious matrices.

Durability and cost assessment are key considerations in fiber-reinforced composites. Akeed et al. (2022) examined ultra-high-performance fiber-reinforced concrete, including its durability properties, cost implications, applications, and challenges, accumulating 125 citations (Case Studies in Construction Materials). Their study offers a comprehensive evaluation of ultra-high-performance fiber-reinforced cementitious systems, essential for advanced structural applications.

Finally, Wang et al. (2021) contributed to the exploration of limestone calcined clay cement (LC3) in high-strength strain-hardening cement-based composites (HS-SHCC), earning 123 citations (Cement and Concrete Composites). Their research showcases the growing interest in hybrid cementitious materials that optimize performance while reducing carbon footprint.

Table 3: Top ten highly cited articles dealing with FCB research from 2021 to 2025.

Article title	Author name	Journal published	Citations	Year
Machine learning-based prediction for compressive and flexural strengths of steel fiber-reinforced concrete	Kang, M. C.; Yoo, D. Y.; Rishi, G	Construction and Building Materials	277	2021
Effect of pumice powder and nano-clay on the strength and permeability of fiber-reinforced pervious concrete incorporating recycled concrete aggregate	Mehrabi, P.; Shariati, M.; Kabirifar, K.; Jarrah, M.; Rasekh, H.; Trung, N. T.; Shariati, A.; Jahandari, S.	Construction and Building Materials	227	2021
Prediction of concrete materials compressive strength using surrogate models	Emad, W.; Mohammed, A. S.; Kurda, R.; Ghafor, K.; Cavaleri, L.; Qaidi, S. M.; Hassan, A. M. T.; Asteris, P. G.	Structures	196	2022
Technological performance of açaí natural fibre reinforced cement-based mortars	de Azevedo, A. R.; Marvila, M. T.; Tayeh, B. A.; Cecchin, D.; Pereira, A. C.; Monteiro, S. N.	Journal of Building Engineering	181	2021
Biopolymeric sustainable materials and their emerging applications	Arif, Z. U.; Khalid, M. Y.; Sheikh, M. F.; Zolfagharian, A.; Bodaghi, M.	Journal of Environmental Chemical Engineering	179	2022
Development of high performance sustainable optimized fiber reinforced geopolymer concrete and prediction of compressive strength	Ganesh, A. C.; Muthukannan, M.	Journal of Cleaner Production	168	2021
Physico-mechanical, durability and thermal properties of basalt fiber reinforced foamed concrete containing waste marble powder and slag	Yavu Bayraktar, O.; Kaplan, G.; Gencel, O.; Benli, A.; Sutcu, M.	Construction and Building Materials	133	2021
CT scanning of internal crack mechanism and strength behavior of cement-fiber-tailings matrix composites	Cao, S.; Yilmaz, E.; Yin, Z.; Xue, G.; Song, W.; Sun, L.	Cement and Concrete Composites	126	2021
Ultra-high-performance fiber-reinforced concrete. Part IV: Durability properties, cost assessment, applications, and challenges	Akeed, M. H.; Qaidi, S.; Ahmed, H. U.; Faraj, R. H.; Mohammed, A. S.; Emad, W.; Azevedo, A. R.	Case Studies in Construction Materials	125	2022
On the use of limestone calcined clay cement (LC3) in high-strength strain-hardening cement-based composites (HS-SHCC)	Wang, L.; Rehman, N. U.; Curosu, I.; Zhu, Z.; Beigh, M. A. B.; Liebscher, M.; Chen, L.; Tsang, D. C. W.; Hempel, S.; Mechtcherine, V.	Cement and Concrete Composites	123	2021

3.5 Keywords Co-Occurrence

The bibliometric analysis of FCB research, as visualized in the VOSviewer-generated keyword network in Figure 7 and Table 4, identifies four primary thematic clusters, each representing a distinct research direction.

Red Cluster: Structural Reinforcement and Fiber Integration in Cement Composites

This cluster predominantly focuses on reinforced concrete and fiber-reinforced cement-based materials, emphasizing structural applications and durability enhancements. Keywords such as “basalt fiber”, “reinforced concrete beams”, and “composite materials” indicate strong research interest in alternative reinforcement methods aimed at improving the mechanical strength and load-bearing capacity of cement composites.

Additionally, terms like “finite element method” and “shear stress” suggest that numerical modeling and simulations play a crucial role in assessing the structural performance of fiber-reinforced cement boards. Research on “carbon fiber-reinforced plastics” within this cluster indicates an ongoing comparison between natural and synthetic fibers,

aimed at optimizing cementitious composites for superior mechanical performance.

Blue cluster: Mechanical Performance and Durability of Cementitious Materials

The blue cluster centers on “compressive strength,” “mechanical properties,” and “water absorption,” highlighting the physical and mechanical characterization of FCB materials. The presence of terms like “microstructure”, “self-compacting concrete”, and “durability properties” suggests an extensive focus on optimizing cement formulations to enhance material resilience.

Additionally, the strong association with “Portland cement”, “concrete mixtures”, and “recycled aggregates” reflects sustainability concerns, with researchers investigating eco-friendly approaches to fiber cement production. Studies incorporating “3D printing” and “thermal conductivity” indicate emerging innovations that explore advanced fabrication techniques and thermal efficiency in fiber-reinforced cement materials.

Green Cluster: Hybrid Composite Materials and Cement Matrix Interactions

This cluster emphasizes the interaction between fiber reinforcement and the cement matrix, focusing on “fracture toughness”, “surface treatment”, and “microstructural analysis”. Keywords such as “cement matrix”, “calcium silicate”, and “Fourier transform infrared spectroscopy (FTIR)” suggest a strong material science perspective, where chemical and spectroscopic analyses are employed to optimize fiber-matrix bonding.

The connection to “yield stress” and “hardness” also points to research aimed at improving the load-bearing capabilities of fiber cement composites through material optimization. The multidisciplinary nature of this cluster highlights the integration of civil engineering, chemistry, and materials science, fostering advancements in the mechanical behavior of hybrid fiber-reinforced cement boards.

Yellow cluster: Polymer and Synthetic Fiber Integration in Cementitiosrius Systems

The yellow cluster focuses on “composite resins”, “glass fibers”, and “epoxy resins”, indicating the integration of synthetic polymer-based reinforcements in FCB. The presence of terms such as “materials testing”, “adhesives”, and “computer-aided design” reflects efforts to evaluate and model the performance of fiber-reinforced cementitious composites under various conditions.

Research in this area also explores the compatibility of synthetic fibers with cement matrices, particularly in balancing mechanical improvements with cost-efficiency and environmental sustainability. Interestingly, the inclusion of “dental procedures and restoration” within this cluster suggests potential cross-disciplinary applications of fiber-reinforced materials in biomedical fields.

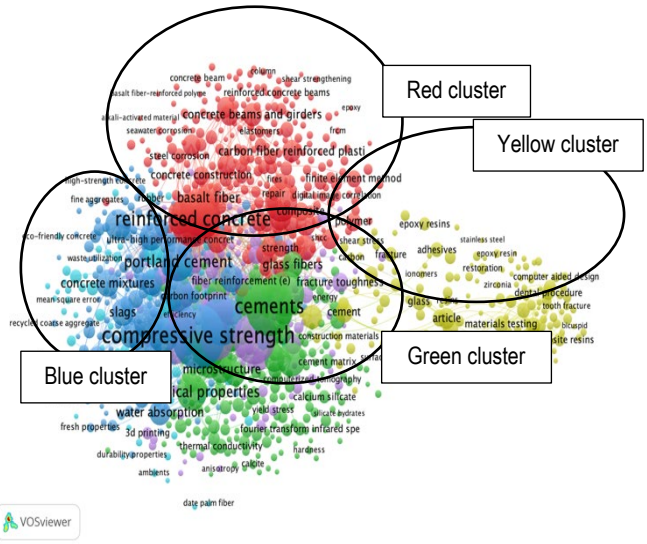


Figure 7: FCB keyword’s theme clustering: 2021-2025.

Table 4: FCB keyword’s theme clustering: 2021-2025.

Cluster	Main Keywords	Theme
Red	Reinforced concrete, basalt fiber, composite materials, concrete beams and girders, shear stress, carbon fiber-reinforced plastics, finite element method	Structural reinforcement and fiber integration in cement composites
Blue	Compressive strength, mechanical properties, water absorption, self-compacting concrete, durability properties, concrete mixtures, recycled aggregates, 3D printing, thermal conductivity	Mechanical performance and durability of cementitious materials
Green	Fracture toughness, cement matrix, calcium silicate, surface treatment, yield stress, microstructure, Fourier transform infrared spectroscopy (FTIR), hardness	Hybrid composite materials and cement matrix interactions
Yellow	Composite resin, glass fibers, epoxy resins, adhesives, materials testing, computer aided design, restoration	Polymer and synthetic fiber integration in cementitious systems

4.0 DISCUSSION

4.1 Emerging Applications of Fiber Cement Boards

The bibliometric keyword clusters identified in this study not only reveal the intellectual trajectory of FCB research but also provide insights into their practical and emerging applications in the construction industry. Four distinct thematic clusters: (1) structural reinforcement and fiber integration, (2) mechanical performance and durability, (3) hybrid composite interactions, and (4) polymer-based reinforcements, underscore how scholarly advances are being translated into industrial adoption across diverse construction domains.

In the first theme, research on structural reinforcement and fiber integration has laid the foundation for using FCBs in load-bearing and high-stress applications. The incorporation of basalt, carbon, or glass fibers has been extensively investigated for enhancing flexural strength and crack resistance. These improvements translate into industry applications such as façade panels (Schabowicz et al., 2021), roofing sheets (Darsana et al., 2016), and reinforced floorboards where mechanical reliability is critical. Moreover, in the United States, fiber reinforced concrete (FRC) has been adopted and employed for many horizontal applications including different kinds of pavements (Figure 8) and bridge decks.

Figure 8: FRC bonded on asphalt used to construct streets and roads (Source: /view/dot/66993).

In the second theme, the bibliometric clustering around compressive strength, durability, and water absorption points to applications in environments where long-term resilience is required. In practice, this corresponds to exterior cladding systems (Brose et al., 2019), wall partitions (Akinyemi & Osasona, 2017), and industrial flooring, particularly in regions with high humidity or exposure to aggressive weather. The low thermal conductivity of optimized FCBs also makes them suitable for energy-efficient building envelopes. Industries engaged in affordable housing and prefabricated construction increasingly adopt FCBs as they combine mechanical robustness with low maintenance requirements. In addition, prefabricated construction methods are able to mitigate ecological footprint, increase resource efficiency, expedite the housing delivery process and facilitate sustainable supply chains. More importantly, the use of prefabricated material such as FCB is able to resolve shortcomings associated with conventional on-site construction practice (Moghayedi & Awuzie, 2023).

The third theme focuses on fracture toughness, matrix-fiber bonding, and microstructural optimization highlights an emerging class of hybrid FCBs designed for advanced applications. Such composites are being considered for modular housing units, fire-resistant panels (Wang et al., 2025), and acoustic insulation boards (Lertwattanaruk et al., 2021), where material performance must balance multiple functionalities. By optimizing interfacial bonding, manufacturers can produce boards with superior impact resistance and dimensional stability, making them ideal for seismic-resilient and disaster-resistant structures. These hybrid boards also offer opportunities in prefabricated building systems that demand lightweight yet high-performance components.

The bibliometric analysis also emphasizes polymer resins, epoxy binders, and glass fibers reflects industry-driven interest in specialized applications. Polymer-modified FCBs exhibit improved flexibility, adhesion, and surface finish, enabling their use in interior design elements, high-end architectural façades, and decorative cladding. In addition, their compatibility with computer-aided design (CAD) and digital fabrication techniques positions them as attractive materials for customized modular panels. This method has been applied in gypsum-based boards to print modular furniture, as studied by Nwokediegwu et al., (2021). Cross-disciplinary applications are also emerging, such as biomedical-grade cement composites for dental and restorative products, illustrating the versatility of polymer integration beyond conventional construction practices.

Overall, the bibliometric themes demonstrate a clear translation of FCB research into real-world applications that address the structural, environmental, and functional requirements of modern construction. From basic structural reinforcement to advanced polymer integration, the industry is progressively adopting FCBs in both conventional and specialized niches (illustrated in Figure 9). These developments suggest that future construction practices will increasingly rely on FCB technology as a sustainable, multifunctional, and performance-driven alternative to traditional building materials.

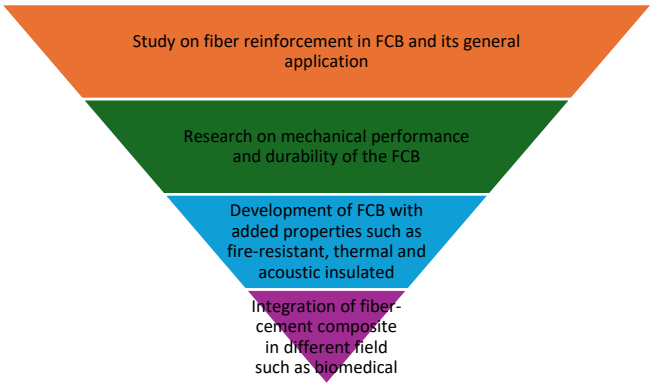


Figure 9: The focus on the research related to FCB.

4.2 Challenges and Limitations in Current Research

Although the bibliometric analysis demonstrates significant progress in FCB research, several challenges and limitations remain evident. These gaps constrain both the academic development of the field and the broader adoption of FCB technology in the construction industry.

Firstly, most experimental studies on FCB performance are conducted under controlled laboratory conditions or in temperate climates, with relatively few investigations in tropical and subtropical environments. Given that high humidity, temperature fluctuations, and termite activity are critical concerns in many developing regions, this represents a substantial research gap. The absence of comprehensive durability testing under these conditions raises questions about the long-term performance of FCBs across diverse geographical contexts. This limitation is particularly significant for Southeast Asia, Africa, and South America, where lower-income communities face increasing demand for affordable, durable, and sustainable housing. In such contexts, FCBs offers notable advantages due to their relatively low production cost, ease of mass manufacturing, and suitability for prefabricated construction. If durability under local climatic conditions can be validated, FCB could play a transformative role in providing low-cost housing solutions and infrastructure in these regions.

While numerous studies focus on mechanical properties and material performance, there is limited research on the full life cycle assessment (LCA) of FCBs. Questions remain regarding embodied energy, recyclability, and end-of-life management. Current claims of FCBs' low environmental impact are largely inferred from the use of alternative or natural raw materials, rather than being supported by comprehensive experimental or empirical LCA studies. This reliance on material-based assumptions without systematic validation weakens the credibility of sustainability claims. In addition, the lack of robust LCA data constrains policymakers and industry stakeholders from accurately quantifying the environmental advantages of FCBs compared to conventional materials such as concrete, steel, and gypsum. Without standardized sustainability metrics, the potential role of FCBs in advancing low-carbon construction remains underexplored.

Although hybrid fiber reinforcement has emerged as a promising research area, current studies often lack standardized methodologies for evaluating fiber–matrix interactions. Variations in fiber type, length, and treatment methods have resulted in inconsistent findings across publications, making it difficult to establish clear design guidelines and performance benchmarks for hybrid FCB systems. Much of this variation stems from the use of different fiber sources depending on regional availability, which, while valuable for local adaptation, complicates global comparability. To ensure that FCBs consistently meet performance requirements regardless of fiber type, developing standardized testing protocols and production criteria is essential. Furthermore, many existing studies remain exploratory in nature, with limited efforts to scale up findings to industrial applications or validate them in real-world construction projects. Thus, greater emphasis should be placed on standardization and performance benchmarking rather than continually diversifying fiber types, ensuring that research outcomes translate into practical, widely applicable benefits for the construction industry and society.

Finally, despite growing interest in artificial intelligence (AI), machine learning, and digital fabrication, the actual implementation of these technologies in FCB research remains limited. Computational models for predicting mix designs or optimizing structural performance are still in the early stages, and their integration with large-scale manufacturing has yet to be realized. This limits the capacity of FCB technology to align with broader Industry 4.0 and smart construction initiatives.

4.3 Policy and Industrial Implications of FCB Research

The increase in research on FCBs carries significant implications for both policy development and industrial practice. As global construction industries face mounting pressure to reduce carbon emissions and adopt sustainable building materials, FCBs represent a viable pathway toward achieving these objectives. However, the translation of research into practice requires alignment among academic advances, policy frameworks, and industrial strategies.

Firstly, the increased focus on sustainability and natural fiber integration in FCB research highlights their potential alignment with internationally recognized green building rating systems such as Leadership in Energy and Environmental Design (LEED), Building Research

Establishment Environmental Assessment Method (BREEAM), and the Green Building Index (GBI) in Malaysia. By incorporating waste-derived fibers and reducing reliance on energy-intensive binders, FCBs contribute to meeting certification requirements in categories such as material sustainability, embodied carbon reduction, and indoor environmental quality. Policymakers may thus encourage FCB adoption by recognizing them explicitly within green procurement guidelines and construction codes.

One recurring gap identified in this study relates to the lack of standardized testing protocols and design benchmarks for hybrid and regionally adapted FCBs. For industry, the absence of such standards creates uncertainty regarding long-term durability, performance, and compliance with structural codes. Regulatory bodies and standards organizations therefore play a crucial role in bridging this gap by developing performance-based criteria that account for diverse fiber sources and ensure consistency in product quality. Establishing internationally recognized standards could accelerate market acceptance and facilitate cross-border trade in FCB products.

From an industrial perspective, the ability of FCBs to be mass-produced at relatively low cost positions them as a strategic material for affordable housing initiatives, particularly in developing countries. By utilizing locally available agricultural residues such as rice husks, coconut coir, or oil palm fibers, industries can lower production costs while simultaneously reducing waste streams. However, large-scale adoption requires industrial investment in automated production technologies, digital fabrication, and quality control systems to ensure that products meet both functional and sustainability benchmarks. Policymakers can incentivize this transition through tax incentives, research grants, and public–private partnerships aimed at advancing green construction technologies.

4.4 Future Directions and Potential Adoption in Malaysia

The future of FCB research and development is likely to be shaped by three key drivers: sustainability, digitalization, and multifunctionality. The push for net-zero construction will continue to encourage the use of alternative reinforcements, bio-based binders, and industrial waste materials. Additionally, the integration of AI, computational modeling, and predictive analytics in FCB design and manufacturing will optimize performance while reducing material waste.

As a rapidly developing nation with a strong construction sector, Malaysia has significant potential for FCB adoption. The country's hot and humid climate necessitates durable, moisture-resistant, and thermally efficient building materials. Given Malaysia's commitment to green building initiatives, the use of FCBs derived from agricultural waste, such as oil palm or bamboo fibers, could align with the nation's sustainability goals. Incorporating FCBs into modular construction, particularly for low-cost housing and industrial applications, could accelerate urban development while maintaining energy efficiency.

Furthermore, Malaysia's growing emphasis on Industry 4.0 and digital construction technologies presents an opportunity to integrate robotic fabrication and AI-driven material optimization into FCB production. Collaborative efforts between academic institutions, industry stakeholders, and policymakers will be crucial in expanding the market for advanced FCB applications in high-rise buildings, prefabricated homes, and climate-resilient infrastructure.

5. CONCLUSION

This study provides a comprehensive bibliometric analysis of FCB research, highlighting key trends, developments, and future directions in the field. The findings underscore the evolution of FCB technology, driven by sustainability, improved mechanical performance, digitalization, and smart material integration. The future of FCB research will depend on advancements in eco-friendly formulations, digital manufacturing techniques, and smart construction applications. Malaysia, with its thriving construction industry and sustainability-focused policies, is well-positioned to adopt and advance FCB technology, ensuring its role in the next generation of resilient and energy-efficient building solutions.

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