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Original Article

Mapping the Innovation–Implementation Gap in Sustainable Construction Materials: Global Trends, Knowledge Structures, and Translational Priorities

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Abstract

Background: *The construction industry is a major contributor to global carbon emissions and resource depletion. Although sustainable construction materials (SCMs) support climate mitigation and circular development, implementation-related research remains less explored despite advances in material innovation and laboratory validation.*

Methods: *This study employed a bibliometric analysis of SCM research indexed in Lens.org from 2010 to 2025. Bibliometric mapping and performance analyses were conducted using Biblioshiny/Bibliometrix (R package) and VOSviewer to examine publication trends, collaboration networks, citation structures, and thematic evolution.*

Results: *A total of 9,601 eligible records were analyzed. SCM research expanded rapidly, with a 23.95% annual growth rate, an average document age of 4.94 years, and 22.38 citations per document. Research outputs were led by China, the United States, Australia, India, and the United Kingdom. Influential journals and studies focused on geopolymers, alkali-activated materials, recycled aggregates, fly ash, durability, and low-carbon cement alternatives. Keyword co-occurrence and thematic analyses highlighted compressive strength, microstructure, durability, geopolymers, and circular economy, while regulation, standardization, scalability, and industry adoption remained underexplored.*

Conclusion: *SCM research has expanded rapidly but remains dominated by studies of material performance and sustainability. Implementation-related themes remain underrepresented, indicating an imbalance between material innovation and practical deployment in the construction sector.*

Keywords

sustainable construction materials, bibliometric analysis, innovation-implementation gap, circular economy, green materials, construction sustainability, UN SDG 9, industry, innovation and infrastructure

INTRODUCTION

The construction sector is among the most resource-intensive industries globally, accounting for approximately 37% of energy-related carbon dioxide emissions and consuming more than half of all extracted raw materials worldwide, thereby exerting substantial pressure on ecological systems and climate stability (International Energy Agency [IEA], 2023; United Nations Environment Programme [UNEP], 2022). In response to these environmental challenges, Sustainable Construction Materials (SCMs) have emerged as a major research and industrial priority within the broader transition toward low-carbon and circular construction systems. SCMs may be broadly defined as construction materials designed to reduce environmental burdens across their life cycle while maintaining structural functionality, durability, safety, and economic feasibility. These materials commonly incorporate recycled, renewable, low-carbon, or waste-derived components intended to minimize embodied energy, greenhouse gas emissions, landfill accumulation, and raw material extraction. Representative examples include geopolymers, recycled aggregates, alkali-activated binders, bio-based composites, agricultural-waste-derived binders, and low-carbon cement alternatives (Pacheco-Torgal et al., 2020; Provis, 2018; Scrivener et al., 2018). Beyond material substitution, SCMs are increasingly positioned within broader sustainability agendas involving circular economy integration, resource efficiency, and climate-resilient infrastructure systems.

Despite substantial advances in material innovation, the transition of SCMs from laboratory-scale experimentation to large-scale implementation within the construction industry remains limited and fragmented. Numerous studies have demonstrated promising compressive strength, durability, thermal performance, and environmental advantages under controlled experimental conditions; however, the commercial adoption and institutional integration of these materials remain inconsistent across regions and construction sectors (Ding et al., 2018). This disconnect is increasingly conceptualized as an innovation–implementation gap, referring to the disparity between technological advancement and practical deployment. Multiple structural barriers contribute to this challenge, including limited standardization frameworks, regulatory uncertainty, fragmented procurement systems, cost-risk perceptions, conservative industry culture, and insufficient coordination among researchers, policymakers, manufacturers, and practitioners (Darko et al., 2017; Hossain et al., 2020). Consequently, while SCM innovation continues to accelerate academically, its translation into mainstream construction practice remains comparatively slow.

Existing literature on SCMs can generally be categorized into three major streams. First, technical and engineering-oriented reviews primarily focus on material properties and laboratory validation, including compressive strength, microstructure, durability, embodied carbon reduction, thermal performance, and life-cycle assessment of alternative construction materials such as geopolymers and recycled concrete systems (Provis, 2018; Scrivener et al., 2018). Second, sustainability-oriented reviews examine broader conceptual frameworks associated with green buildings, circular economy strategies, environmental assessment systems, and sustainable construction governance (Pomponi & Moncaster, 2017). While these studies provide important technical and environmental insights, they largely emphasize performance optimization and sustainability assessment rather than implementation pathways or knowledge diffusion structures. Third, bibliometric studies on construction sustainability have emerged in increasing numbers, focusing on topics such as green buildings, circular construction, concrete technologies, low-carbon materials, and sustainable built environments. However, these bibliometric investigations often remain narrowly material-specific, concentrated on geopolymers, concrete systems, or green-building frameworks, while giving limited attention to the broader ecosystem of SCM innovation and implementation dynamics.

More importantly, previous bibliometric studies have seldom examined whether implementation-oriented concepts such as adoption, regulation, standardization, procurement, commercialization, scalability, and research-to-practice integration occupy meaningful positions within the intellectual structure of SCM research. Most existing bibliometric analyses primarily emphasize publication growth, citation performance, or thematic clustering related to sustainability and material performance without critically evaluating the structural imbalance between technical innovation and deployment-oriented research. Furthermore, many prior studies rely predominantly on Scopus or Web of Science databases, which, although highly influential, provide comparatively limited integration of broader innovation-linked metadata and interdisciplinary indexing. In contrast, Lens.org offers expanded integration of scholarly outputs, citation relationships, institutional affiliations, and innovation-linked research ecosystems, making it particularly well-suited to examining research-to-practice dynamics and interdisciplinary knowledge diffusion in sustainable construction materials research.

Accordingly, this study addresses these gaps by conducting a bibliometric analysis of SCM research with explicit emphasis on the research–practice divide and innovation–implementation dynamics. Using Lens.org-indexed publications as the primary data source, this bibliometric study examines the global research landscape of the field by mapping publication trends, identifying influential journals, authors, institutions, and countries, and analyzing collaboration and intellectual structures through citation and co-citation networks. It also investigates the evolution of themes and keyword relationships to assess whether implementation-oriented concepts remain underrepresented compared with the dominant focus on laboratory-based research on material performance. By integrating performance analysis with conceptual and thematic mapping, this study seeks to provide evidence-based insights into how current research priorities may influence the translation of sustainable construction materials from experimental innovation toward broader construction-industry adoption and policy integration.

METHODS

Study design

This paper employed a bibliometric analysis approach to analytically map research output on sustainable construction materials and identify structural patterns influencing innovation adoption and acceptance. The bibliometric analysis quantifies and illustrates publication growth, citation impact, collaboration networks, and thematic development, offering a comprehensive and visualized overview of research directions. This approach generates historical patterns, structural arrangements, leading research themes, journal impacts, and citation landscape (Donthu et al., 2021). Furthermore, in an era marked by the rapid growth of scientific output, bibliometric analysis is an indispensable tool for understanding the dynamics of research fields (Hassan et al., 2024).

Data sourcing and specifications

This bibliometric review utilized Lens.org as the primary bibliographic database for data extraction and analysis. Lens.org was selected for its broad interdisciplinary coverage, integration of scholarly and innovation-linked metadata, and transparent citation indexing, making it well-suited to examining the evolution of sustainable construction materials (SCMs) research across the engineering, sustainability, and construction domains (Penfold, 2020). Compared with traditional databases such as Scopus and Web of Science, Lens.org additionally enables broader mapping of institutional linkages, interdisciplinary diffusion, and research-development trajectories relevant to sustainable construction research.

To minimize retrieval bias and ensure that the dataset represented the broader SCM research landscape rather than only implementation-focused studies, a two-tier retrieval strategy was adopted. First, the primary search strategy broadly captured literature on sustainable construction materials using material-, sustainability-, and construction-oriented terminology, without requiring implementation-related concepts. The Boolean search string included the following terms:

> ("sustainable construction material*" OR "green construction material*" OR "eco-friendly construction material*" OR "low-carbon construction material*" OR "alternative construction material*" OR "recycled aggregate*" OR geopolymer* OR "alkali-activated material*" OR "bio-based construction material*" OR "supplementary cementitious material*" OR "low-carbon concrete" OR "green concrete") AND (construction OR building OR "built environment" OR concrete OR cement)

The search was applied to article titles, abstracts, and author keywords to maximize retrieval sensitivity while maintaining thematic relevance. Following corpus retrieval, implementation-oriented concepts such as implementation, adoption, standardization, commercialization, scalability, deployment, procurement, regulation, barriers, and industry practice were examined during thematic and keyword-network analyses rather than during initial data extraction. This approach enabled a more neutral representation of the broader SCM knowledge structure and reduced the risk of pre-filtering the literature toward implementation-focused publications. Consequently, the study evaluated whether implementation-related themes occupied central or peripheral positions within the overall research landscape.

The temporal scope of the analysis covered publications from 2010 to 2025. Although preliminary searches initially identified records indexed for 2026, these records were excluded from the final analysis because citation accumulation and annual productivity for the current indexing year remain incomplete and may distort longitudinal bibliometric interpretation. Restricting the analysis to completed publication years improved temporal consistency and ensured more reliable trend analysis.

Eligible document types included only peer-reviewed journal articles. Book chapters, conference proceedings, editorials, notes, errata, and other non-peer-reviewed materials were excluded to maintain methodological consistency and scholarly rigor. Only English-language publications at the final publication stage were included. All retrieved records were exported as CSV files for bibliometric processing and visualization using Biblioshiny (the Bibliometrix package in RStudio) and VOSviewer.

Table 1. *Data Requirements of the Bibliometric Study*

Category	Specific standard requirements
Database	Lens.org
Search String	("sustainable construction material*" OR "green construction material*" OR "eco-friendly construction material*" OR "low-carbon construction material*" OR "alternative construction material*" OR "recycled aggregate*" OR geopolymer* OR "alkali-activated material*" OR "bio-based construction material*" OR "supplementary cementitious material*" OR "low-carbon concrete" OR "green concrete") AND (construction OR building OR "built environment" OR concrete OR cement)
Search category	Article title, abstract, keywords
Time frame	January 01, 2010 to December 31, 2025
Document type	Journal articles
Source type	Journals
Language	English
Publication stage	Final
Data export format	CSV

Data screening

The study followed a PRISMA-informed screening workflow to ensure transparency and reproducibility of record selection (Figure 1). An initial search of the Lens.org database retrieved 56,050 records. After removal of records indexed outside the finalized study period (2010–2025), 31,651 records remained for screening. Two researchers independently reviewed titles, abstracts, keywords, and source information to assess thematic relevance and eligibility. Disagreements during screening were resolved through discussion and consensus. During eligibility assessment, 5,309 records were excluded based on predefined criteria. An additional 16,741 records were excluded because they did not directly address sustainable construction materials within the context of construction, building systems, concrete technologies, or sustainable built-environment applications. Publications focused exclusively on unrelated environmental technologies, energy systems, or non-construction industrial materials were excluded to maintain thematic specificity and prevent conceptual dilution of the dataset.

Following the screening process, 9,601 records satisfied all inclusion criteria and were retained for the final bibliometric analysis. The PRISMA-style flow diagram includes all major stages of record identification, screening, eligibility assessment, exclusion categories, and final inclusion to ensure methodological transparency and reproducibility.

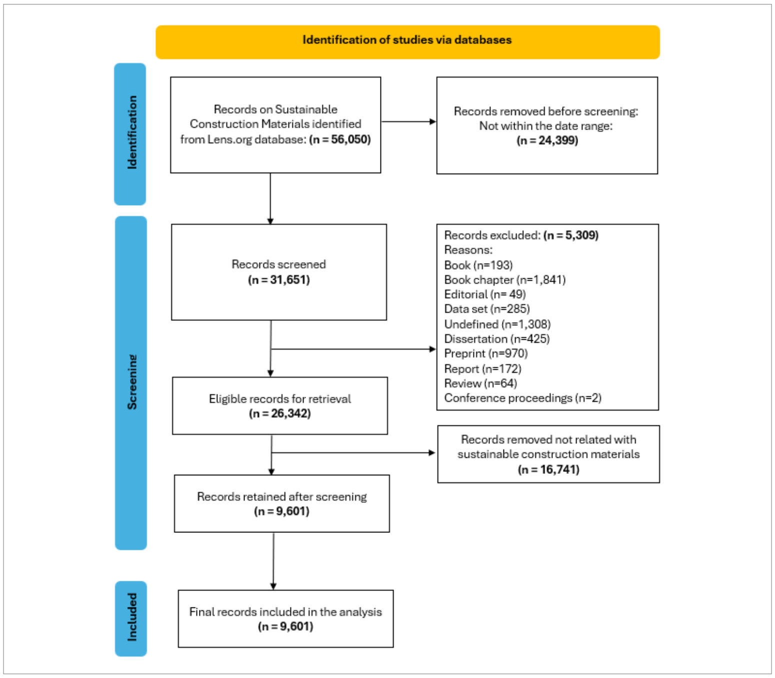

Figure 1. *PRISMA Flowchart of the Bibliometric Analysis in SCM Research*

Data cleaning and harmonization

To ensure data accuracy and validity, a manual data cleaning was conducted in the extracted dataset. The dataset was cleaned by deduplicating records, standardizing author and institutional names, and manually harmonizing keywords using a curated thesaurus. Minimum thresholds were applied for network analyses (≥5 keyword occurrences and ≥10 institutional publications) to reduce noise and improve interpretability. It also involved removing keyword artifacts and harmonizing terms using a manually curated synonym file (.txt), enabling consistent keyword merging and improved analysis accuracy. In addition, manual screening of titles and abstracts was conducted to remove irrelevant records (e.g., studies unrelated to SCM despite keyword overlap), thereby addressing database noise.

Data analysis

Bibliometric analysis was primarily used in this study, employing multiple software tools to enhance data visualization and interpretation. It provides a complete quantitative framework for assessing large volumes of scholarly literature, allowing systematic evaluation of research performance and the evolution of a given research domain (Phoong et al., 2022). In the context of sustainable construction materials, this approach provides a means to critically assess the persistent disconnect between laboratory-scale innovation and real-world implementation, often described as the innovation–implementation gap (Markard et al., 2012). Data processing and descriptive bibliometric indicators were performed using Biblioshiny, an open-source web interface for the bibliometrix R package, implemented in RStudio (version 4.4.0). Biblioshiny supports comprehensive analytical workflows, including performance analysis, citation metrics, conceptual structure mapping, and thematic evolution assessment (Aria & Cuccurullo, 2017). Complementarily, VOSviewer (version 1.6.20), a Java-based visualization tool specifically designed for constructing and exploring bibliometric networks, was utilized to generate graphical representations of co-authorship, keyword co-occurrence, citation, bibliographic coupling, and co-citation relationships (Van Eck et al., 2014). The combined application of these tools enabled methodological triangulation, integrating quantitative indicators with network visualization to reveal both structural and conceptual dimensions of the field. Through this integrated bibliometric approach, the study elucidates structural knowledge gaps and emerging directions necessary to bridge sustainable material innovation with field-level application.

RESULTS

Table 2 presents a detailed summary of the bibliometric dataset spanning 16 years (2010–2025) and comprising 9,601 documents indexed across 525 sources, reflecting a broad and multidisciplinary knowledge base within the study domain. The field demonstrates a high annual growth rate of 23.95%, indicating rapidly increasing scholarly attention and suggesting that the topic has gained substantial momentum in recent years. The average document age of 4.94 years highlights the research area's relative novelty and evolving nature, while an average of 22.38 citations per document suggests moderate to strong academic impact, indicating that the research community actively engages with published works. A total of 162,284 references were cited across the dataset, underscoring extensive intellectual grounding and cross-fertilization of ideas. Authorship patterns reveal a highly collaborative research landscape. The dataset includes 20,120 authors, of whom only 466 are single-authored. The average of 4.44 co-authors per document further evidences a strong collaborative culture, likely driven by the interdisciplinary and applied nature of the topic. This trend aligns with contemporary research practices emphasizing team-based approaches and cross-institutional expertise. These structural attributes provide a solid foundation for subsequent performance analysis, thematic mapping, and network visualization.

Table 2. *Description of the Bibliometric Data of SCM Research*

Description	Results
Timespan	2010:2025
Sources	525
Documents	9,601
Annual growth rate %	23.95
Document average age	4.94
Average citations per document	22.38
References	162,284
Index keywords	14,008
Author’s keywords	14,008
Authors	20,120
Single-authored documents	466
Co-authors per document	4.44
Journal Article	9601

Annual scientific production

TThe annual publication trend shown in Figure 2 reveals a strong and sustained growth trajectory in research on sustainable construction materials from 2010 to 2025. The production grew steadily from 53 publications in 2010 to 177 in 2015, indicating the field's emergence and gradual development. A more pronounced increase was observed between 2016 and 2019, during which the number of annual publications rose from 304 to 647, reflecting growing scholarly interest in sustainable construction materials. The most significant growth occurred from 2020 to 2022, with publication output increasing sharply from 941 to a peak of 1,459 documents. This period reflects not only growing academic attention, but also a broader alignment of research on sustainable construction materials with global sustainability agendas, particularly the adoption of the United Nations' Sustainable Development Goals (SDGs) in 2015.

Meanwhile, the number of publications declined to 1,043 in 2023, but the field quickly regained momentum, reaching 1,092 publications in 2024 and 1,328 in 2025. Overall, the publication trend demonstrates the rapid expansion and increasing maturity of SCM research, suggesting that sustainable construction materials have become a major and continuously evolving area of scientific inquiry.

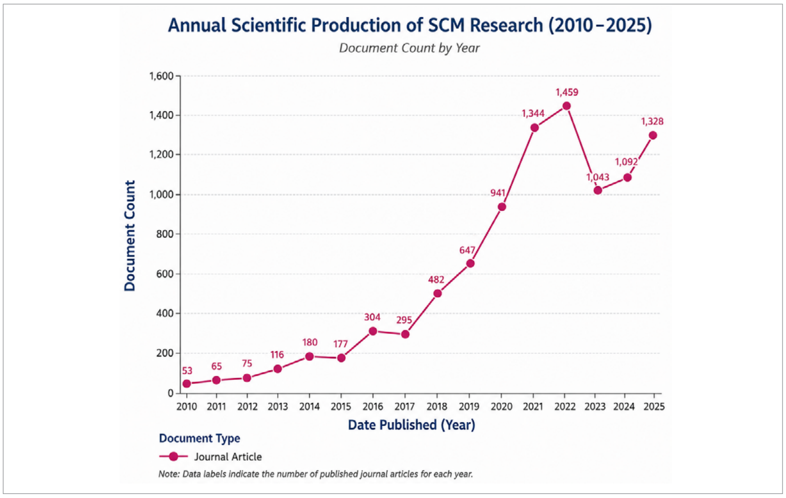

Figure 2. *Annual Scientific Production of SCM Research*

Geographic distribution of research outputs

Figure 3 shows the global distribution of Sustainable Construction Materials (SCM) research, highlighting broad international participation while revealing a concentration of outputs among a few leading countries. China dominated the field with 1,756 publications, followed by the United States (558), Australia (446), India (369), and the United Kingdom (329). The presence of top-performing countries from Asia, North America, Europe, and Oceania demonstrates the worldwide relevance of sustainable construction research. Moreover, contributions from countries across South America, the Middle East, and other parts of Europe indicate that SCM has become a globally recognized research area. This widespread geographic distribution reflects the shared global commitment to developing sustainable, resource-efficient, and environmentally responsible construction materials and practices. This widespread institutional engagement suggests a cross-border consensus on the importance of the research area.

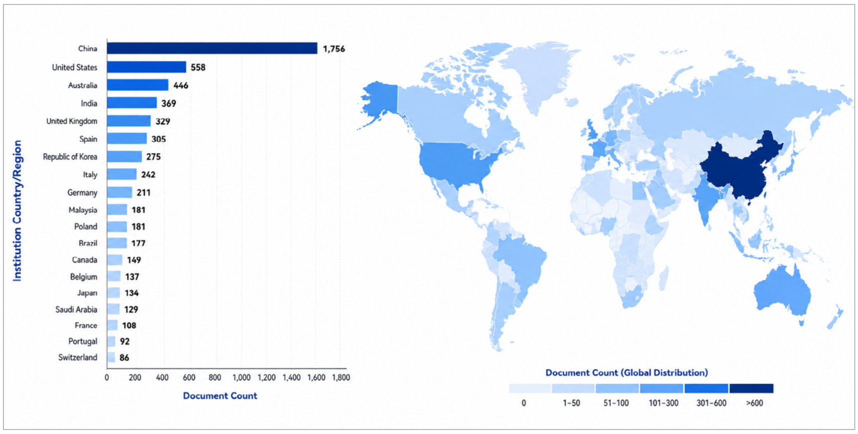

Figure 3. *Geographic Distribution of Research Outputs*

In the United States, initiatives such as the Inflation Reduction Act and the Buy Clean Program have spurred research into low-carbon and environmentally sustainable building materials. At the same time, Australia has advanced circular-economy strategies and pioneered research on geopolymer concrete and the use of industrial by-products in construction. These supportive policy environments, coupled with strong university–industry collaborations, have contributed to the high research productivity and influence of both countries in the SCM field (Heeren et al., 2025; Hossain et al., 2020; Provis, 2018).

Leading journal and sources

Table 3 presents the leading and most impactful journals on sustainable construction materials, along with their innovation and application gaps. Evaluated using h-index, g-index, m-index, total citations (TC), number of publications (NP), and publication start year (PY). Materials emerges as the most influential journal, ranking highest in h-index (93) and g-index (132), and recording the largest publication volume (NP = 3,072) and total citations (TC = 63,985) since 2013. Its elevated m-index (6.643) further indicates rapid citation accumulation, underscoring its central role in shaping recent scholarly discourse. Followed by Sustainability demonstrates comparable intellectual influence (h-index = 92; g-index = 108) despite a substantially lower publication count (NP = 963), reflecting higher average citation impact per article and a longer engagement with the topic beginning in 2010. Similarly, Materials and Structures shows strong performance (h-index = 69; g-index = 117) with moderate output, positioning it as a specialized but impactful venue.

Notably, Advances in Materials Science and Engineering exhibits a high m-index (3.333) despite its late entry in 2018, signaling accelerated visibility and citation uptake, characteristic of rapidly expanding interdisciplinary platforms. The distribution reveals a concentration of scholarly influence within multidisciplinary, open-access journals, highlighting how broad-scope platforms now dominate knowledge diffusion in this field. This pattern suggests that research on sustainable construction materials is increasingly situated at the intersection of materials science, sustainability, and built-environment studies, reinforcing the field's interdisciplinary maturation.

Table 3. *Most Impactful Journals in SCM Research*

Rank	Journal	Country	h-index	g-index	M-index	TC	NP	PY
1	Materials	Switzerland	93	132	6.643	63,985	3072	2013
2	Sustainability	Switzerland	72	108	4.235	25,956	963	2010
3	Materials and Structures	Netherlands	69	117	4.059	15,691	281	2010
4	Waste Management (New York, N.Y.)	United States	50	80	2.941	6,440	84	2010
5	International Journal of Concrete Structures and Materials	South Korea	39	71	2.294	5,413	122	2010
6	Journal of Hazardous Materials	Netherlands	39	51	2.294	4,897	51	2010
7	Structural Concrete	Belgium	37	54	2.313	4,731	267	2011
8	Minerals	Switzerland	33	48	2.538	3,586	179	2014
9	The Science of the Total Environment	Netherlands	33	45	1.941	4,287	45	2010
10	Advances in Materials Science and Engineering	Egypt	30	46	3.333	3,336	187	2018

**TC - total citations; NP - number of publications; PY – publication start year*

Leading Institution

Figure 4 illustrates the top-contributing institutions in sustainable construction materials (SCM) research, as measured by the number of publications. Tongji University emerges as the most productive institution, with approximately 150 documents, significantly outperforming all others. It is followed by Southeast University (109 publications) and the Spanish National Research Council (CSIC) (104 publications). Other notable contributors include Central South University, Curtin University, Harbin Institute of Technology, and Wuhan University of Technology, each producing between 80 and 95 publications. The dominance of these institutions indicates their strong research capacity, established expertise, and sustained commitment to advancing sustainable construction materials.

A closer examination reveals the prominence of Chinese universities, with more than half of the top 20 institutions originating in China. This finding aligns with China's substantial investments in infrastructure development, green construction technologies, and sustainability research. Meanwhile, institutions from Europe, Australia, the Middle East, and South Asia, such as Ghent University, Delft University of Technology, RWTH Aachen University, King Saud University, and Islamic Azad University, demonstrate the global and multidisciplinary nature of SCM research. The participation of these institutions highlights the widespread recognition of sustainable materials as a critical solution to environmental challenges in the construction sector.

The distribution also suggests a concentration of scientific productivity within a relatively small group of highly active institutions. Such concentration often reflects the presence of specialized research centers, advanced laboratory facilities, strong international collaborations, and access to substantial research funding. Institutions with high publication outputs frequently serve as knowledge hubs, influencing research directions and establishing methodological standards within the field.

From a practical perspective, the findings imply that future collaborations, benchmarking initiatives, and research partnerships in sustainable construction materials may benefit from engaging with these leading institutions. Their strong publication records indicate not only high research productivity but also significant influence on the generation and dissemination of knowledge. Consequently, these institutions are likely to continue shaping innovations in low-carbon materials, waste valorization technologies, and sustainable construction practices, thereby driving the global transition toward a more environmentally responsible construction industry.

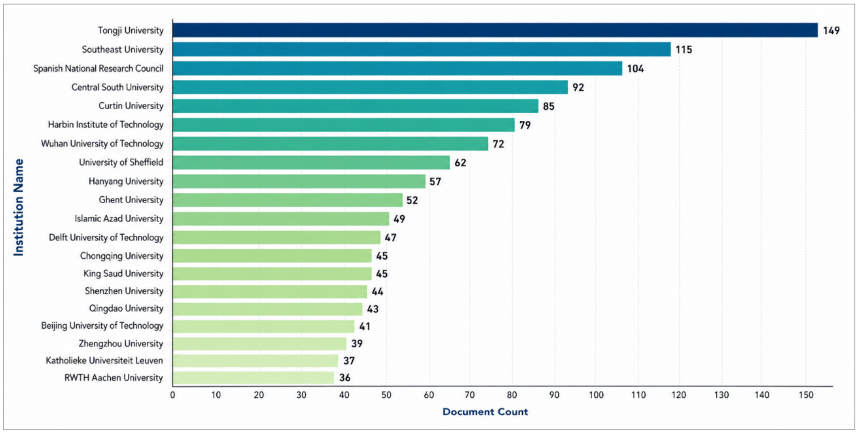

Figure 4. *Leading Institution in SCM Research*

Most cited documents

Table 4 presents the most-cited documents in the sustainable construction materials literature, ranked by total citations (TC), citations per year (TC/year), and normalized citation impact. Moreover, sustainable construction materials (SCM) research reveals that the development of low-carbon cement alternatives, recycled construction materials, and durable, sustainable concrete systems primarily drives the field. The highest-cited publications, particularly those by Provis on alkali-activated materials and geopolymers, dominate the citation landscape with 1,758 and 1,428 citations, respectively, highlighting their role as foundational works in reducing dependence on ordinary Portland cement. Their high normalized citation scores further indicate sustained influence and continued relevance in advancing environmentally friendly construction technologies.

A second major research focus is the circular utilization of industrial and construction wastes, as evidenced by highly cited studies on coal fly ash and recycled concrete aggregates. The article on coal fly ash utilization exhibits the highest normalized citation impact (14.96), reflecting growing interest in waste valorization and circular economy practices. Meanwhile, influential studies on blended cements, durability of alkali-activated materials, and ultra-high-performance concrete demonstrate the field's progression from material innovation toward ensuring long-term performance and practical implementation. Collectively, these highly cited works indicate that SCM research is increasingly focused on developing sustainable, durable, and commercially viable materials that can significantly reduce the construction industry's environmental footprint.

Further observed that normalized citation scores reveal recent high-impact contributions alongside established materials science benchmarks, indicating both thematic diversification and emerging impact. In general, the table shows that while materials innovation dominates citation leadership, comparatively fewer top-cited papers address regulatory integration or large-scale construction practice, reinforcing the broader bibliometric pattern of a persistent innovation-to-adoption gap within sustainable construction research.

Table 4. *Top 10 Most Cited Articles in SCM Research*

Rank	Article Title & Authors	Journal	TC	TC per year	Norm. TC
1	Alkali-activated materials John L. Provis	Cement and Concrete Research	1,758	195.33	10.91
2	Geopolymers and related alkali-activated materials Provis et al.	Annual Review of Materials Research	1,428	109.85	12.42
3	The pore solution of blended cements Vollpracht et al.	Springer Nature	503	41.92	11.91
4	Progressive utilization prospects of coal fly ash Gollakota et al.	Science of the Total Environment	497	62.13	14.96
5	Recycled concrete aggregates Mcneil et al.	International Journals of Concrete Structures and Materials	488	34.86	6.97
6	Durability of alkali-activated materials: progress and perspectives Bernal et al.	Journal of the American Ceramic Society	472	36.31	6.95
7	Influence of field recycled coarse aggregate on properties of concrete Rao et al.	Materials and Structures	458	26.94	4.60
8	Recycled concrete as aggregate for structural concrete production Malesev et al.	Sustainability	450	26.47	4.52
9	Ulta-high performance concrete: mechanical performance, durability, sustainability and implementation challenges Abbas et al.	International Journal of Concrete Structures and Materials	445	40.45	9.40
10	Chemical research and climate change as drivers in the commercial adoption of alkali activated materials Deventer et al.	Waste and Biomass Valorization	442	26.00	4.44

**TC - total citations*

Co-Authorship analysis

Figure 5 presents the co-authorship network illustrating a collaborative research structure within the field of sustainable construction materials, characterized by several interconnected author clusters. The largest cluster, centered on Jianzhuang Xiao, John L. Provis, and Susan A. Bernal, demonstrates strong and consistent co-authorship ties, indicating an established research team actively advancing sustainable and alternative construction materials. The dense connections within this cluster suggest frequent scholarly collaboration, which is essential in addressing complex issues related to material innovation, durability, and environmental sustainability in construction research.

Other significant collaborative groups are led by Muhammad Nasir Amin and Mohd Mustafa Al Bakri Abdullah, both of which exhibit cohesive co-authorship relationships and active research productivity. These clusters likely focus on emerging sustainable materials such as geopolymer concrete, recycled aggregates, and industrial waste-based binders, reflecting the growing global interest in eco-friendly construction solutions. The presence of multiple clusters highlights the multidisciplinary nature of sustainable construction materials research, where collaboration among researchers enhances knowledge sharing, methodological development, and technological innovation.

Although the network demonstrates strong collaboration within individual clusters, inter-cluster connections remain relatively limited, suggesting that the research field is still partially fragmented. A few bridging authors play a crucial role in linking separate research communities, thereby facilitating international cooperation and broader dissemination of scientific knowledge. Overall, the co-authorship pattern indicates that sustainable construction materials research is driven by key collaborative hubs that significantly advance sustainable engineering practices and the global transition toward environmentally responsible construction technologies.

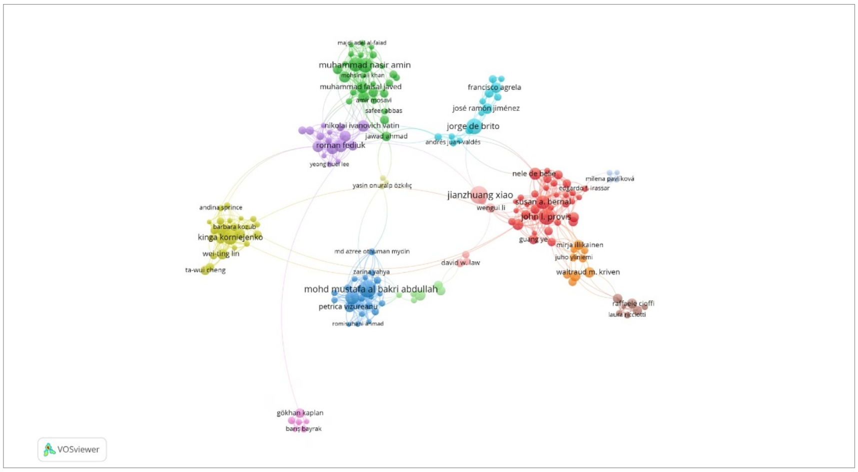

Figure 5. *Co-authorship Network in SCM Research*

Keywords co-occurrence analysis

The keyword co-occurrence network (Figure 6) in sustainable construction materials (SCM) demonstrates a highly interconnected and multidisciplinary research landscape dominated by themes related to geopolymer, compressive strength, mechanical properties, and microstructure. These keywords occupy central positions with large node sizes, indicating their high frequency and strong conceptual relevance within the field. The prominence of terms such as recycled aggregate, construction and demolition waste, circular economy, and recycling reflects the increasing scholarly focus on sustainable resource utilization and waste valorization in construction materials research. The dense linkages among these nodes suggest that current SCM studies are strongly oriented toward improving material performance while simultaneously addressing environmental sustainability concerns.

The temporal evolution of themes suggests a transition from conventional performance-oriented studies toward broader sustainability-driven and technology-integrated research. Earlier studies were primarily concentrated on mechanical behavior, hydration, durability, and microstructural characterization of geopolymer and recycled aggregate materials. Over time, newer themes such as life cycle assessment, environmental impact, circular economy, construction and demolition waste, and machine learning emerged and became increasingly connected to the core network. This evolution indicates a shift from purely engineering-focused investigations to holistic sustainability assessments incorporating environmental evaluation, waste management strategies, and predictive computational approaches. The emergence of keywords related to 3D printing, artificial intelligence, and image analysis further demonstrates the integration of digital technologies into sustainable materials research.

Despite the field's growing maturity, several conceptual gaps remain evident within the network. First, sustainability-related themes such as circular economy and life cycle assessment appear moderately connected but still somewhat peripheral compared to dominant mechanical-property-centered topics, suggesting limited integration between material performance research and long-term sustainability evaluation. Second, the social, economic, and policy dimensions of sustainable construction materials are largely unapparent, indicating that the field remains heavily techno-centric. Third, while machine learning and advanced characterization methods are emerging, their links with durability prediction, large-scale implementation, and industrial applications should be strengthened. These gaps suggest future research opportunities in integrating environmental, economic, and digital innovation frameworks to support the practical adoption and lifecycle optimization of sustainable construction materials.

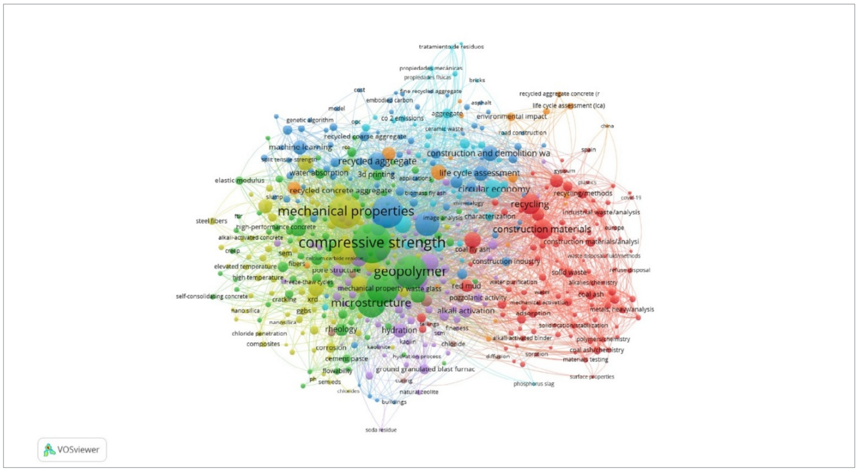

Figure 6. *Keyword Co-Occurrence Network of SCM Research*

Thematic map analysis

The thematic map (Figure 7) indicates that SCM research is structured around a highly developed and strategically central motor theme represented by the "fly ash–geopolymer–metakaolin" cluster. Its position in the upper-right quadrant reflects both strong internal coherence and high relevance to the broader field, suggesting that alkali-activated binders and geopolymer systems remain among the most mature and influential knowledge domains in sustainable construction materials research. The proximity of "fly ash," "geopolymer," and "metakaolin" highlights the field's sustained emphasis on low-carbon cementitious alternatives derived from industrial by-products and aluminosilicate precursors. Closely associated with this motor space is the "sustainability–recycling–circular economy" cluster, which reinforces the conceptual orientation of SCM research toward resource efficiency, waste valorization, and circular material flows. Although this cluster appears slightly less dense than the geopolymer cluster, its high centrality demonstrates that circularity and sustainability concepts function as organizing principles across multiple SCM subdomains rather than as isolated research topics.

In contrast, the lower-right quadrant identifies "mechanical properties–microstructure–durability" as a basic theme, indicating that performance characterization remains fundamental and broadly connected to the SCM literature, but with comparatively lower thematic development. This suggests that mechanical and durability assessment serves as a methodological backbone across SCM studies rather than a fully self-contained research specialty. The upper-left quadrant contains the "compressive strength–geopolymer concrete–flexural strength" cluster, which appears as a niche theme: internally mature but less central to the overall thematic structure. This placement implies that strength-based evaluation of geopolymer concrete has become a specialized research area. However, its conceptual integration with broader sustainability, circular economy, and material innovation discourses may remain limited.

Meanwhile, the lower-left quadrant includes "recycled aggregate–strength–supplementary cementitious materials" and "concrete–cement–mortar," representing emerging or declining themes. Their low centrality and density may indicate either early-stage development, fragmentation, or reduced novelty within SCM research. Overall, the map suggests that the field is transitioning from conventional cement-and-aggregate substitution studies toward more integrated, circular, and chemically engineered material systems, with geopolymer-based binders currently serving as the dominant intellectual and technological frontier.

Figure 7. *Thematic Map of SCM Research*

Thematic evolution overtime

The thematic evolution map (Figure 8) indicates that SCM research has progressed from a relatively materials-centered and performance-oriented phase toward a more diversified, system-level research landscape. During 2010–2018, the field was anchored by foundational themes such as fly ash, concrete, durability, mechanical properties, and compressive strength, reflecting an early emphasis on validating alternative binders and supplementary cementitious materials through conventional engineering performance indicators. These early themes expanded during 2019–2021, with fly ash and compressive strength remaining dominant but increasingly linked to microstructure, sustainability, Portland cement substitution, and concrete performance. This suggests that SCM scholarship began moving beyond simple replacement-material studies toward mechanistic explanations of strength development, hydration behavior, and durability enhancement. The strong continuity of compressive strength across successive periods confirms that mechanical performance has remained a central evaluative criterion in SCM research, functioning as a persistent bridge between early cement-replacement investigations and later advanced binder systems. Similarly, fly ash maintained intellectual continuity from the earliest period into 2022, underscoring its role as one of the most extensively studied precursor materials for low-carbon cementitious systems.

From 2022 onward, the thematic structure became more specialized and application-driven, with the emergence of sustainability, rheology, rice husk ash, thermal conductivity, geopolymer concrete, and red mud indicating broader interest in waste valorization, fresh-state behavior, and functional material properties. By 2023, the field had clearly shifted toward geopolymer-based systems, with geopolymers and geopolymer appearing as prominent themes alongside mechanical properties, rheology, sustainability, microstructure, and strength. This transition reflects a maturation of SCM research from isolated material substitution toward integrated alkali-activated and low-clinker binder technologies. In 2024, the thematic profile further diversified, with mechanical properties remaining dominant, while geopolymers, geopolymer, concrete, durability, compressive strength, porosity, recycled aggregate concrete, and pozzolanic activity emerged as distinct terminal themes. The emergence of porosity and pozzolanic activity suggests growing attention to microstructural densification and reaction mechanisms, whereas recycled aggregate concrete reflects a broader circular-economy orientation. Overall, the figure demonstrates that SCM research has evolved from conventional performance validation of fly ash and concrete systems into a multidimensional research domain integrating mechanical optimization, durability, rheology, geopolymer technology, waste-derived precursors, and sustainability-driven material innovation.

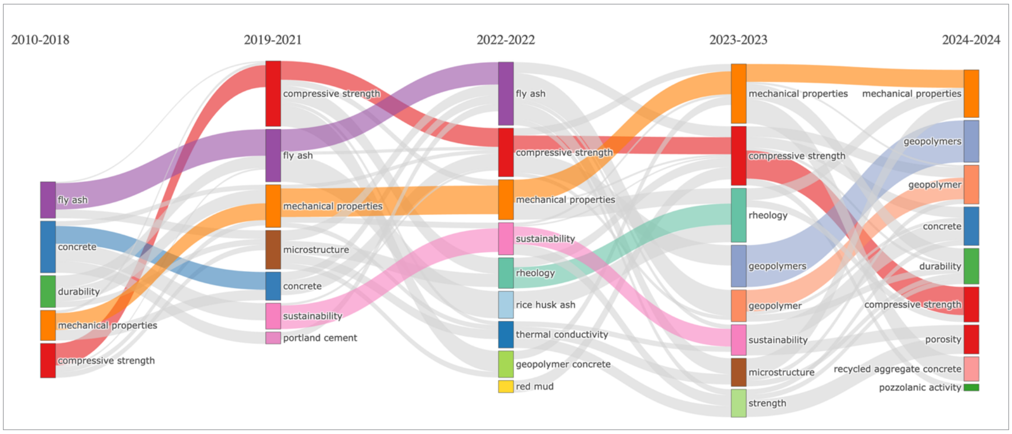

Figure 8. *Sankey Diagram (Thematic evolution) of SCM Research*

DISCUSSION

The bibliometric evidence supports three overarching analytical claims regarding the evolution of SCM research:

SCM research is expanding rapidly, but growth remains concentrated in technical and performance-oriented knowledge domains

There has been a significant increase in sustainable construction materials (SCM) research over the past decade, driven by concerns about carbon reduction, resource efficiency, and sustainable infrastructure. Despite this growth, the field remains largely concentrated on technical and performance-related topics. The thematic evolution analysis reveals the continued prominence of themes such as fly ash, concrete, durability, mechanical properties, and compressive strength. In contrast, the thematic map identifies "mechanical properties–microstructure–durability" as a core basic theme. These findings indicate that SCM research continues to be primarily oriented toward material validation and performance optimization rather than broader implementation or policy-related concerns.

This pattern aligns with previous reviews, which found that sustainable construction materials are frequently evaluated for strength development, durability, and microstructural characterization before broader implementation considerations are addressed (Ahmad et al., 2025). The persistence of these themes highlights the scientific necessity of establishing technical reliability but also reveals a research landscape still dominated by laboratory-based investigations, with comparatively less attention given to field validation, lifecycle performance, and large-scale implementation challenges (Abbas et al., 2016; Sinha et al., 2026).

Citation leadership is dominated by material science research, particularly geopolymers, cement alternatives, durability, and microstructural innovation

The citation structure of SCM research is strongly dominated by material science and cement technology studies, particularly those focusing on geopolymers, alkali-activated materials, cement alternatives, durability, and microstructural engineering. This is reflected in the thematic map, where the "fly ash–geopolymer–metakaolin" cluster emerges as the principal motor theme, highlighting the maturity and strategic importance of geopolymer technologies. Thematic evolution further reveals a shift from traditional supplementary cementitious materials toward advanced geopolymer and waste-derived binder systems, with increasing emphasis on porosity, pozzolanic activity, rheology, and microstructure. Overall, scholarly influence in the field is increasingly driven by efforts to optimize material performance through microstructural engineering and innovations in binder chemistry that support the development of low-carbon alternatives to conventional cementitious systems (Habert et al., 2020; Juenger et al., 2019; Scrivener et al., 2018).

Implementation-oriented knowledge remains underrepresented

Despite substantial advances in material innovation, the thematic structure indicates that SCM research remains largely technology-driven, with limited attention to implementation-related issues such as policy, procurement, regulation, supply chains, construction governance, and industry adoption. While the "sustainability–recycling–circular economy" cluster reflects growing interest in broader sustainability goals, the dominant themes remain focused on material characterization, laboratory validation, and performance optimization. This reveals a persistent gap between technological innovation and practical deployment, as research has generated extensive evidence on material performance but comparatively little on the institutional and operational mechanisms required for large-scale adoption. As a result, the disconnect between laboratory success and industry implementation remains a key challenge, highlighting the need for future studies that integrate engineering innovation with policy, implementation science, and construction management perspectives (Scrivener et al., 2018).

Future SCM research should adopt translational and systems-oriented frameworks

The thematic evolution map indicates that SCM research is gradually transitioning toward a more diversified and sustainability-oriented knowledge structure. The recent emergence of themes such as sustainability, recycled aggregate concrete, thermal conductivity, rheology, and waste-derived precursors demonstrates increasing interest in circular economy principles and multifunctional material performance (Ahmed, 2024; Aziz et al., 2024). Nevertheless, future advancement of the field will likely depend on moving beyond material validation toward translational research frameworks that connect technical innovation with real-world implementation (Li et al., 2024; Shukla et al., 2025).

Future studies should integrate lifecycle assessment, lifecycle costing, policy readiness, supply chain feasibility, contractor acceptance, and building code compliance into SCM evaluation frameworks. Such an approach would facilitate the translation of laboratory-scale innovations into commercially viable and industry-adoptable solutions. Moreover, interdisciplinary collaboration among materials scientists, construction engineers, policymakers, public administrators, and industry stakeholders may help bridge the existing gap between technological development and sustainable construction practice (Li et al., 2024; Shukla et al., 2025).

Overall, the thematic evidence suggests that SCM research is evolving from conventional cement replacement studies toward more advanced geopolymer and circular-economy-based systems. However, achieving meaningful sustainability impacts will require a parallel expansion of research addressing implementation, governance, market adoption, and regulatory integration. Such a shift would enable the field to progress from demonstrating material performance to facilitating large-scale transformation of the construction sector.

CONCLUSION

This bibliometric study provides a comprehensive assessment of the evolution and intellectual structure of sustainable construction materials (SCM) research from 2010 to 2025. The findings reveal a rapidly expanding field driven primarily by material science innovations, particularly in geopolymers, fly ash-based systems, and other low-carbon cementitious alternatives. Thematic and citation analyses indicate that research has remained strongly focused on mechanical performance, durability, microstructure, and material optimization. In contrast, thematic evolution shows a gradual shift toward geopolymer technologies, waste valorization, circular-economy principles, and sustainability-oriented material development. However, the limited prominence of themes related to policy, regulation, procurement, supply-chain feasibility, and industry adoption suggests a persistent gap between technological advancement and practical implementation. Thus, the study highlights the maturity of SCM research in developing and validating sustainable materials while underscoring the need for future interdisciplinary and translational research that integrates technical innovation with economic, regulatory, and implementation considerations to accelerate the adoption of sustainable construction materials in practice.

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Competing interest
The author declares no conflicts of interest.

Data Availability
All data generated in this study are included in the manuscript.

Declaration of Artificial Intelligence Use
The author declares that artificial intelligence (AI) tools were used solely for language editing and formatting. All scientific content, analyses, and conclusions were independently developed and verified by the author.

REFERENCES

Abbas, S., Nehdi, M. L., & Saleem, M. A. (2016). Ultra-high performance concrete: Mechanical performance, durability, sustainability and implementation challenges. International Journal of Concrete Structures and Materials, 10(3), 271–295. https://doi.org/10.1007/s40069-016-0157-4

Ahmad, J., Sabri, M. M., Majdi, A., Alattyih, W., Khan, I., & Alam, M. (2025). Durability and microstructure aspects of sustainable concrete made with ceramic waste: A review. Frontiers in Materials, 11. https://doi.org/10.3389/fmats.2024.1508989

Ahmed, A. (2024). Assessing the effects of supplementary cementitious materials on concrete properties: A review. Discover Civil Engineering, 1, 145. https://doi.org/10.1007/s44290-024-00154-z

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Aziz, A., Mehboob, S. S., Tayyab, A., Khan, D., Khizar Hayyat, Ali, A. Qadir. (2024). Enhancing sustainability in self-compacting concrete by optimizing blended supplementary cementitious materials. Scientific Reports, 14, 12326. https://doi.org/10.1038/s41598-024-62499-w

Darko, A., Chan, A. P. C., Gyamfi, S., Olanipekun, A. O., He, B. J., & Yu, Y. (2017). Driving forces for green building technologies adoption in the construction industry: Ghanaian perspective. Building and Environment, 125, 206–215. https://doi.org/10.1016/j.buildenv.2017.08.053

Ding, Z., Fan, Z., Tam, V. W. Y., Bian, Y., Li, S., Illankoon, I. M. C. S., & Moon, S. (2018). Green building evaluation system implementation. Building and Environment, 133, 32–40. https://doi.org/10.1016/j.buildenv.2018.02.012

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Habert, G., Miller, S. A., John, V. M., Provis, J. L., Favier, A., Horvath, A., & Scrivener, K. L. (2020). Environmental impacts and decarbonization strategies in the cement and concrete industries. Nature Reviews Earth & Environment, 1(11), 559–573. https://doi.org/10.1038/s43017-020-0093-3

Hassan, W., & Duarte, A. E. (2024). Bibliometric analysis: A few suggestions. Current Problems in Cardiology, 49(8), 102640. https://doi.org/10.1016/j.cpcardiol.2024.102640

Heeren, N., & Fishman, T. (2019). A database seed for a community-driven material intensity research platform. Scientific Data, 6(1), 23. https://doi.org/10.1038/s41597-019-0021-x

Hossain, M. U., Ng, S. T., Antwi-Afari, P., & Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. Renewable and Sustainable Energy Reviews, 130, 109948. https://doi.org/10.1016/j.rser.2020.109948

International Energy Agency. (2023). Buildings: Tracking clean energy progress. International Energy Agency. https://www.iea.org/reports/tracking-clean-energy-progress-2023

Juenger, M. C. G., Snellings, R., & Bernal, S. A. (2019). Supplementary cementitious materials: New sources, characterization, and performance insights. Cement and Concrete Research, 122, 257–273. https://doi.org/10.1016/j.cemconres.2019.05.008

Li, Z., Bian, Y., Zhao, J., Wang, Y., Qiu, X., Liu, Q. (2024). Sustainable building materials—recycled aggregate and concrete: A systematic review of properties, modification techniques, and environmental impacts. Environmental Science and Pollution Research, 31, 20814–20852. https://doi.org/10.1007/s11356-024-32397-9

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. Research Policy, 41(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Pacheco-Torgal, F., Ding, Y., & Labrincha, J. (Eds.). (2020). Handbook of recycled concrete and demolition waste. Woodhead Publishing. https://www.sciencedirect.com/book/edited-volume/9780857096821/handbook-of-recycled-concrete-and-demolition-waste

Penfold, R. (2020). Using the Lens database for staff publications. Journal of the Medical Library Association, 108(4), 664–666. https://doi.org/10.5195/jmla.2020.918

Phoong, S.W., Phoong, S.Y., & Khek, S.L. (2022). Systematic literature review with bibliometric analysis on Markov switching model: Methods and applications. SAGE Open, 12(2), Article 21582440221093062. https://doi.org/10.1177/21582440221093062

Pomponi, F., & Moncaster, A. (2017). Circular economy for the built environment: A research framework. Journal of Cleaner Production, 143, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055

Provis, J. L. (2018). Alkali-activated materials. Cement and Concrete Research, 114, 40–48. https://doi.org/10.1016/j.cemconres.2017.02.009

Scrivener, K., John, V. M., & Gartner, E. (2018). Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. Cement and Concrete Research, 114, 2–26. https://doi.org/10.1016/j.cemconres.2018.03.015

Shukla, B. K., Yadav, H., Singh, S., Verma, S., Shukla, A. K., & Sharma, C. (2025). Sustainable engineering of recycled aggregate concrete: Structural performance and environmental benefits under circular economy frameworks. Construction Materials, 5(3), 67. https://doi.org/10.3390/constrmater5030067

Sinha, S., Sudarsan, J. S., & Abhyankar, A. A. (2026). Compressed stabilized earth blocks for sustainable building construction: A PRISMA-guided systematic review and TCCM analysis. Buildings, 16(8), 1633. https://doi.org/10.3390/buildings16081633

United Nations Environment Programme. (2022, November 9). 2022 global status report for buildings and construction. United Nations Environment Programme (UNEP). https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction

Van Eck, N.J., Waltman, L. (2014). Visualizing Bibliometric Networks. In: Ding, Y., Rousseau, R., Wolfram, D. (eds) Measuring Scholarly Impact. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-10377-8_13

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