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MICROBIAL BIOTECHNOLOGY IN CONCRETE ENGINEERING: A BIBLIOMETRIC AND SCIENTOMETRIC REVIEW

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Abstract:

This bibliometric review maps the evolution of microbial biotechnology in concrete engineering using Scopus records (final stage, English) retrieved on 30 September 2025. After OpenRefine cleaning and harmonisation, 1,732 publications were analysed with VOSviewer (association-strength normalisation; full counting) to construct networks of author keywords, countries, and sources. Publications have accelerated since 2015, with Engineering, Materials Science, and Environmental Science dominating the field. Keyword co-occurrence reveals four clusters centred on MICP mechanisms, durability/self-healing, characterisation methods, and sustainable construction. India, the United States, and China lead in output, while Belgium shows high citation impact. We highlight methodological transparency (query, access date, thresholds) and report gaps in long-term field validation and scale-up strategies. The study provides an evidence-based map of hotspots and collaborations to guide future research on durable, low-carbon concrete.

Keywords:

Self-Healing Concrete, Bacteria, Calcium Carbonate, Cracks, Durability

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Introduction

Microbial biotechnology has surfaced as a promising domain in concrete engineering, providing innovative approaches to improve the durability and sustainability of concrete structures. A key application of microbial technology in this field is the utilization of urease-producing bacteria to facilitate calcium carbonate precipitation, which can efficiently mend cracks in concrete. This mechanism, referred to as microbially induced calcite precipitation (MICP), entails the breakdown of urea by bacteria, resulting in the creation of calcium carbonate that fills and seals the cracks (Chen, 2017; Saridhe & Selvaraj, 2020). The application of Bacillus species, especially Bacillus sphaericus, has demonstrated considerable success in increasing the compressive strength and impermeability of concrete, which in turn enhances its durability (Reddy et al., 2012; Saridhe & Selvaraj, 2020) . Furthermore, enclosing these bacteria in carrier substances such as expanded clay or perlite can prolong their shelf life and enable large-scale utilization (Saridhe & Selvaraj, 2020) .

The use of microbial biotechnology in concrete engineering goes beyond simply fixing cracks. Researchers are creating microbial cements, grouts, polysaccharides, and bioplastics as cost-effective, sustainable, and eco-friendly options to replace traditional construction materials (Ivanov et al., 2015; Ivanov & Stabnikov, 2016). These bio-based substances can be applied in multiple ways, such as soil biogrouting, bioclogging, biocementation, and the biorepair of concrete surfaces (Ivanov et al., 2015; Ivanov & Stabnikov, 2016). The application of microbial technology in building construction enhances the mechanical characteristics of concrete, including its compressive strength and tensile durability, while also supporting sustainable building methods by reducing the need for maintenance and waste of materials (Asgharpour et al., 2024; Stabnikov et al., 2015). The adaptability of microorganisms in improving material characteristics highlights their capability to transform the construction sector (Asgharpour et al., 2024).

Although the outcomes are encouraging, the use of microbial biotechnology in concrete engineering encounters numerous obstacles. The mass production of bacterial concrete necessitates advanced lab facilities for cultivating microorganisms and formulating media, presenting significant technical difficulties (Saridhe & Selvaraj, 2020). Moreover, varying environmental conditions can greatly influence microbial activity and the effectiveness of MICP, creating obstacles for its broad application (Chang et al., 2024) . Researchers are investigating ways to enhance bacterial dosages, treatment conditions, and the incorporation of natural materials or waste products as sources of nutrients and calcium to tackle these challenges (Asgharpour et al., 2024; Chang et al., 2024). Future studies ought to aim at clarifying the intricate relationships between microbial agents and concrete composites, examining their performance over extended periods, and analyzing the environmental and economic viability of using microbial methods in construction (Asgharpour et al., 2024; Chang et al., 2024).

In summary, microbial biotechnology provides a revolutionary approach to concrete engineering by enhancing durability, sustainability, and self-repairing capabilities through processes like MICP and the use of Bacillus species. Although there have been significant

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improvements in terms of strength, crack resistance, and reduced permeability, the large-scale implementation still encounters various technical, environmental, and economic hurdles. Recent research highlights the importance of optimizing bacterial formulations, developing advanced encapsulation techniques, and utilizing sustainable nutrient sources, in addition to conducting long-term performance and life-cycle evaluations, to guarantee reliability in practical applications (Asgharpour et al., 2024; Chang et al., 2024; Gupta et al., 2023).

Research Question

RQ1. What are the trend / What are the research trends in online bacterial concrete according to the year of publication?
RQ2. Who and how much has been published in the area with document by subject area?
RQ3. What are the most cited articles?
RQ4. Map Chart for Document by Countries or Territory
RQ5. What are the popular keywords related to the study?
RQ6: Network visualization map of author keywords or contributing countries

Methodology

Bibliometric analysis involves gathering, organizing, and analyzing bibliographic data from scientific writings. Along with fundamental metrics such as the journals in which works are published, the years they were issued, and the most productive authors, it also employs sophisticated techniques like co-citation analysis to reveal intellectual connections. A comprehensive literature review requires a cyclical process that includes meticulous keyword selection, methodical searching, and detailed evaluation. This procedure enables the creation of an extensive reference framework and guarantees reliable results (Donthu et al., 2021). The current research focused on high-impact publications, as they provide important insights into the theoretical underpinnings of the discipline. To ensure precision, Scopus was selected as the main database due to its extensive coverage and dependability in bibliometric research. (Ng et al., 2025). In addition, to maintain high academic standards, only articles from peer-reviewed journals were considered, whereas books and lecture notes were omitted. Information was sourced from Elsevier's Scopus, targeting publications from 2020 through December 2023, in line with the latest bibliometric methodologies in engineering and materials science research. (Konu Kadirhanogullari & Ozay Kose, 2024; Ramirez Malule et al., 2023).

After extracting the data, OpenRefine was employed to clean and standardize the dataset. This phase was essential for eliminating duplicates, rectifying inconsistencies in author names and affiliations, and aligning variations in journal titles. OpenRefine also facilitated the clustering and transformation of metadata, ensuring that minor discrepancies (like spelling differences or variations in abbreviations) were merged for accuracy. This cleaning process not only bolstered data reliability but also enhanced the precision of bibliometric mapping and visualization.

Data Search Strategy

This study employs a bibliometric approach, utilizing data systematically sourced from the Scopus database, recognized for its comprehensive coverage of peer-reviewed scientific works. Referring to Table 1: The Search String, a specific search query was applied to concentrate the dataset: TITLE-ABS-KEY ("Bacterial" AND "Concrete"). The search results were further refined by limiting them to publications labeled as "final" to exclude articles that are in press or incomplete entries, thereby enhancing the reliability and quality of the analyzed data.

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Additionally, only documents published in English were considered to ensure consistency in interpretation and to avoid language-related biases during the analysis.

The search was executed on 30 September 2025, marking the official date of access for the dataset employed in this paper. A total of 1,732 documents were retrieved from the database for analysis. In bibliometric research, recording the access date and the size of the dataset is crucial, as the contents of databases are continually updated with new publications and citation data. By clearly defining the search query, publication stage, language criteria, access date, and the final dataset size, this study ensures transparency and reproducibility in its data collection methodology. Such thoroughness lays a solid groundwork for further analyses, including the detection of research trends, prolific authors, influential journals, and emerging themes in the domain of bacterial applications in concrete. (Table 2: The selection criterion is searching)

Table 1: The Search String.

Scopus	TITLE-ABS-KEY (Bacterial AND Concrete) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English")) Accees date : 30 September 2025

Table 2: The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Publication Stage	Final	In Press

Data analysis

VOSviewer is an easy-to-use bibliometric tool created by Nees Jan van Eck and Ludo Waltman at Leiden University in the Netherlands. (van Eck & Waltman, 2010, 2017). Commonly used for the visualization and analysis of scientific literature, this tool excels at producing clear network visualizations, grouping related items, and creating density maps. Its adaptability enables the exploration of co-authorship, co-citation, and keyword co-occurrence networks, offering researchers an in-depth view of the research landscape. The user-friendly interface, along with ongoing updates, facilitates the effective and dynamic examination of extensive datasets. VOSviewer's capacity to calculate metrics, personalize visualizations, and its compatibility with a range of bibliometric data sources make it an essential asset for researchers aiming to gain insights into intricate research areas.

One of the key strengths of VOSviewer is its ability to convert complex bibliometric data into easily understandable maps and charts. The software specializes in network visualization, effectively clustering related elements, analyzing patterns of keyword co-occurrence, and creating density maps. Its user-friendly interface allows researchers, whether they are beginners or seasoned professionals, to navigate research landscapes with ease. Ongoing development of VOSviewer ensures it stays at the cutting edge of bibliometric analysis, providing valuable insights through the computation of metrics and customizable visual representations. Its flexibility in handling various types of bibliometric information, such as co-authorship and

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citation networks, makes VOSviewer a versatile and essential tool for scholars aiming to gain a deeper comprehension and meaningful insights within their research fields.

Datasets containing details such as publication year, title, author name, journal, citation, and keywords in PlainText format were acquired from the Scopus database, covering the years from 1961 to December 2025. These datasets were analyzed using VOSviewer software version 1.6.19. By utilizing VOS clustering and mapping techniques, this software enabled the exploration and creation of maps. As an alternative to the Multidimensional Scaling (MDS) method, VOSViewer emphasizes positioning items within low-dimensional spaces, ensuring that the closeness between any two items accurately reflects their relationship and similarity. (van Eck & Waltman, 2010). In this regard, VOSViewer exhibits a resemblance to the MDS method. (Appio et al., 2014). Moving away from MDS, which mainly focuses on calculating similarity metrics like cosine and Jaccard indices, VOS employs a more appropriate approach for normalizing co-occurrence frequencies, including the association strength (ASij), which is determined by the following calculation: (Van Eck & Waltman, 2007):

$$AS_{ij} = \frac{C_{ij}}{w_i w_j}$$

which is "related to the relationship between the observed frequency of co-occurrences of i and j and the anticipated frequency of co-occurrences of i and j, assuming that the co-occurrences of i and j occur independently of each other."

Findings

RQ1. What are the trend / What are the research trends in online bacterial concrete according to the year of publication?

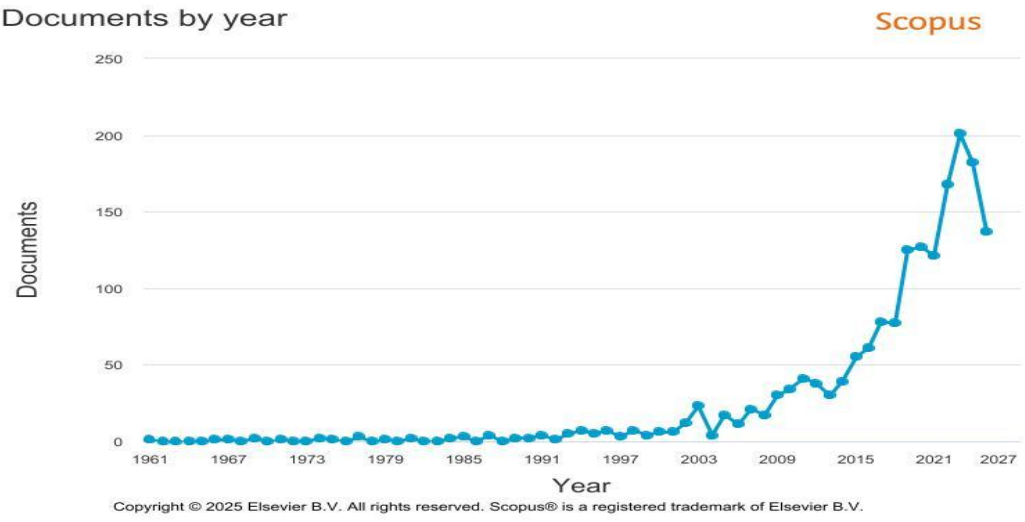

Figure 1: Trend of research in bacterial concrete by years

The publication trend regarding Microbial Biotechnology in Concrete Engineering shows a distinct shift from a specialized research field to a rapidly growing interdisciplinary domain. From 1961 until the early 2000s, the number of publications was very low, typically under 10 per year, indicating a lack of awareness and minimal collaboration between microbiology and

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civil engineering during that period. A significant rise in publications started after 2005, paralleling the increasing global focus on sustainable construction materials and the application of microbial-induced calcite precipitation (MICP) for improving self-healing properties and durability in concrete. Since 2010, there has been a consistent increase in research output, with annual publications reaching between 55 and 78 from 2015 to 2018. This increasing trend suggests that the use of microbes in concrete is moving from preliminary research toward broader acceptance within both academic and engineering sectors.

A notable increase occurred between 2019 and 2023, during which annual publications consistently surpassed 120, reaching a high of 201 papers in 2023. This swift growth can be attributed to a heightened global emphasis on sustainability, circular economy initiatives, and the pressing requirement for climate-resilient infrastructure that aligns with the United Nations Sustainable Development Goals (SDGs). The acknowledgment of microbial biotechnology in concrete as an environmentally friendly substitute for conventional chemical admixtures has fostered collaboration among biologists, material scientists, and engineers. The minor decrease in 2024 (182 publications) and 2025 (137 publications) does not signify a diminished importance; instead, it reflects a phase of stabilization where research focus is transitioning from broad exploratory studies to more specialized applied research, including the genetic modification of bacteria, innovative encapsulation techniques, and extensive field validation. Overall, the data supports the notion that microbial biotechnology has emerged as a crucial element in sustainable concrete innovation, maintaining significance for both academic inquiry and industrial use.

RQ2. Who and how much has been published in the area with document by subject area?

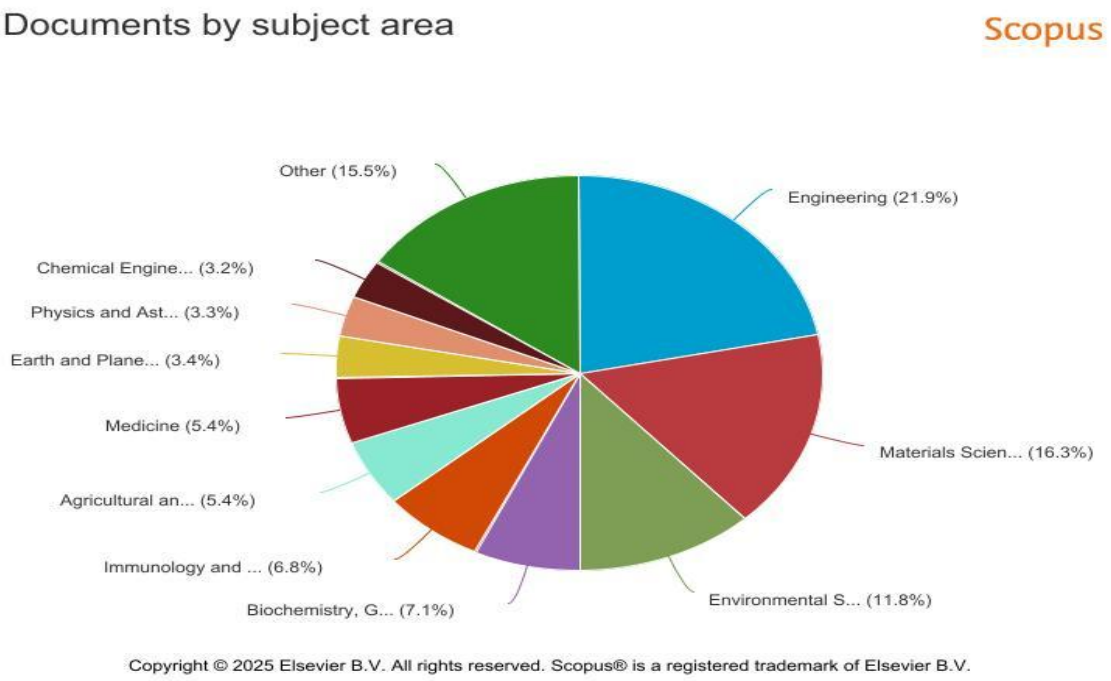

Figure 2: Top Subject Area

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Table 3: Top Subject Area

Num	Subject Area	Number Of Publication	Percentage
1	Engineering	703	22%
2	Materials Science	523	16.30
3	Environmental Science	378	11.8
4	Biochemistry, Genetics and Molecular Biology	228	7.1
5	Immunology and Microbiology	218	6.8
6	Agricultural and Biological Sciences	174	5.4
7	Medicine	173	5.4
8	Earth and Planetary Sciences	109	3.4
9	Physics and Astronomy	105	3.3
10	Others	602	15.5

The analysis of subject area distribution reveals that Engineering (21.9%) and Materials Science (16.3%) are the leading fields in research related to microbial biotechnology applied to concrete, which makes sense given that the main applications pertain to construction technology, materials longevity, and the development of self-healing concrete. In a similar vein, Environmental Science (11.8%) represents a considerable portion, highlighting the growing focus on sustainability, carbon footprint reduction, and eco-friendly practices in the construction sector. These fields illustrate the interdisciplinary nature of microbial concrete research, where engineering advancements need to be paired with environmental factors and material innovations.

The involvement of Biochemistry, Genetics, Molecular Biology (7.1%), and Immunology and Microbiology (6.8%) reinforces the necessity of integrating biological sciences, as comprehending bacterial strains, metabolic processes, and microbial resilience in concrete is vital for progress in this area. At the same time, smaller albeit significant contributions from Agriculture, Medicine, Earth Sciences, and Physics indicate a cross-disciplinary influence, where concepts of microbial biotechnology extend beyond construction into fields like soil stabilization, bioremediation, and biomedical materials. The relatively substantial "Others" category (15.5%) demonstrates the extensive interdisciplinary applications and burgeoning interest from a variety of fields. This distribution emphasizes how microbial biotechnology in concrete has evolved into a multidisciplinary research center, motivated by the demand for lasting infrastructure and global sustainability initiatives.

RQ3. What are the most cited articles?

Table 4: Most cited author

Authors	Title	Year	Source title	Cited by
H.M.(., Jonkers, Henk Marius (Henk) et. al	Application of bacteria as self-healing agent for the development of sustainable concrete. (Chang et al., 2024)	2010	Ecological Engineering	1273

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W., de Muynck, et. al	Microbial carbonate precipitation in construction materials: A review (De Muynck et al., 2010)	2010	Ecological Engineering	1243
V., Wiktor, et. al	Quantification of crack-healing in novel bacteria-based self-healing concrete. (Wiktor & Jonkers, 2011)	2011	Cement and Concrete Composites	983
S., Ahmad, Shamsad et. al	Reinforcement corrosion in concrete structures, its monitoring and service life prediction - A review. (Ahmad, 2003)	2003	Cement and Concrete Composites	956
K., van Tittelboom et. al	Use of bacteria to repair cracks in concrete. (Van Tittelboom et al., 2010)	2010	Cement and Concrete Research	897
J., Wang, Jianyun et. al	Self-healing concrete by use of microencapsulated bacterial spores. (J. Y. Wang, Soens, et al., 2014)	2014	Cement and Concrete Research	874
J., Wang, Jianyun et. al	Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. (J. Wang et al., 2012)	2012	Construction and Building Materials	657
W.D., de Muynck, Willem D.; D., et. al	Bacterial carbonate precipitation improves the durability of cementitious materials. (de Muynck et al., 2008)	2008	Cement and Concrete Research	639
W.D., de Muynck, Willem D.; K., et. al	Bacterial carbonate precipitation as an alternative surface treatment for concrete. (de Muynck et al., 2008)	2008	Construction and Building Materials	538
J., Wang, Jianyun et. al	Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. (J. Y. Wang, Snoeck, et al., 2014)	2014	Construction and Building Materials	504

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RQ4. Map Chart for Document by Countries or Territory

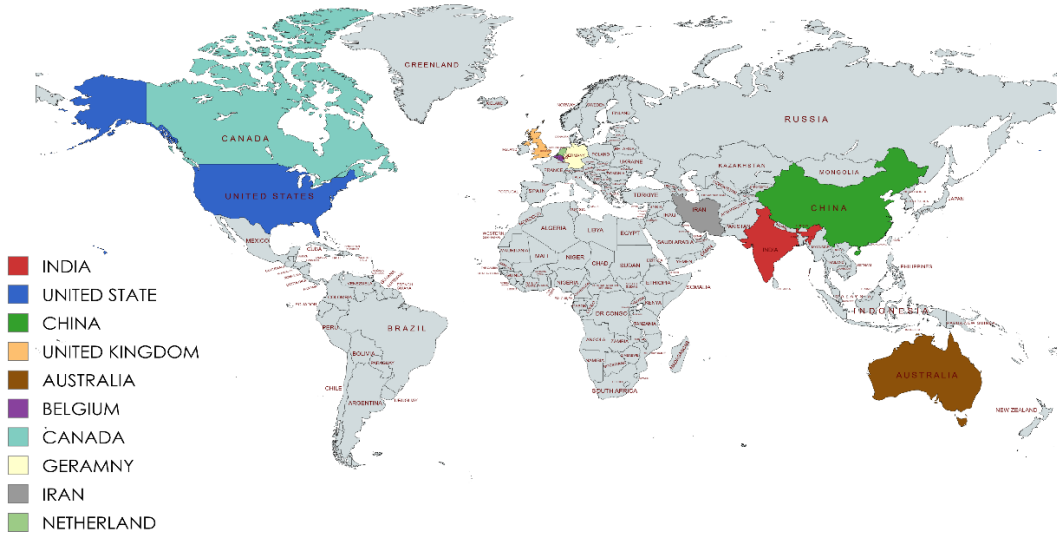

Figure 3: Map Chart for Document by Countries or Territory

Table 5: Document by Countries or Territory

Country/Territory	Citation	Percentage
India	394	22.75
United States	260	15.01
China	237	13.68
United Kingdom	75	4.33
Australia	61	3.52
Belgium	60	3.46
Canada	59	3.41
Germany	53	3.06
Iran	53	3.06

The distribution of citations among countries reveals that India (22.75%), the United States (15.01%), and China (13.68%) are the top contributors to research in microbial biotechnology within concrete engineering, together making up over half of the global output. India's prominence illustrates its increasing investment in sustainable construction methods, extensive infrastructure initiatives, and growing interest in microbial-induced calcite precipitation (MICP) as a cost-effective approach for enhancing the durability and repair of concrete structures. The United States and China also significantly contribute, supported by advanced research facilities, substantial funding for interdisciplinary projects, and a worldwide movement towards eco-friendly construction materials. The involvement of the United Kingdom (4.33%), Australia (3.52%), and Belgium (3.46%) further indicates that both

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developed and developing nations are acknowledging the importance of microbial applications in tackling issues like concrete deterioration, high maintenance costs, and sustainability.

The notable citation shares from countries such as Belgium, Canada, Germany, and Iran (each around 3%) highlight that meaningful contributions are tied not just to quantity but also to research quality and international collaboration. For instance, Belgium has a comparatively modest output but a substantial citation impact, implying that influential research groups are conducting widely acknowledged studies on microbial self-healing concrete. These trends illustrate the interconnectedness of global research ecosystems, with countries contributing from varying angles: India and China in terms of publication volume, the US in technological innovation, and European nations through specialized, high-impact research. The overarching pattern emphasizes the interdisciplinary and international character of microbial biotechnology in concrete engineering, driven by the pressing global need for sustainable, durable, and low-carbon construction materials.

RQ5. What are the popular keywords related to the study?

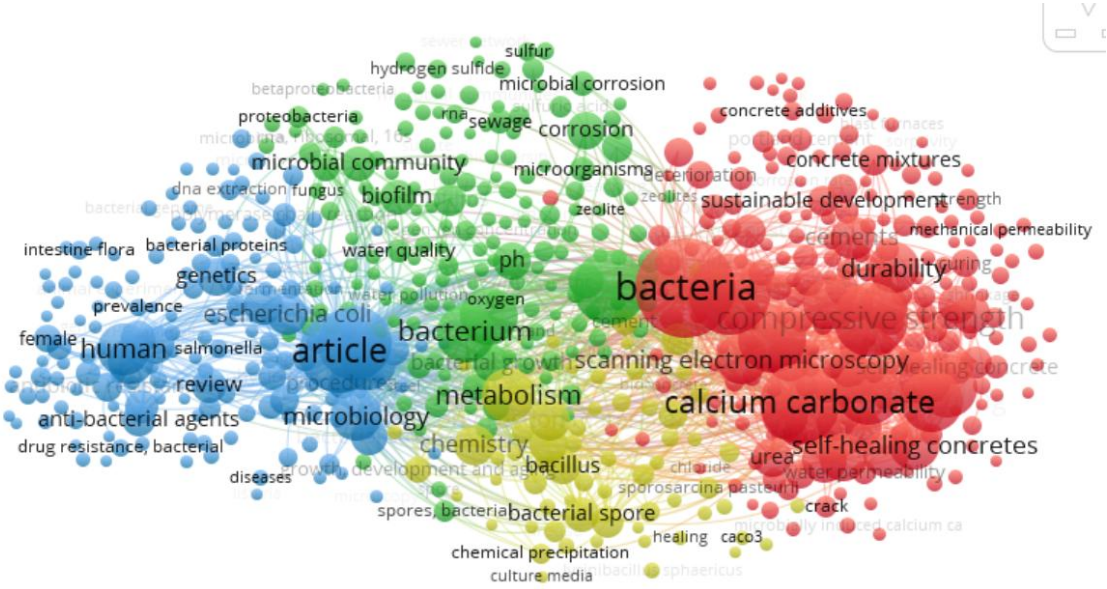

Figure 4: Network Visualization Map Of Keywords' Co-Occurrence

Analyzing the co-occurrence of author keywords is a bibliometric method used to pinpoint the most commonly appearing terms in research articles and how they correlate across the literature. Within VOSviewer, this type of analysis facilitates the visualization of relationships among keywords, with nodes symbolizing terms and links demonstrating co-occurrence in the same publication. The strength of these connections illustrates the frequency of co-appearance, enabling researchers to identify prevailing themes, research hotspots, and interdisciplinary overlaps within a specific area. In the realm of Microbial Biotechnology in Concrete Engineering, keywords like bacteria, calcium carbonate, concretes, and compressive strength highlight the primary focus areas associated with microbial-induced calcite precipitation (MICP), concrete durability, and self-healing mechanisms.

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To create this visualization, the study utilized the full counting approach, which treats each co-occurrence of a keyword pair equally, irrespective of its frequency within a document. A minimum occurrence threshold of 20 was established, filtering the dataset to 249 keywords from an initial total of 14,466, ensuring that only the most significant and impactful terms were included. Furthermore, the minimum cluster size was set to 1, allowing smaller yet relevant research themes to be part of the analysis. As a result of these parameters, four distinct clusters emerged, each representing a thematic grouping such as microbial activity and bacterial strains, concrete materials and durability, bio-mineralization and precipitation processes, and analytical or testing methods.

The results make a substantial contribution to the existing knowledge by emphasizing the multifaceted nature of microbial biotechnology research in concrete engineering. For example, the recurring connection of terms like self-healing, durability, and compressive strength highlights the engineering-driven impetus for implementing microbial solutions, while terms such as Bacillus subtilis, calcite precipitation, and urease indicate the biological processes that support the technology. Additionally, methodological keywords like scanning electron microscopy, X-ray diffraction, and thermogravimetric analysis underscore the significance of characterization tools in confirming microbial processes within concrete. This organized clustering offers researchers a clearer outline of the current research environment, identifies gaps such as scaling up microbial applications, and reinforces the interdisciplinary character of the field, connecting microbiology, materials science, and civil engineering.RQ6: Network visualization map of author keywords or contributing countries

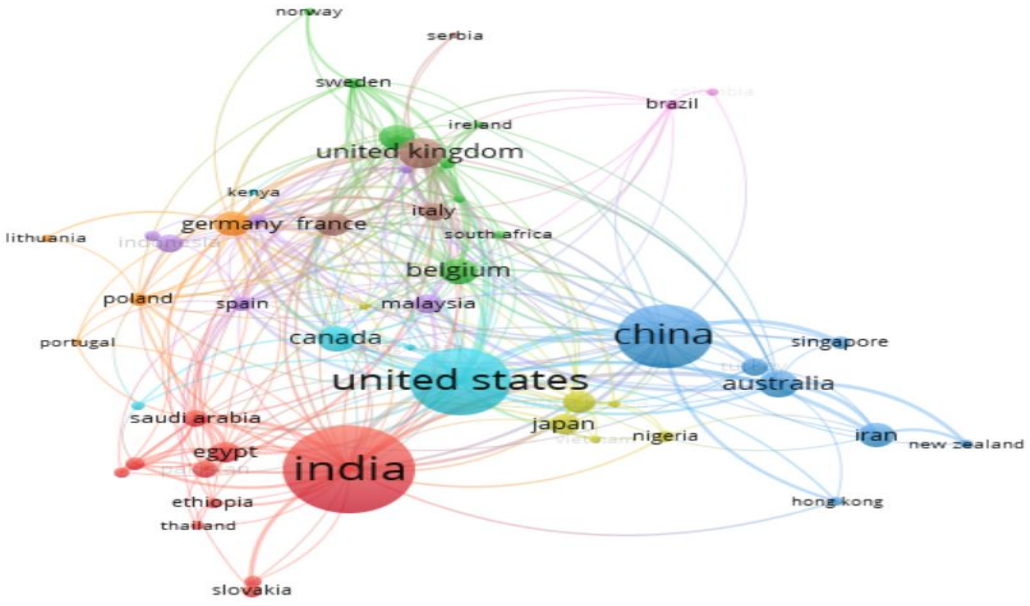

Figure 5: Network Visualization Map of Author Keywords Or Contributing Countries

Co-occurrence analysis of author keywords or contributing nations in VOSviewer is a bibliometric mapping method that emphasizes how frequently items (in this context, nations) appear together in scientific literature. Each nation is represented as a node, with connections between them indicating collaborative research through co-authorship or shared publication contributions. The strength of these connections reflects the degree of collaboration and research connectivity between nations. By examining these patterns, researchers can pinpoint

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global leaders in the field, the geographical spread of expertise, and international partnerships that drive knowledge generation in Microbial Biotechnology within Concrete Engineering.

In this study, the full counting approach was utilized, where every instance of a country in a co-authored publication is assigned equal significance. A minimum threshold of 5 occurrences was established, narrowing the dataset to 53 countries out of 92 identified, ensuring only nations with significant contributions were included in the mapping. The minimum cluster size was set to 1, allowing for the inclusion of all qualifying countries in the visualization. As a result of these parameters, 9 clusters were formed, representing various collaborative research networks. These clusters reveal regional alliances, such as robust networks in Europe (e.g., Belgium, Netherlands, UK, Germany, France), Asia (India, China, Japan, Malaysia), and North America (USA, Canada), demonstrating both localized and intercontinental collaboration.

The results enhance the existing body of knowledge by illustrating the global research landscape and highlighting key contributors in microbial concrete research. India (392 publications, 8789 citations), the United States (261 publications, 7935 citations), and China (235 publications, 7374 citations) emerge as the top contributors in terms of quantity, while Belgium (60 publications, 9368 citations) is notable for having the highest citation impact, signifying high-quality and influential research. These trends illustrate that while some nations lead in productivity, others shine in citation impact, showcasing diverse strengths within the field. The emergence of 9 clusters confirms that microbial biotechnology in concrete engineering is genuinely interdisciplinary and global, benefiting from the exchange of knowledge among communities in engineering, materials science, and microbiology. This reinforces the necessity of nurturing international collaboration to promote sustainable construction technologies on a global scale..

Conclusion

This research aimed to explore the advancement of microbial biotechnology within concrete engineering through a bibliometric analysis, focusing on identifying research patterns, key contributors, significant subject areas, and collaborative networks. Utilizing Scopus as the main database, along with Scopus Analyzer for statistical mapping, OpenRefine for data normalization, and VOSviewer for visualization, a comprehensive review was conducted on a total of 1,732 documents published from 1961 to 2025.

The results indicated a consistent increase in publications after 2005, with a notable surge beginning in 2015, illustrating the growing acknowledgment of microbial-induced calcite precipitation (MICP) and other biotechnological methods as sustainable options in concrete engineering. Engineering, materials science, and environmental science were found to be the leading subject areas, showcasing the interdisciplinary nature of the domain. India, the United States, and China emerged as the most prolific countries, while Belgium distinguished itself with a significant citation impact, reflecting the global importance of the research. The analysis of keyword co-occurrence generated thematic clusters that highlighted durability, self-healing mechanisms, and advanced characterization techniques, showcasing both scientific depth and practical relevance.

This research offers a summarized insight into the development and trajectory of microbial biotechnology in concrete, thereby enhancing the comprehension of its research landscape. The findings highlight the synergy between biology and engineering in creating eco-efficient

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materials and emphasize its practical potential in tackling urgent sustainability issues. The outcomes provide important information for policymakers, engineers, and scientists to align future research with real-world applications, especially in the context of climate-resilient infrastructure and sustainable construction practices.

However, certain limitations persist, such as dependence on a single database and possible exclusion of literature not in English. Future studies might integrate various databases, broaden the focus to include patents and industrial reports, and examine long-term field applications of microbial concrete. In conclusion, the bibliometric method utilized in this research illustrates its importance as a resource for charting intellectual developments, pinpointing research deficiencies, and steering future progress. The advancement of microbial biotechnology in concrete engineering signifies not just an academic endeavour but also a proactive measure in creating durable, cost-efficient, and sustainable materials for the construction sector.

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