MATERIALS PHYSICS AND MECHANICS REVIEW

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Advancing sustainable construction: comprehensive analysis of the innovative geopolymer bricks

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ABSTRACT

Innovative geopolymer brick is an alternative to conventional building materials, notably enhancing its mechanical properties and reducing construction costs. This research used a bibliographic approach based on specific keywords and the Scopus database to collect data, resulting in 490 papers that contain the keyword "geopolymer brick" used as sustainable construction materials between 2004 and 2024. The main approach includes scientometric analysis, in which the patterns of the acquired articles are examined with respect to different characteristics like countries with the highest number of publication sources, the most frequently occurring keywords, affiliations, authors, and articles with more research works that are relevant. Scientometric instruments, such as R-Studio and Vos Viewer, have been important in elucidating the complex network of geopolymer research. The scientometric review facilitates the exchange of innovative concepts and knowledge among scholars from different countries and promotes international collaboration in research. The use of scientific instruments not only amplifies the accuracy of the study analysis but also showcases the multidisciplinary character of modern research, establishing a pattern for forthcoming investigations. It is still necessary to carry out an extensive investigation of the novel geopolymer bricks as an innovative building material while taking the research gaps into account. To do this, it is necessary to examine the results of previous studies and identify the research components and development trends and future endeavours by highlighting the necessity for continued research and the advancement of geopolymers as a cutting-edge and ecologically responsible alternative in construction techniques across the globe.

KEYWORDS

geopolymer bricks • sustainable construction • environmental impact • innovative building materials scientometric analysis

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Introduction

For thousands of years, bricks have been an important part of construction and building projects. Even though burnt clay is a consistently workable and accessible material, its manufacture has always required a significant amount of energy and resources. The extraction of raw materials, consumption of energy techniques for manufacturing, and massive amounts of waste production associated with traditional building materials like clay bricks and concrete blocks all contribute significantly to increasing carbon emissions and resource degradation [1–4]. It is an urgent demand for innovative and

sustainable building materials in this era of mounting environmental concerns and the need to reduce the ecological footprint of human activity. Geopolymer bricks are more ecologically friendly than conventional bricks since they use less water and energy and produce fewer waste materials [5,6].

Numerous scholars are investigating the possibility of substituting traditional building materials with innovative, eco-friendly alternatives [7]. Sustainability has become more important in the construction industry as a result of growing environmental consciousness and the need to minimize the environmental impact of structures. Since the energy cost of their extraction, treatment, and disposal influences the environmental effect of construction, novel building materials are an important topic [8–10]. Among these innovations, the idea of Geopolymer Bricks has gained popularity recently. It was created with the same specifications as concrete bricks, fly ash bricks, lightweight bricks, and geopolymer bricks. The introduction of waste from industries in brick manufacturing was a breakthrough, and it produced opportunities for the reuse of waste, reducing the harmful impact on the environment [11]. The shift from conventional bricks to geopolymers is complemented by a concise examination of alternative brick varieties, including concrete bricks, fly ash bricks, and lightweight bricks [12–17]. The incorporation of waste materials from businesses into brick production is emphasized as a groundbreaking measure, not only mitigating environmental damage but also offering prospects for waste repurposing [18,19].

Geopolymers are known for their reduced impact on the carbon footprint as they can be created at low temperatures, unlike cement. Geopolymers are sustainable and environmentally friendly materials as they are prepared from waste materials from the industry, such as fly ash and slag. Apart from their raw material being industrial waste, they are reusable at the end of their life span. Scholars used a variety of waste resources, such as ceramic powder, glass powder [20], granulated blast furnace slag [21], mine tailings [22], fly ash [23] and others [24,25], as ingredients for a revolutionary geopolymer brick.

Geopolymers have an advantage over traditional construction materials as their better resistance to corrosion and chemical attack, which makes them a suitable option for the replacement of conventional construction materials. Cement uses raw materials from earth minerals, which makes it a limited and restricted production material as it can cause problems to the environment like mineral scarcity and air pollution on the other hand geopolymers act as a solution for the use of industrial waste without the requirement of a high temperature of about 900 to 1200 °C which is necessary for cement manufacturing process [26–30]. Apart from this, geopolymers can achieve the desired strength with a shorter curing period and less greenhouse gas emissions. The current review focuses on the scientometric analysis of the information available on the geopolymer brick in the Scopus database using R-Studio and Vos-viewer applications that provide essential information on the articles available in the database about the sources, affiliations, authors, and their relation with the different parameters [31,32]. The Scientometric Approach is used in this study to analyze the bibliometric dataset obtained from the Scopus Database. The scientometric analysis is a scientific methodology that uses a variety of statistical and computational tools to analyze patterns, trends, and relationships among scientific works, authors, institutions, and research topics. It involves

quantitative and qualitative assessments of scientific literature, publications, citations, and collaborations within a particular field or discipline.

The current study evaluated the positive impacts of innovative geopolymer bricks for building by conducting a scientometric analysis of published works that address the issue of advancing sustainable construction. Based on 490 publications published between 2004 and 2024, this article examines a growing collection of research on geopolymer bricks and provides a qualitative evaluation of the historical development of bricks. The study utilizes a scientometric methodology, using technologies like Web of Science, R-Studio, and Vos Viewer to carry out a comprehensive analysis of the current body of literature on geopolymer bricks [33,34]. The sheer magnitude of publications, affiliations, and authors exemplifies the growing interest and the worldwide scope of study in this field. India has emerged as a leading contender in the field of geopolymer brick papers, highlighting the global reach and importance of this area of study [35–38]. The introduction establishes the foundation for the next parts by concisely outlining the historical path of bricks, identifying the environmental obstacles presented by conventional materials, and offering geopolymers as a modern, environmentally friendly substitute [39–41]. These establishes are the framework for the extensive investigation of geopolymer bricks in the next parts, spanning their production methods, mechanical characteristics, uses, and the future potential of this revolutionary substance in the field of environmentally friendly building. This assessment is notable for its primary emphasis on resolving a crucial problem within the building industry—the ecological consequences linked to traditional construction binding materials such as cement [42]. The research suggests a revolutionary approach by promoting the use of geopolymers, particularly in the form of bricks, as a basic construction component. The article thoroughly examines alternative mix compositions, investigates the mechanical characteristics, and includes a full analysis of numerous experiments performed on geopolymer bricks. Moreover, the assessment provides insight into the most recent developments in geopolymer brick technology, clarifying its many uses in building projects.

The research investigation makes use of cutting-edge scientific instruments, including sophisticated scientometric analysis techniques like R-studio and Vos Viewer software, and it obtains its analytical data from the Scopus database. The collection of tools includes Network Visualization, Density Visualization, Topic Dendrogram, and Cluster Analysis, along with Bar Charts and Pie Chart representations. The use of this analytical toolbox enhances the research by offering a sophisticated comprehension of the current research evolution [43,44].

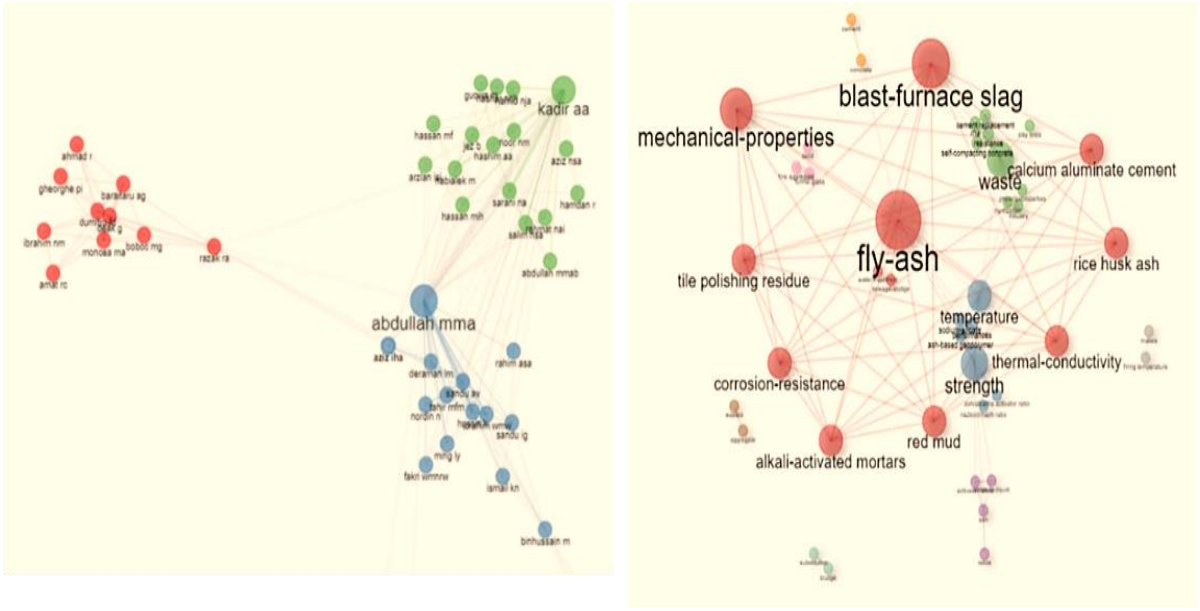
The study takes into account a wide range of elements and criteria, including Sources, Articles, Authors, Co-authors, Citations, Affiliations, and Keywords. This methodical approach guarantees a comprehensive examination of the topic, enhancing the understanding of the interrelated aspects of geopolymer bricks in infrastructure. This comprehensive evaluation distinguishes itself from past reviews by thoroughly exploring the complex interactions among crucial material qualities rather than focusing just on physical aspects and future research directions. The study utilizes advanced scientometric analysis to pioneer multidisciplinary methodologies, setting a new standard in research methodology [45–48]. By prioritizing cost-effective solutions, this study investigates the elements that impact the qualities of geopolymer bricks, ultimately improving their

availability for a wide variety of building projects. The analysis highlights the significant role of geopolymers, especially in brick manufacturing, as a critical aspect in providing environmentally friendly choices for building projects [49–53]. These choices not only foster sustainable infrastructure development but also conform to environmentally conscious practices. In addition to its academic importance, this review plays a crucial role in sharing information and promoting cooperation within the construction sector [54–57]. By serving as a catalyst, it stimulates innovation and advancement, leading to beneficial transformations in the field of building materials and processes.

Literature search methods

Literature Search

This section should clearly outline which bibliographic databases and time frames were used for the literature search, providing examples of keywords, phrases, and search queries employed to identify relevant studies. Observing the articles on innovative geopolymer bricks as a sustainable construction material for the record of 490 articles in Web of Science throughout the period of 2004 to 2024, the researchers evaluated their significance to conclude the investigation of the current study. These articles are published in 182 different sources with an overall number of authors as 1536. The most relevant source is identified as CONSTRUCTION AND BUILDING MATERIALS with a total of 103 articles on the topic of geopolymer brick, followed by JOURNAL OF BUILDING ENGINEERING and JOURNAL OF CLEANER PRODUCTION with several articles 33 and 23 respectively. The top three Authors were identified as ABDULLAH MM, SAHMARAN M, and KADIR AA with the number of articles as 20, 19, and 18 respectively. The most relevant Affiliations are UNIV MALAYSIA PERLIS, SWINBURNE UNIV TECHNOL, and HACETTEPE UNIV with 54, 27, and 25 articles respectively. India is the country with the maximum number of publications in geopolymer bricks, with 59 articles followed by China (57), and Malaysia (39).



(a) (b)

Fig. 1. (a) Author co-relation (b) Author keywords reoccurrence network

After screening for the most relevant affiliation UNIV MALAYSIA PERLIS, 31 articles were obtained for the research related to geopolymer brick with the contribution of 81 authors, among which 20 articles are published by ABDULLAH MMA as shown in Fig. 1(a). It was seen in Fig. 1(b) in the network analysis that most of the work in these articles was done on the fly ash and blast furnace slag, considering their mechanical properties. Over the last few decades, the growth of industries and increased population demands have given a tremendous rise to the emissions of greenhouse gases, which CO_2 is a major contributor which results in about 8 % of CO_2 emissions every year due to cement manufacturing and the use of cement-based products [58–61]. It is estimated to have a production of 6.1 billion metric tons of cement in the world by 2050 to fulfil the demands of the population.

Data collection and processing

Based on information gathered from the majority of existing literature, which was used in Fig. 2 out the results' scientific foundation, Scopus was selected as the bibliographic database since it is thorough and well-organized, making it an effective tool for in-depth scientific investigation. The dataset obtained was further screened to scrutinize the unwanted articles. The obtained articles were saved in a CSV format so that they could be adjusted in the Vos Viewer and R Studio software for required analysis. The procedure is shown in Fig. 2 using a flowchart. Due to the nature of the research procedure, the data contained in the obtained file was processed and displayed using networks, clustering, and graphics.

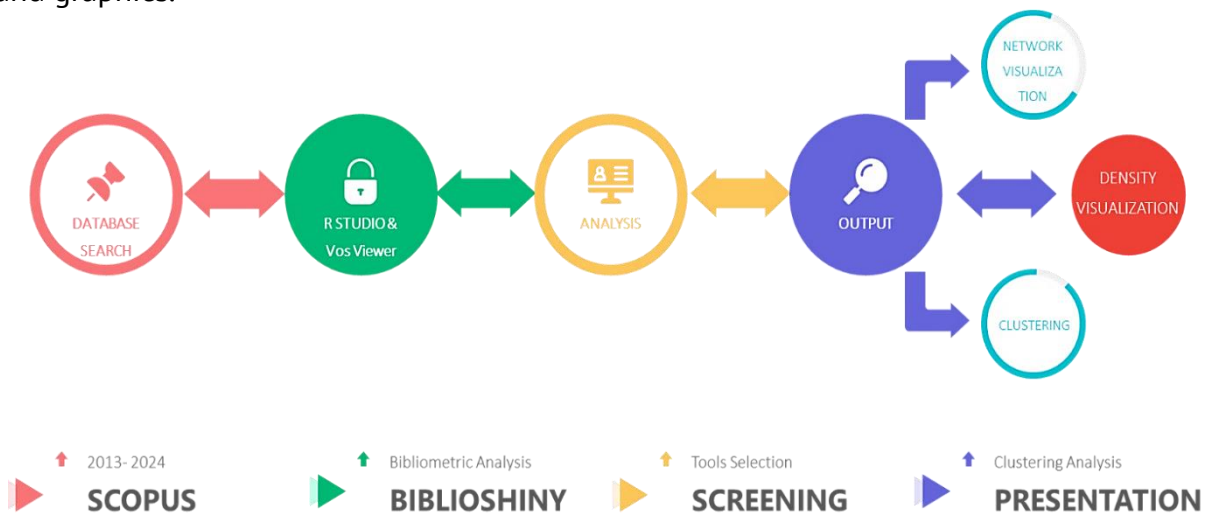


Fig. 2. Research methodology flowchart

Result and Analysis

Scopus database analysis

For the identification of important research fields in the geopolymer bricks topic, an analysis was performed in the Scopus database, as shown in Fig. 3. In the year range of 2013 to 2023, a total of 85 documents were received. Boost in the research can be seen after 2018-2019, where 15.3 % of articles were published in the years 2020 and 2021

each, 17.65 % in the year 2022, and 31.77 % in 2023, as shown in Fig. 4. This rise in the frequency indicates the increasing interest of researchers in the field of geopolymer.

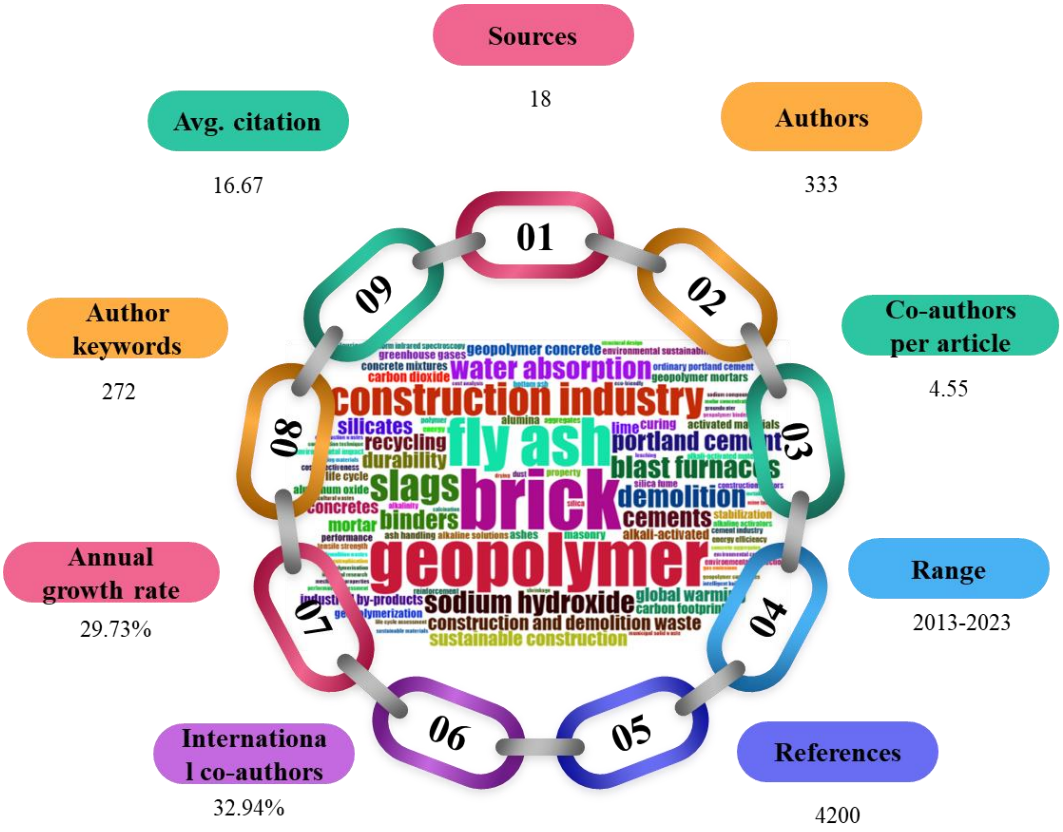


Fig. 3. Main Information received in the scientometric analysis in R studio

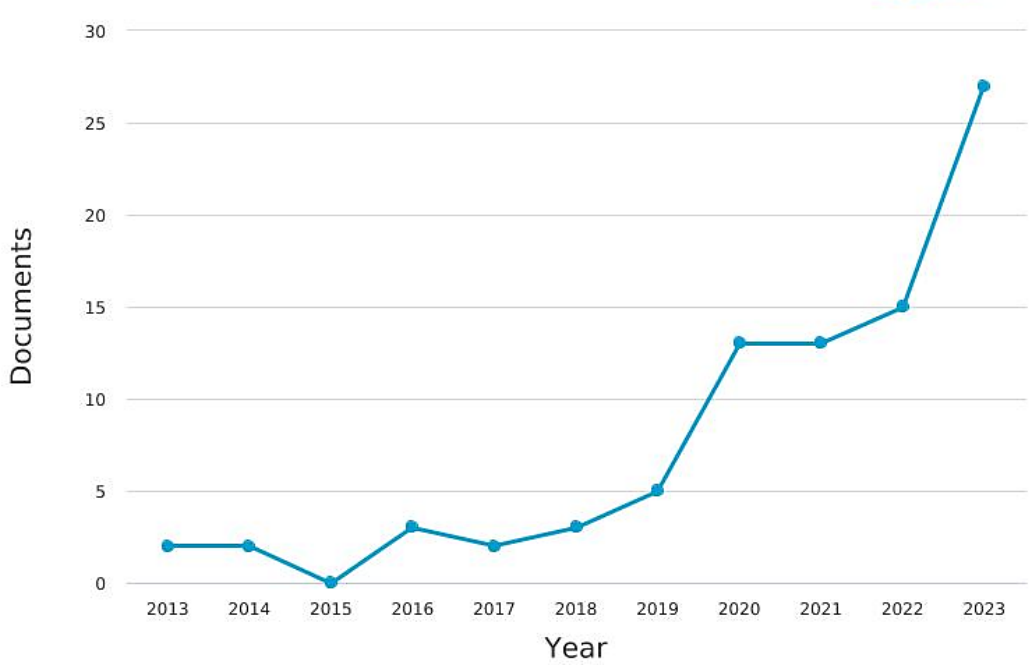


Fig. 4. Articles published per year in geopolymer brick topic

The renown and significance of a paper for other researchers can be determined by its citations. In this dataset, the Construction and Building Materials Journal contains the maximum cite-score for the articles related to the topic of geopolymer brick which shows that the articles published in this journal are more popular for containing important information as shown in Fig. 5.

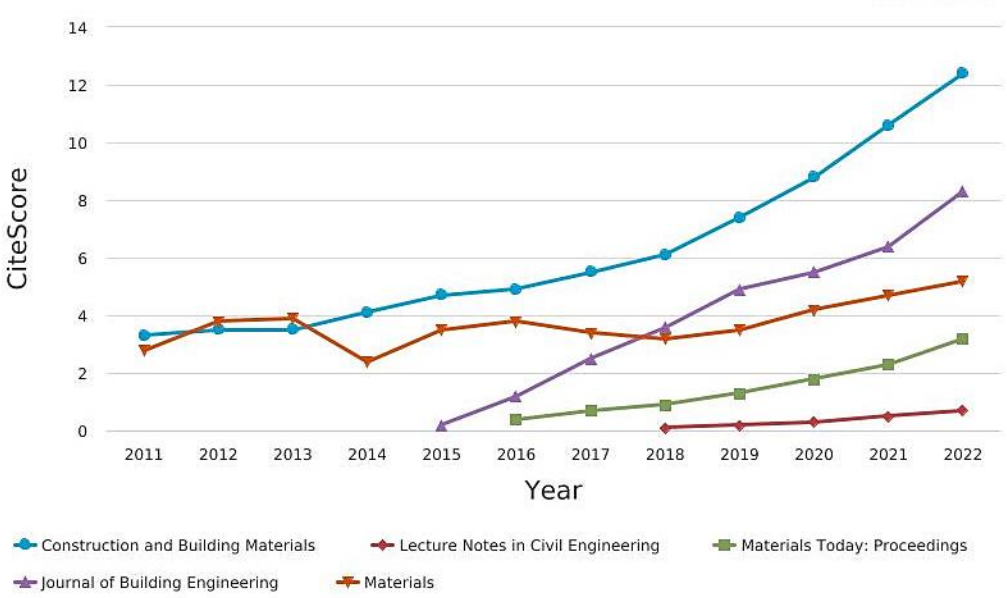


Fig. 5. Cite-score obtained in different sources of the dataset

Apart from the cite score, the most relevant source list is also topped by the Construction and Building Materials Journal, which contains 20 % of the articles available in the dataset. This relevancy is followed by LECTURE NOTES IN CIVIL ENGINEERING and MATERIALS TODAY: PROCEEDINGS with 9.4 and 7 %, respectively.

Research and innovation trends by year

Geopolymer bricks, as an innovative building material, have been the subject of relevant research studies over recent decades. The frequency of documents published per year is a symbol of consistent research in the concerned field. This consistency was maintained by the Construction and Building Materials till 2017. Thereafter, it was surpassed by Materials Today: Proceedings and later since 2020-21 Materials Journal has been holding the top position for the publication of maximum documents per year in the concerned field as shown in Fig. 6.

Analysis of articles from the author

A maximum of 6 articles were published by Sahmaran, H followed by Kul, A, and Khan, S.A with 5 and 4 articles, respectively, as shown in Fig. 7(a). Figure 7(b) shows that a maximum of 8 articles were received from Hacettepe Universitesi, followed by Ankara and Hana Bin Khalifa University, with 4 articles each. India has contributed to this topic with a maximum of 30 articles in the dataset, making 35.29 % of the whole, as shown in

Fig. 7(c). In the funding institutes shown in Fig. 7(d), a maximum contribution of 4 articles was seen from the Qutar National Research Fund.

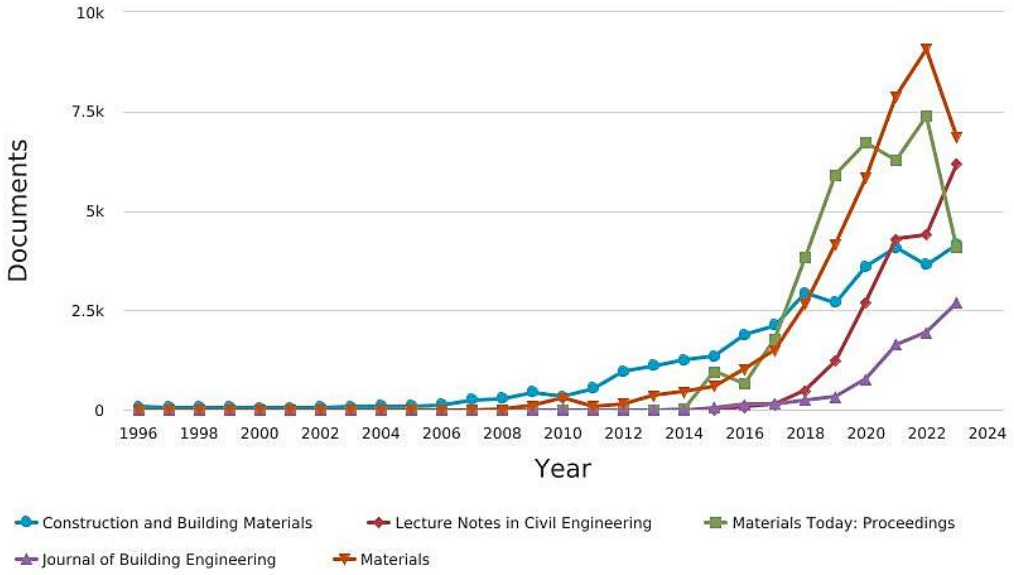


Fig. 6. Year-wise document publication in the sources

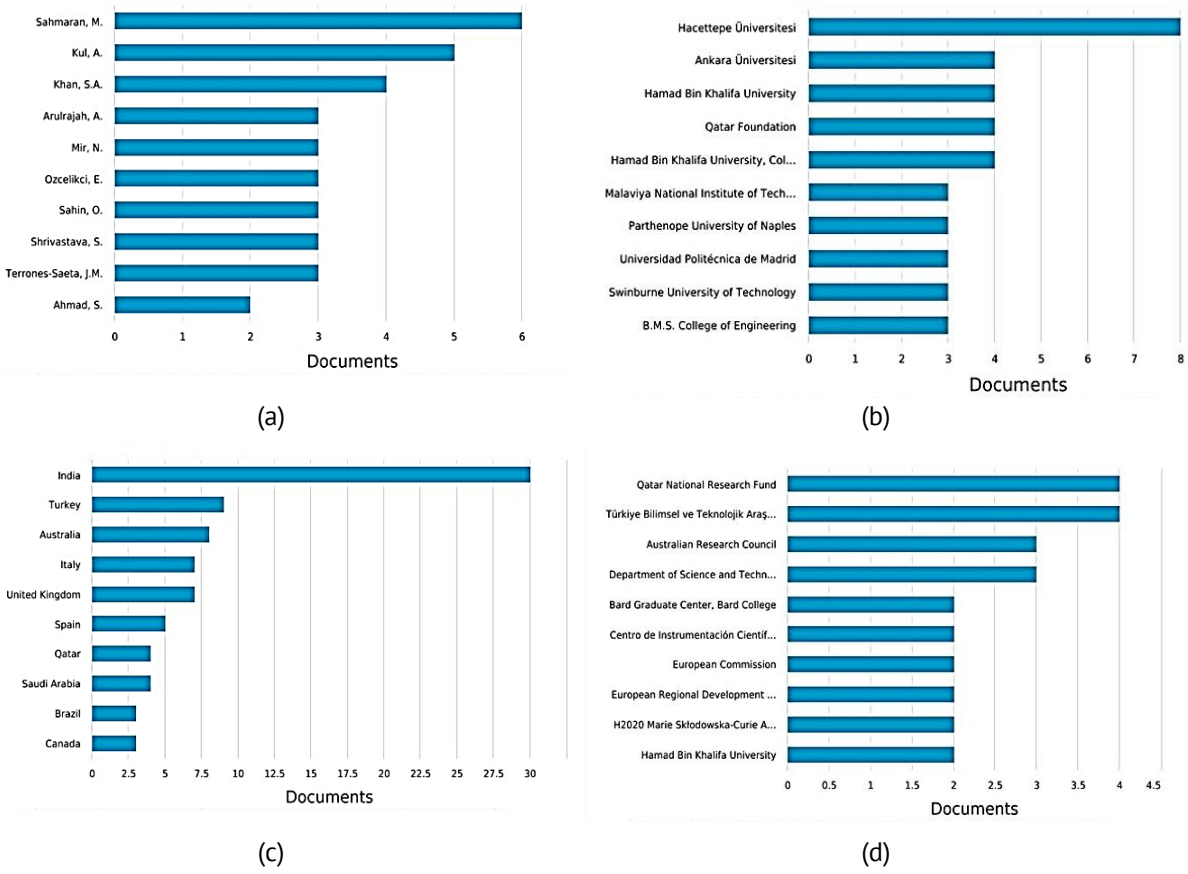


Fig. 7. (a) Author-wise document publication; (b) affiliation-wise document publication; (c) country-wise document publication; (d) funding institute-wise document publication

In the document type analysis of Fig. 8(a), 62.4 % are articles, 23.5 % are conference papers, 8.2 % are review papers, and 4.7 % are book chapters. In the discipline of the research in Fig. 8(b), a maximum of 36.1 % are from Engineering, 31 % are from material science, and others are from diverse fields of environment, computing, chemicals, and Business management.

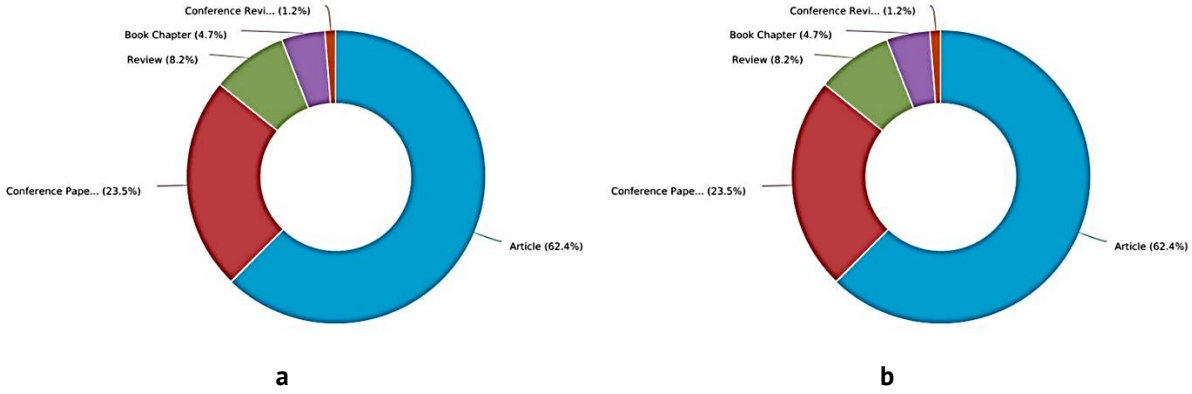


Fig. 8. (a) Document type in the dataset; (b) subject type in the dataset

The most relevant documents obtained in this dataset are Lignola GP, 2017 published in Compos Part B: ENG, Ahmari S, 2013 published in Construction Building Materials, and Tang Z, 2020 published in Conservation and Recycling Journal with an overall citation score of 190, 158, and 135 respectively which can be seen in Fig. 9.

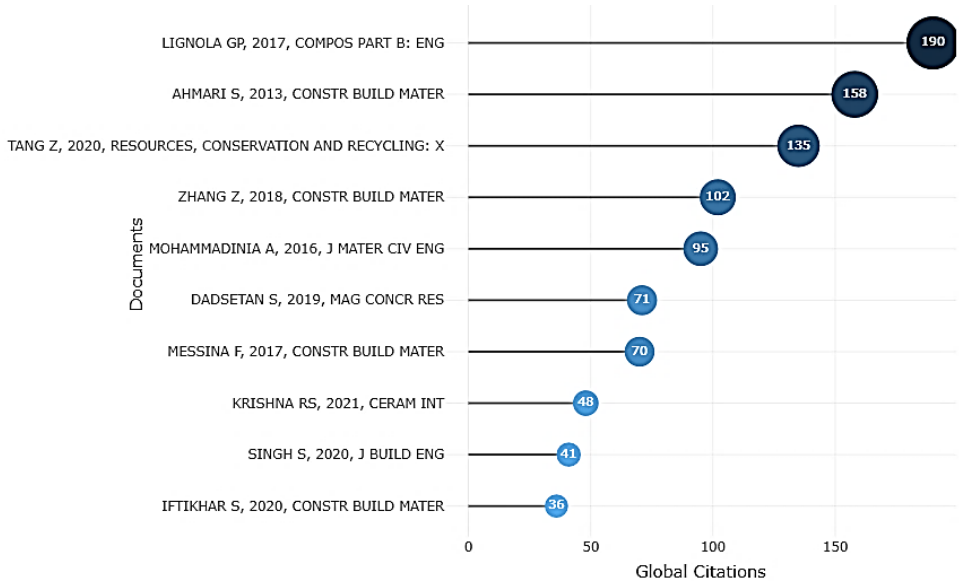


Fig. 9. Cite-score of the top ten articles

Analysis of co-occurrence network

The co-occurrence network of the keywords in Fig. 10 is a representation of the author's keywords, showing the importance and relevance of the keywords that are mostly used. The terms "geopolymers," "inorganic polymers," "brick," "sustainable development," and "fly ash" are most commonly used in the researchers examined in this collection. Out of

861, 60 keywords, 10 occurrences, co-occurrences, all of the keywords, and complete counting match the criterion.

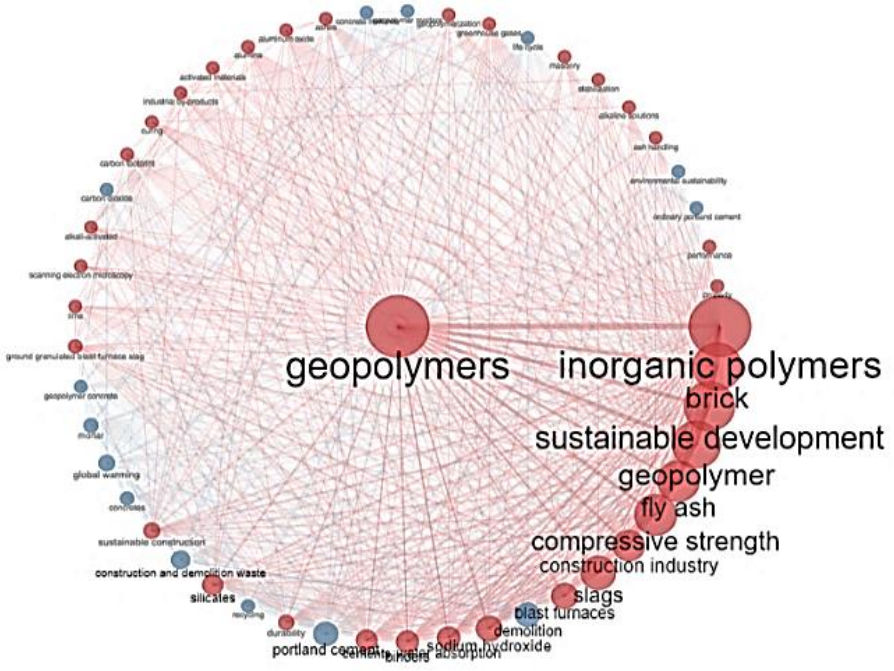


Fig. 10. Co-occurrence network of the author keywords

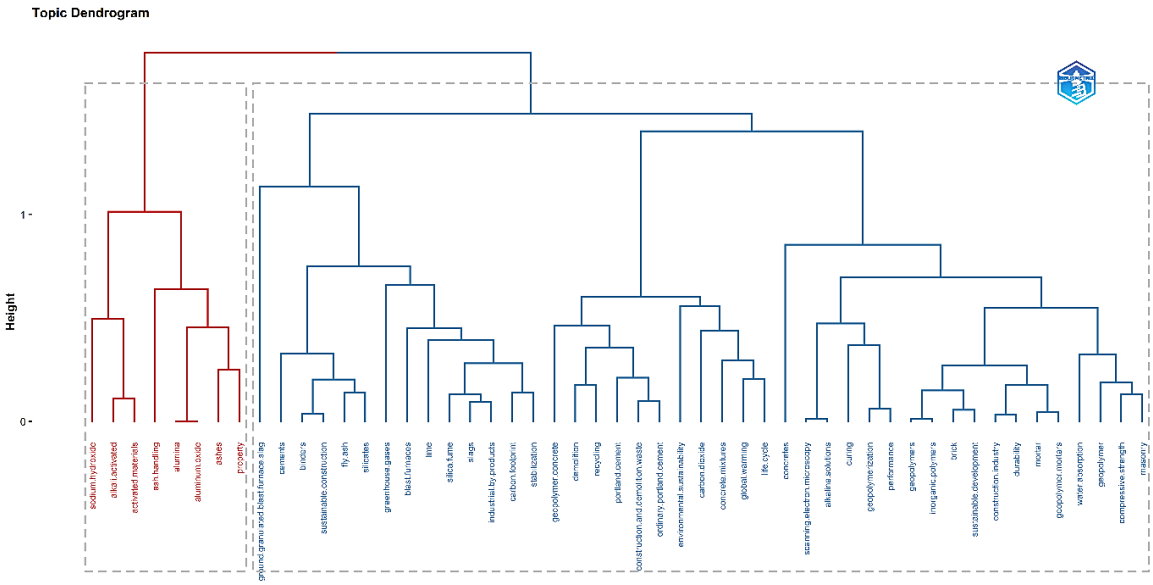
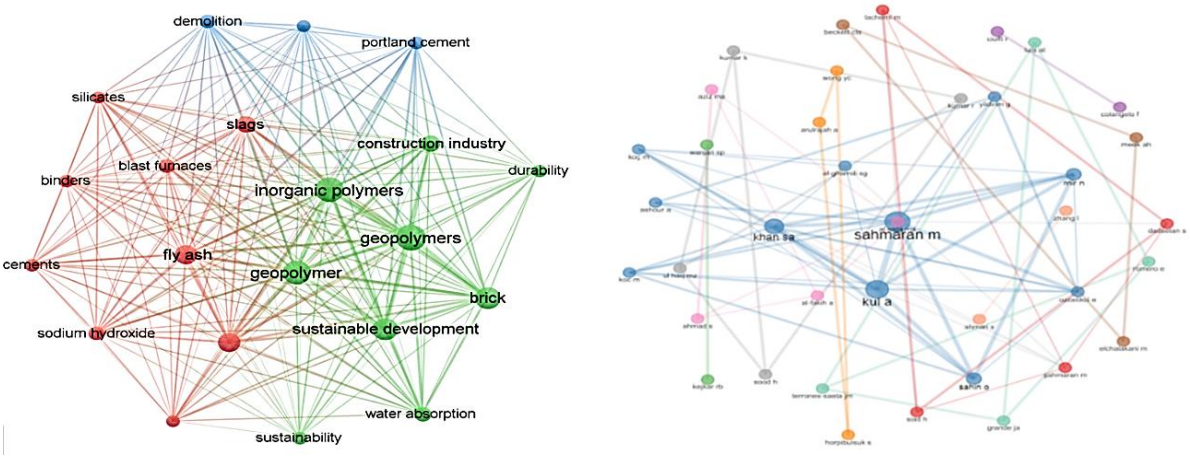


Fig. 11. Topic dendrogram as per multiple correspondence analysis.

Hierarchical clustering is presented in the topic dendrogram in Fig. 11. Two colours, blue and red, represent the clusters with similarities. 1st group of clusters shown in red represents the clusters of primary units in the geopolymer formation. In contrast, different subgroups of the blue-coloured group represent the other ingredients, processes, analysis, and final output obtained in the different clusters, which have similarities. Co-

authorship and authors network analysis was done using Vos Viewer with max author per doc as 5 and min documents of the author as 1, taking minimum citation score as 10, and a total of 64 Authors met the threshold.

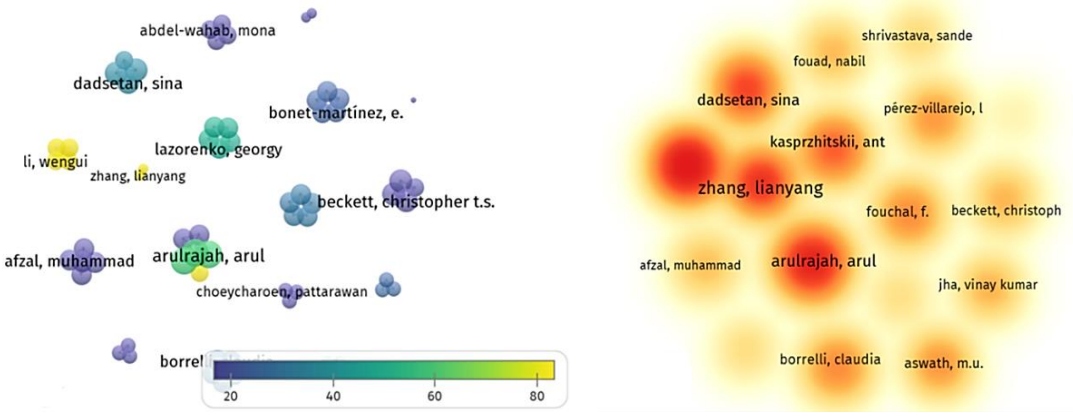
Network visualization represents the clusters of authors in Fig. 12(b) with higher numbers of citations, which can be easily identified in the density visualization. Arulrajah, Arul Zhang, Lianyang and Li Wengui are the authors with the most citations and the highest temperatures in heat density visualization.



(a) (b)

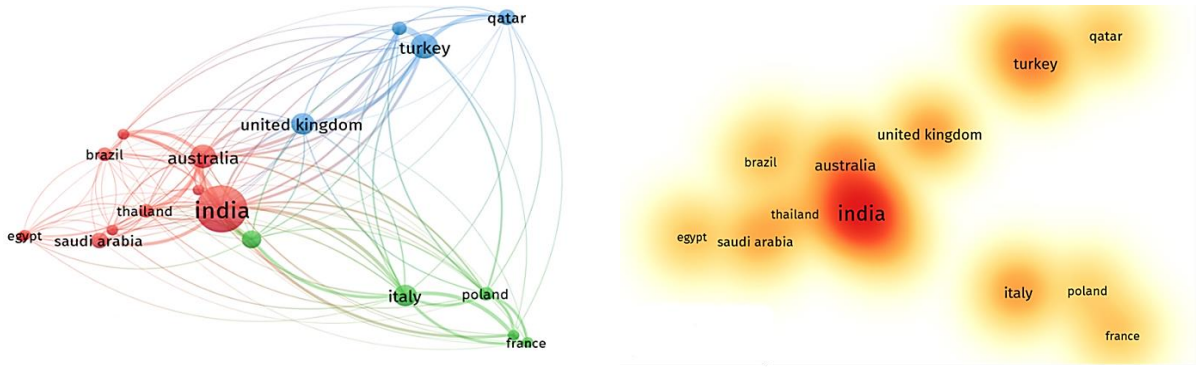
Fig. 12. (a) Author keywords network visualization; (b) Author co-occurrence network

A structure of collaboration networks in the application of geopolymers in the field of advancing sustainable construction is revealed by the Co-Authorship visualization and Co-Authorship density visualization network, as shown in Fig. 13(a,b), respectively, and can be helpful in organising future scientific collaboration. Bibliographic coupling and countries clustering analysis was done in Vos Viewer with full counting, taking countries with minimum documents as 2 and minimum citation as 10. Out of a total of 35, 19 met the threshold. Network visualization of bibliographic coupling and countries shows the maximum number of research articles from India, followed by Australia and Turkey, which can be interpreted in the heat density visualization, as shown in Fig. 14. The most minor research is shown in countries located at a farther place with small diameters, such as Egypt, France, Brazil, and Poland.



(a) (b)

Fig. 13. (a) Co-authorship network visualization; (b) co-authorship density visualization



(a) (b)

Fig. 14. (a) Bibliographic coupling network of countries; (b) bibliographic coupling density visualization

Physio-mechanical properties

Compressive strength. The compressive strength of the brick was seen to vary according to the type and proportion of the materials and activator used. The most common and important thing that makes this research sustainable is the use of waste materials from industries, which is common in almost all research papers. The compressive strength of the brick was seen to vary from 2.1 to 42 MPa, as reported by different researchers [62–64]. The bricks with less compressive strength are suitable for interior works where they don't have to carry the load. Otherwise, the bricks with good strength can be utilized in the load-carrying members of the structure. The proportion of the materials depends upon availability. If the percentage of fly ash and ground granulated ballast furnace slag is suitable, then the complete replacement of soil and other ingredients in the conventional bricks will be achieved. The optimum percentage was seen to be between 10 to 30% for good compressive strength. If we only use GGBS (25 %) and fly ash (75 %) with 30 % NaOH and 70 % Na_2SiO_3, a good increase in compressive strength can be achieved with better durability properties [58] and detailed mechanical properties performed by researchers are shown in Table 1.

Durability and chemical resistance. The inclusion of silica-added brick kiln rice husk ash and activators such as NaOH and Na_2SiO_3 solution resulted in increased durability. A reduction in water absorption was seen by 34 %, which is considerable in preventing harmful ingredient absorption, especially in the case of coastal regions. The acidic environment of coastal regions is well known to cause issues for building materials by reducing their durability. Because of this, it's critical that building materials be chemically resistant. Even a 10 to 15 % proportion of pozzolanic materials in geopolymer bricks will give them good resistance to such environments [19]. In addition, resistance to abrasion was seen in comparison to conventional brick [71]. Finding the ideal amount of mine tailings in the brick will allow for the control of leaching properties [72]. While employing low-reactive copper mine tailings does not significantly improve compressive strength, durability qualities can be improved [73].

Flexural strength. It is evident that geopolymer bricks have higher flexural strength than conventional materials. The use of fly ash (FA) and ladle furnace slag (LFS) with varying percentages of silica fume along with sodium silicate and sodium hydroxide as

Table 1. Summary of geopolymer brick studies with optimized compositions and properties

Authors	Ingredients	Activator	Test	Optimum %	Comp. strength, MPa	Time	Ref.
Haq et al. 2024	Rice husk ash (rha), ground granulated blast furnace slag (ggbs), red mud, and recycled washed sand as filler	Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3)	Compressive strength and water absorption	60 % rha, 20 % ggbs, and 20 % red mud	27.34	28	[65]
Mortada et al. 2023	Calcium hydroxide	Calcium hydroxide	Compressive strength	1 wt. % of nano-silica	42	28	[66]
Ahmad et al. 2022	Fly ash	–	Compressive strength and water absorption	–	40	7 and 28	[67]
Shilar et al. 2023	Granite waste powder and iron chips	Sodium hydroxide	Compressive strength and water absorption	20 %	10.1	7 and 28	[68]
Morsy et al. 2022,	Rice straw ash,soil	Sodium hydroxide	Compressive strength, thermal conductivity, and water absorption	10 % sodium hydroxide and 20 % RSA	2.1	28	[5]
Li et al. 2022	Brick powder	Na_2O	Compressive and flexural strengths, bulk density, water absorption and softening coefficient	6 % Na_2O	31.1	7	[69]
Kakodkar et al. 2023,	Iron ore tailings	–	Compressive strength	10 % fly ash and 30 % GGBS with 50 %	11.15	28	[70]

activators was seen to increase the flexural strength of the brick [74]. Apart from fly ash, if waste fibre cement is being used with a suitable activator, it has the capability of increasing the flexural strength of the geopolymers to about 20 % of its compressive strength [75]. Additional strength and sustainability can be achieved using carbon or steel fiber reinforcement as a replacement for steel in the concrete [76]. Geopolymer bricks have a vast application among the various structural units, and their performance is far better than that of traditional clay bricks and fly ash bricks [77,78]. The application is determined by the ratio of materials to be used and the improved properties, such as increased flexural strength for use in the building's beams or increased compressive

strength for use as paver bricks. For high resistance to chemicals and water absorption, the application can be made on the structure's exposed surface likewise after serving the life span as a main unit in the structures, the geopolymer recycled brick aggregate-filled steel tubes can be made with good strength as compared to the traditional concrete-filled steel tubes [79].

Discussion and Recommendations

The findings showed that there is a notable and consistently rising trend in the research study on the subject of geopolymers as cutting-edge building materials, indicating that the researchers are fully aware of and interested in the potential benefits and applications of geopolymers as advancing sustainable construction. The statistical analysis and mapping of the bibliographic databases and time periods utilized for the literature search were carried out by a systematic review, which also provided examples of the keywords, phrases, and search queries used to find relevant studies. The ability to fully and accurately connect divergent sections of the literature is lacking in previous review studies. The researchers assessed the relevance of the 490 publications on innovative geopolymer bricks as a sustainable building material published in Web of Science between 2004 and 2024 in order to wrap up the inquiry of the current study. There are 1536 writers total, and these papers are published in 182 distinct sites. Researchers from China, Malaysia, and India have made significant contributions to the field of geopolymer brick research by collaborating extensively with other researchers in the discipline and utilizing their knowledge. Table 1 summarizes studies on geopolymer bricks with optimized compositions and properties. Several researches observed the compressive strength of bricks based on the ideal constituent proportions to replace the traditional brick. The analysis carried out in this study suggests the following investigations for the future.

In anticipation, the recognition of forthcoming avenues for study underscores the need for economically viable resolutions and a more profound comprehension of the variables impacting the characteristics of geopolymer bricks. The ever-evolving characteristics of this domain need ongoing investigation, ingenuity, and cooperation to tackle developing obstacles and unleash the whole capabilities of geopolymer technology in the realm of building.

Fundamentally, this assessment not only consolidates preexisting information but also functions as a catalyst for the spread of knowledge, promoting cooperation within the construction sector and driving innovation and advancement. The use of scientometric instruments not only enhances the analysis but also signifies the amalgamation of conventional and state-of-the-art approaches in furthering our comprehension of geopolymer brick study. As we find ourselves at the intersection of historical significance and groundbreaking advancements, the investigation into geopolymer bricks arises as an illuminating beacon, directing the building sector towards a more environmentally friendly and enduring future.

Conclusion

The investigation of geopolymer bricks as a groundbreaking and environmentally friendly substitute for conventional building materials is a revolutionary expedition that mirrors the changing demands of the construction sector. The current study evaluated the positive impacts of innovative geopolymer bricks for building by conducting a scientometric analysis of 490 papers published between 2004 and 2024 that address the issue of advancing sustainable construction.

There are numerous strong connections among the research communities in China, Malaysia, and India, all of which have made substantial contributions. With 59 publications, India leads the world in geopolymer brick publications, followed by China (57), Malaysia (39), and other countries.

These research articles have been published in 182 different sources, and there are 1536 authors in total. Having 103 articles on the subject of geopolymer brick, CONSTRUCTION AND BUILDING MATERIALS is the most relevant source. Journal of Building Engineering and Journal of Cleaner Production, with multiple articles 33 and 23, are the following two most relevant sources.

The extensive contributions from writers such as Abdullah MM, Sahmaran M, and Kadir AA, in conjunction with affiliations such as Univ Malaysia Perlis, highlight the worldwide cooperation that drives geopolymer research. Significantly, India emerges as a prominent participant, exemplifying the extensive acknowledgment of the potential of geopolymer technology in tackling the obstacles presented by traditional building materials.

The environmental issues linked to the manufacturing of conventional cement-based products, notably the concerning amounts of carbon dioxide emissions, provide a striking context for the environmentally beneficial characteristics of geopolymer bricks. Through the use of lower temperatures throughout the manufacturing process and the inclusion of industrial byproducts such as fly ash and slag, geopolymers effectively reduce their carbon footprint. The inherent durability of geopolymers and their capacity for being repurposed after their life span establishes geopolymers as a tempting option for building methods that prioritize environmental consciousness.

Scientometric instruments, such as R-Studio and Vos Viewer, have been important in elucidating the complex network of geopolymer research. The methodical technique, as shown in the flowchart, guarantees a meticulous screening procedure, enabling a sophisticated study of sources, affiliations, authors, and keywords. The use of scientific instruments not only amplifies the accuracy of the study but also showcases the multidisciplinary character of modern research, establishing a pattern for forthcoming investigations.

The main fields of study on geopolymer bricks used as building materials and any knowledge gaps were outlined in a qualitative evaluation. This thorough analysis broadens the framework's understanding and helps researchers identify high-impact journals and scholars. It also clarifies current patterns in the field's investigation of novel applications for geopolymer brick as construction materials.

The use of waste resources not only enhances sustainability but also establishes geopolymer bricks as feasible substitutes for traditional building materials. The

compressive strength, which varies from 2.1 to 42 MPa in different experiments, highlights the versatility and robustness of geopolymer bricks, rendering them appropriate for use in paver bricks, beams, and exposed surfaces. The versatility, along with the environmentally conscious characteristics, establishes geopolymer bricks as a fundamental element in the development of a sustainable future.

CRediT authorship contribution statement

Nikolai Ivanovich Vatin: conceptualization, drafting of the paper, methodology, formal analysis, writing – review & editing, revising it critically for intellectual content; **Tesfaldet H. Gebre**: writing – review & editing, drafting of the paper, formal analysis, revising it critically for intellectual content.

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Iftikhar S, Rashid K, Haq EU, Zafar I, Alqahtani FK, Khan MI. Synthesis and Characterization of Sustainable Geopolymer Green Clay Bricks: An Alternative to Burnt Clay Brick. *Constr Build Mater*. 2020;259: 119659.
2. Esparham A, Vatin NI, Kharun M, Hematibahar M. A Study of Modern Eco-Friendly Composite (Geopolymer) Based on Blast Furnace Slag Compared to Conventional Concrete Using the Life Cycle Assessment Approach. *Infrastructures*. 2023;8(3): 58.
3. Ibraheem M, Butt F, Waqas RM, Hussain K, Tufail RF, Ahmad N, Usanova K, Musarat MA. Mechanical and Microstructural Characterization of Quarry Rock Dust Incorporated Steel Fiber Reinforced Geopolymer Concrete and Residual Properties after Exposure to Elevated Temperatures. *Materials*. 2021;14(22): 6890.
4. Amran M, Lee YH, Fediuk R, Murali G, Mosaberpanah MA, Ozbakkaloglu T, Lee YY, Vatin N, Klyuev S, Karelia M. Palm Oil Fuel Ash-Based Eco-Friendly Concrete Composite: A Critical Review of the Long-Term Properties. *Materials*. 2021;14(22): 7074.
5. Shilar FA, Ganachari SV, Patil VB, Almakayeel N, Yunus Khan TM. Development and Optimization of an Eco-Friendly Geopolymer Brick Production Process for Sustainable Masonry Construction. *Case Studies in Construction Materials*. 2023;18: e02133.
6. Madani H, Ramezanianpour AA, Shahbazinia M, Ahmadi E. Geopolymer Bricks Made from Less Active Waste Materials. *Constr Build Mater* 2020;247: 118441.
7. Hodhod OA, Alharthy SE, Bakr SM. Physical and Mechanical Properties for Metakaolin Geopolymer Bricks. *Constr Build Mater* 2020;265: 120217.
8. Moonphukhiao A, Samran B, Chaiwichian S. Preparation and characterization of geopolymer/activated carbon composite materials used as a bone substitute material. *Materials Physics and Mechanics*. 2025;53(1): 150–158.
9. Subash N, Avudaiappan S, Adish Kumar S, Amran M, Vatin N, Fediuk R, Aepuru R. Experimental Investigation on Geopolymer Concrete with Various Sustainable Mineral Ashes. *Materials*. 2021;14(24): 7596.
10. Arunachelam N, Maheswaran J, Chellapandian M, Murali G, Vatin NI. Development of High-Strength Geopolymer Concrete Incorporating High-Volume Copper Slag and Micro Silica. *Sustainable*. 2022;14(13).
11. Wang Q, Ahmad W, Ahmad A, Aslam F, Mohamed A, Vatin NI. Application of Soft Computing Techniques to Predict the Strength of Geopolymer Composites. *Polymers*. 2022;14(6): 7601.
12. Nematollahi B, Ranade R, Sanjayan J, Ramakrishnan S. Thermal and Mechanical Properties of Sustainable Lightweight Strain Hardening Geopolymer Composites. *Archives of Civil and Mechanical Engineering*. 2017;17: 55–64.
13. Kuppusamy Y, Jayaseelan R, Pandulu G, Kumar VS, Murali G, Dixit S, Vatin NI. Artificial Neural Network with a Cross-Validation Technique to Predict the Material Design of Eco-Friendly Engineered Geopolymer Composites. *Materials*. 2022;15(10): 3443.

14. Gailitis R, Sprince A, Kozlovskis T, Radina L, Pakrastins L, Vatin N. Long-Term Properties of Different Fiber Reinforcement Effect on Fly Ash-Based Geopolymer Composite. *Crystals*. 2021;11(7): 760
15. Kumar VS, Ganesan N, Indira PV, Murali G, Vatin NI. Flexural Behaviour of Hybrid Fibre-Reinforced Ternary Blend Geopolymer Concrete Beams. *Sustainability*. 2022;15(10): 3443.
16. Wang S, Xue Q, Zhu Y, Li G, Wu Z, Zhao K. Experimental Study on Material Ratio and Strength Performance of Geopolymer-Improved Soil. *Construction and Building Materials*. 2020;267: 120469.
17. Al-Ghouti MA, Khan M, Nasser MS, Al-Saad K, Heng OE, Recent Advances and Applications of Municipal Solid Wastes Bottom and Fly Ashes: Insights into Sustainable Management and Conservation of Resources. *Environ Technol Innov*. 2021;21: 101267.
18. Bhogayata AC, Arora NK. Utilization of Metalized Plastic Waste of Food Packaging Articles in Geopolymer Concrete. *J Mater Cycles Waste Manag*. 2019;21: 1014–1026.
19. Matsimbe J, Dinka M, Olukanni D, Musonda I, A Bibliometric Analysis of Research Trends in Geopolymer. *Materials*. 2022;15(19): 6979.
20. Dhamija P, Bag S, Role of Artificial Intelligence in Operations Environment: A Review and Bibliometric Analysis. *TQM Journal*. 2020;32: 869–896.
21. Uysal M, Aygörmez Y, Canpolat O, Cosgun T, Faruk Kuranlı Ö. Investigation of Using Waste Marble Powder, Brick Powder, Ceramic Powder, Glass Powder, and Rice Husk Ash as Eco-Friendly Aggregate in Sustainable Red Mud-Metakaolin Based Geopolymer Composites. *Construction and Building Materials*. 2022;361: 129718.
22. Mahakhud R, Priyadarshini M, Prakash Giri J. Utilization of Ground Granulated Blast-Furnace Slag Powder in Brick Industry: A New Generation Building Material. *Materials Today: Proceedings*. [Preprint] 2023. Available from: doi.org/10.1016/j.matpr.2023.03.707.
23. Nikvar-Hassani A, Hodges R, Zhang L. Production of Green Bricks from Low-Reactive Copper Mine Tailings: Durability and Environmental Aspects. *Construction and Building Materials*. 2022;337: 127571.
24. Ahmed MM, El-Naggar KAM, Tarek D, Ragab A, Sameh H, Zeyad AM, Tayeh BA, Maafa IM, Yousef A. Fabrication of Thermal Insulation Geopolymer Bricks Using Ferrosilicon Slag and Alumina Waste. *Case Studies in Construction Materials*. 2021;15: e00737.
25. Ahmad M, Rashid K. Novel Approach to Synthesize Clay-Based Geopolymer Brick: Optimizing Molding Pressure and Precursors' Proportioning. *Construction and Building Materials*. 2022;322: 126472.
26. Das D, Gołąbiewska A, Rout PK. Geopolymer Bricks: The next Generation of Construction Materials for Sustainable Environment. *Construction and Building Materials*. 2024;445: 137876.
27. Youssef N, Lafhaj Z, Chapiseau C. Economic Analysis of Geopolymer Brick Manufacturing: A French Case Study. *Sustainability*. 2020;12(18): 7403.
28. Hematibahar MH, Kharun M, Fediuk RS, Vatin NI, Porvadov MG, Sabitov LS. Predicting the flexural strength of 3D-printed geopolymer reinforced concrete using machine learning techniques. *Materials Physics and Mechanics*. 2025;53(4): 22–34.
29. Saeed A, Najm HM, Hassan A, Sabri MMS, Qaidi S, Mashaan NS, Ansari K. Properties and Applications of Geopolymer Composites: A Review Study of Mechanical and Microstructural Properties. *Materials*. 2022;15(22): 8250.
30. Amran M, Al-Fakih A, Chu SH, Fediuk R, Haruna S, Azevedo A, Vatin N. Long-Term Durability Properties of Geopolymer Concrete: An In-Depth Review. *Case Stud. Constr. Mater.* 2021;15: e00661.
31. Qin Z, Shi Q, Qin D, Wang H, Luo Y, Wang W. Performance comparison of geopolymer and clay-cement grouting pastes and goaf effect evaluation of grouting backfilling method. *Front. Mater.* 2023;10: 1301504.
32. Rihan Maaze M, Shrivastava S. Design Development of Sustainable Brick-Waste Geopolymer Brick Using Full Factorial Design Methodology. *Constr Build Mater*. 2023;370: 130655.
33. Zheng Y, Xiao Y. A Comparative Study on Strength, Bond-Slip Performance and Microstructure of Geopolymer/Ordinary Recycled Brick Aggregate Concrete. *Constr Build Mater*. 2023;366: 130257
34. Pilien VP, Promentilla MAB, Leaño JL, Oreta AWC, Ongpeng JMC. Confinement of Concrete Using Banana Geotextile-Reinforced Geopolymer Mortar. *Sustainability*. 2023;15(7): 6037.
35. Elemam WE, Tahwia AM, Abdellatief M, Youssf O. Kandil MA. Durability, Microstructure, and Optimization of High-Strength Geopolymer Concrete Incorporating Construction and Demolition Waste. *Sustainability*. 2023;15: 15832.
36. Hosseinbor J, Madani H, Norouzifar MN. Improving the Characteristics of Less Active Geopolymer Binders Utilizing Ground Granulated Blast-Furnace Slag under Different Curing Conditions. *Sustainability*. 2023; 15(16): 12165.
37. Azimi Z, Toufigh V. Influence of Blast Furnace Slag on Pore Structure and Transport Characteristics in Low-Calcium Fly-Ash-Based Geopolymer Concrete. *Sustainability*. 2023;15(18): 13348.

38. Samarina T, Guagneli L, Takaluoma E, Tuomikoski S, Pesonen J and Laatikainen O. Ammonium removal by metakaolin-based geopolymers from municipal and industrial wastewaters and its sequential recovery by stripping techniques. *Front. Environ. Sci.* 2020;10: 1033677.
39. Chen L, Wang T, Li F, Zhou S. Preparation of geopolymer for *in-situ* pavement construction on the moon utilizing minimal additives and human urine in lunar regolith simulant. *Front. Mater.* 2024;11: 1413432.
40. Medpelli D, Seo D-K. Synthesis and Characterization of Dispersible Geopolymer Nanoaggregates. *Front. Chem.* 2020;9: 751085.
41. Singh N, Colangelo F, Farina I. Sustainable Non-Conventional Concrete 3D Printing—A Review. *Sustainability*. 2023;15(13): 10121.
42. Tukaziban A, Shon CS, Zhang D, Kim JR, Kim JH. Chung, CW. Synthesis and Evaluation of Geopolymer Mixtures Containing Chronologically Aged Basic Oxygen Furnace Slags. *Sustainability*. 2023;15(24): 16934.
43. Zhang J, Fernando S, Law DW, Gunasekara C, Setunge S, Sandanayake M, Zhang G. Life Cycle Assessment for Geopolymer Concrete Bricks Using Brown Coal Fly Ash. *Sustainability*. 2023;15(9): 7718.
44. Popovich J, Chen S, Iannuzo N, Ganser C, Seo D-K and Haydel SE. Synthesized Geopolymers Adsorb Bacterial Proteins, Toxins, and Cells. *Front. Bioeng. Biotechnol.* 2020;8: 527.
45. Kang X, Gan Y, Chen R, Zhang C. Sustainable Eco-Friendly Bricks from Slate Tailings through Geopolymerization: Synthesis and Characterization Analysis. *Constr Build Mater*. 2021;278: 122337.
46. Cong M, Zhang S, Sun D, Zhou K. Optimization of Preparation of Foamed Concrete Based on Orthogonal Experiment and Range Analysis. *Front. Mater.* 2021;8: 778173.
47. Robayo-Salazar R, Martínez F, Vargas A, Mejía de Gutiérrez R. 3D Printing of Hybrid Cements Based on High Contents of Powders from Concrete, Ceramic and Brick Waste Chemically Activated with Sodium Sulphate (Na_2SO_4). *Sustainability*. 2023;15(13): 9900.
48. Zhao X, Wang H, Gao H, Liang L, Yang J. Synthesis, Stability and Microstructure of a One-Step Mixed Geopolymer Backfill Paste Derived from Diverse Waste Slags. *Sustainability*. 2023;15(8): 6708.
49. Ivanović M, Knežević S, Mirković MM, Kljajević L, Bučevac D, Pavlović VB, Nenadović M. Structural Characterization of Geopolymers with the Addition of Eggshell Ash. *Sustainability*. 2023;15(6): 5419.
50. Zhang M, Qiu X, Shen S, Wang L, Zang Y. Mechanical and Thermal Insulation Properties of RGFRP Fiber-Reinforced Lightweight Fly-Ash-Slag-Based Geopolymer Mortar. *Sustainability*. 2023;15(9): 7200.
51. Nagaraju TV, Bahrami A, Azab M and Naskar S. Development of sustainable high performance geopolymer concrete and mortar using agricultural biomass—A strength performance and sustainability analysis. *Front. Mater.* 2023;10: 1128095.
52. Yatsenko EA, Goltsman BM, Novikov YV, Trofimov SV, Ryabova AV, Smoliy VA, Klimova LV. Recycling of Coal Combustion Waste through Production of Foamed Geopolymers with Improved Strength. *Sustainability*. 2023;15(23): 16296.
53. Haq Md ZU, Sood H, Kumar R, Merta I. Taguchi-Optimized Triple-Aluminosilicate Geopolymer Bricks with Recycled Sand: A Sustainable Construction Solution. *Case Studies in Construction Materials*. 2024;20: e02780.
54. Mortada Y, Masad E, Kogbara RB, Mansoor B, Seers T, Hammoud A, Karaki A. Development of Ca(OH)2-Based Geopolymer for Additive Manufacturing Using Construction Wastes and Nanomaterials. *Case Studies in Construction Materials*. 2023;19: e02258.
55. Ahmad M, Rashid K, Hameed R, Ul Haq E, Farooq H, Ju M, Physico-Mechanical Performance of Fly Ash Based Geopolymer Brick: Influence of Pressure – Temperature – Time. *Journal of Building Engineering*. 2022;50: 104161.
56. Li C, Tan G, Weng H, Shi J, Li S, Xie J. Feasibility of using FA and GGBS-derived geopolymer for high liquid limit soil stabilization. *Front. Mater.* 2025;12: 1643683.
57. Morsy MI, Alakeel KA, Ahmed AE, Abbas AM, Omara AI, Abdelsalam NR, Emaish HH. Recycling Rice Straw Ash to Produce Low Thermal Conductivity and Moisture-Resistant Geopolymer Adobe Bricks. *Saudi J Biol Sci*. 2022;29: 3759–3771.
58. Li Y, Shen J, Lin H, Lv J, Feng S, Ci J. Properties and Environmental Assessment of Eco-Friendly Brick Powder Geopolymer Binders with Varied Alkali Dosage. *Journal of Building Engineering*. 2022;58: 105020.
59. Kakodkar S, Sawaiker U. Composite Material Design for Bricks Manufacturing. *Mater Today Proc*. 2023;05: 663.
60. Usman Kankia M, Baloo L, Danlami N, Zawawi NA, Bello A, Muhammad SI. Microstructural Analysis and Compressive Strength of Fly Ash and Petroleum Sludge Ash Geopolymer Mortar under High Temperatures. *Sustainability*. 2023;15(12): 9846.
61. Aperador W, Bautista-Ruiz J, Sánchez-Molina J. Geopolymers Based on a Mixture of Steel Slag and Fly Ash, Activated with Rice Husks and Reinforced with Guadua Angustifolia Fibers. *Sustainability*. 2023;15(16): 12404.

62. Dai BB, Zou Y, He Y, Lan M, Kang Q. Solidification Experiment of Lithium-Slag and Fine-Tailings Based Geopolymers. *Sustainability*. 2023;15(5): 4523.
63. Hwalla J, Bawab J, El-Hassan H, Abu Obaida F, El-Maaddawy T. Scientometric Analysis of Global Research on the Utilization of Geopolymer Composites in Construction Applications. *Sustainability*. 2023;15(14): 11340.
64. Muhammad MK, Mohd Arif Zainol MRR, Ikhsan J Zawawi MH, Abas MA, Mohamed Noor N, Abdul Razak N, Sholichin M, Assessment of Debris Flow Impact Based on Experimental Analysis along a Deposition Area. *Sustainability*. 2023;15(17): 13132.
65. Nisa AU, Singh P. An Alkali Activated Geopolymer Concrete Brick Incorporated with Devri Stone Quarry Dust. *Mater Today Proc*. [Preprint] 2023. Available from: doi.org/10.1016/j.matpr.2023.03.085.
66. Hussain S, Amritphale S, Matthews J, Paul N, Matthews E, Edwards R. Advanced Solid Geopolymer Formulations for Refractory Applications. *Materials*. 2024;17(6): 1386.
67. Łach M, Róg G, Ochman K, Pławecka K, Bąk A, Korniejenko K. Assessment of Adhesion of Geopolymer and Varnished Coatings by the Pull-Off Method. *Eng*. 2022;3(1): 42-59.
68. Mukhametkaliyev T, Ali MH, Kutugin V, Savinova O, Vereschagin V. Influence of Mixing Order on the Synthesis of Geopolymer Concrete. *Polymers*. 2022;14(21): 4777.
69. Boros A, Korim T. Development of Geopolymer Foams for Multifunctional Applications. *Crystals*. 2022;12(3): 386.
70. Migunthanna J, Rajeev P, Sanjayan J. Waste Clay Bricks as a Geopolymer Binder for Pavement Construction. *Sustainability*. 2022;14(11): 6456.
71. Aurelie Tchouateu Kamwa R, Tchadjie Noumbissie L, Tome S, Idriss E, Giogetti Deutou Nemaleu J, Tommes B, Woschko D, Janiak C, Etoh MA. A Comparative Study of Compressed Lateritic Earth Bricks Stabilized with Natural Pozzolan-Based Geopolymer Binders Synthesized in Acidic and Alkaline Conditions. *Constr Build Mater*. 2023;400: 132652.
72. Mahdi SN, Babu RDV, Hossiney N, Abdullah MMAB. Strength and Durability Properties of Geopolymer Paver Blocks Made with Fly Ash and Brick Kiln Rice Husk Ash. *Case Studies in Construction Materials*. 2022;16: e00800.
73. Ahmari S, Zhang L. Durability and Leaching Behavior of Mine Tailings-Based Geopolymer Bricks. *Constr Build Mater*. 2013;44: 743–750.
74. Kabantsev O, Cajamarca-Zuniga D. Proposal for improving the solid clay brick contact surface to increase the initial shear strength of masonry. *Materials Today: Proceedings*. [Preprint] 2023. Available from: doi.org/10.1016/j.matpr.2023.05.640.
75. Yong-Sing N, Yun-Ming L, Cheng-Yong H, Abdullah MMAB, Rojviriya C, Khalid MS, Shee-Ween O, Wan-En O, Yong-Jie H. Interaction of Silica Fume on Flexural Properties of 10 Mm-Thickness Geopolymers Based on Fly Ash and Ladle Furnace Slag under the Thermal Conditions. *Journal of Building Engineering* 2023;69: 106331.
76. Naenudon S, Vilaivong, Zaetang Y, Tangchirapat W, Wongsa A, Sata V, Chindaprasirt P. High Flexural Strength Lightweight Fly Ash Geopolymer Mortar Containing Waste FIber Cement. *Case Studies in Construction Materials* 2022;16: e01121.
77. George G, Shreeram PK, Minalan AS, Lokesh K, Mano M, Prince A. Numerical Investigation on the Flexural Behavior of Geopolymer Concrete Beam Reinforced with Different Types of Fiber-Reinforced Polymer Bars. *Mater Today Proc*. 2023;16: e01121.
78. Cajamarca-Zuniga D, Kabantsev OV, Campos D. Geometric characterization of solid ceramic bricks for construction in Ecuador. *Structural Mechanics of Engineering Constructions and Buildings*. 2023;19(3): 329-336.
79. Zheng Y, Xiao Y, Wang C, Li Y. Behavior of Square Geopolymer Recycled Brick Aggregate Concrete Filled Steel Tubular Stub Columns under Axial Compression. *Constr Build Mater*. 2023;363: 129823.