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Bricks and Brick Modification: A Bibliometric Perspective of Research Trends and Collaborations

Tolulope Elizabeth Aniyikaiye[1]
[1]*Department of Civil Engineering, Faculty of Engineering, Built Environment and Information Technology, Walter Sisulu University, Buffalo City Campus, College Street Site, Private Bag X1421, East London, 5201, Eastern Cape, South Africa.*
taniyikaiye@wsu.ac.za

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ABSTRACT

Introduction: Bricks have long been regarded as one of the most valuable building materials due to their cost-effectiveness, durability, and thermal insulation properties. Traditionally manufactured from clay and burned in kilns, bricks have played a vital role in the development of architecture and infrastructure across nations. Nonetheless, advancements in brick production have been driven by growing environmental concerns, the depletion of natural resources, and the increasing demand for sustainable construction techniques. Modified bricks manufactured by incorporating agricultural or industrial waste products, or alternative binders, provide enhanced environmental sustainability without compromising structural integrity.

Objectives: This study aims to assess the evolutionary trend in publications, citations, and collaborative networks, and explore the prevalent themes in bricks and brick modification-related research.

Methods: The bibliometric data for this study were retrieved from the Web of Science Core Collection database. The search strategy focused on articles related to *bricks* and *brick modification* published between 2003 and 2025. The collected data was visualised using the VOSviewer software.

Results: Findings from the study indicate that the People's Republic of China is the most influential country in the research domain, as measured by publication output and total citation counts, with four Chinese institutions leading globally. However, in terms of international research collaboration, the United States of America ranks first, followed by China. Furthermore, the major schools of thought within this research domain focus on: the transition of brick production from rudimentary pottery techniques to advanced ceramic innovations; sustainable brick production through the incorporation of waste materials into brick raw materials; the partial shift toward earthen construction materials; improvement of clay and earthen brick characteristics; the performance of brick masonry in modern buildings; the reuse of recycled bricks in mortar and concrete production; and brick market dynamics and sales.

Conclusions: Traditional clay bricks remain essential in construction, yet their production raises concerns about sustainability and resource depletion. Modified bricks, developed through the incorporation of industrial and agricultural by-products, provide an eco-friendly alternative while maintaining desirable mechanical and thermal properties. Their adoption represents a practical step toward greener construction practices; however, further research and standardization are needed to ensure widespread adoption.

Keywords: *bibliometric analysis, bricks, environmental sustainability, modified brick, waste products*

INTRODUCTION

The rapid growth of the global population and increased migration to urban centers have led to a significant rise in housing demand (Murmu & Patel, 2018). This surge in shelter has, in turn, increased the request for various

building materials, including cement, timber, and bricks (Esidir & Gültekin, 2023). Among these, bricks remain one of the most sought-after materials in the modern world for use in the construction of various civil engineering structures (Weyant et al., 2016). Brick has several advantages over natural stone and wood, including easy access to its georesources, low production cost, and the flexibility of modifying its raw material composition or production procedure to acquire specific technical and aesthetic qualities (Aniyikaiye et al., 2021; Coletti et al., 2016). Additionally, the toughness and light weight of bricks make them an excellent alternative construction material, as they are easy to stack, load, and transport without damage (Littlejohn, 2019).

The origins of bricks date back to around 7000 BC in Mehrgarh, during the pre-Harappan era, when bricks were used in the form of sun-dried mud blocks. This was followed by the emergence of baked brick in the Indus Valley culture (Khan & Lemmen, 2013). Brick composition and brick-making techniques have undergone significant changes since then. Nowadays, bricks are mostly made from a suitable ratio of clay and sand (Aniyikaiye, 2024). To develop clay brick as a sustainable building material, utilising industrial and agricultural waste materials is a practical solution (Phonphuak & Chindaprasirt, 2015). Numerous waste materials with varying compositions are used as raw materials at different dosage levels to produce fired masonry bricks. Waste materials used in past studies include blast furnace slag, duff, biochar, fly ash, and rice husk, among others. These wastes often serve as pore formers and internal fuel in fired brick, thus potentially reducing soil exploitation and external energy consumption for brick production (Aniyikaiye et al., 2021).

The brick-production procedure could also be modified to incorporate or improve specific characteristics in the final product. For example, fired brick was found to exhibit a more complete mineralogical evolution and excellent mechanical resistance, but a weak water absorption capacity when a firing temperature of 1050 °C was used. On the contrary, good pore interconnections with a low coefficient of capillarity but weak resistance to under-load and decay tests were observed in bricks fired at 600 °C, while bricks fired at 950- 980 °C showed intermediate behaviour (Coletti et al., 2016).

Bricks are primarily used as building materials because they offer a distinct combination of thermal and structural properties that could be enhanced by other types of construction medium (Rice & Vosloo, 2014). The high tensile strength, resilience, thermal and acoustic insulation, as well as fire and weather resistance of fired bricks make them preferable to sun-dried bricks (Dalkılıç & Nabikoğlu, 2017). However, considering the high energy requirement and greenhouse gas (GHG) emissions associated with fired bricks, it is imperative to utilize construction materials with less energy demand. Oti & Kinuthia (2012) discovered a more sustainable method of clay brick production. The method entails stabilising clay with ground granulated blast furnace slag, which has been activated with lime or Portland cement prior to use for unfired bricks production. This method yielded unfired bricks with lowered GHG emissions and improved durability. Bricks could also be composed of earthen materials such as rammed earth, adobe bricks, and stabilized soil blocks. These earthen materials are sustainable construction materials, with their raw materials being locally available. The earthen soil could be stabilized with various compounds, after which the stabilized block is pressed into a suitable shape and size that can be either fired or sun-dried (Murmu & Patel, 2018).

Besides the sun-dried clay bricks, fired clay bricks, and earthen bricks, there is the cement brick type. Generally, the characteristics of bricks can be improved by incorporating certain innovative materials into the raw materials of the brick. Surol et al. (2024) improved the compressive strength and water absorption capability of cement bricks by incorporating varying proportions (20-40%) of egg tray wastes into the cement mixture. Ouedraogo et al. (2020) included 2-4% of cement into earth bricks to improve the compressive strength and water resistance characteristics of the earth brick. Sadouri et al. (2024) also improved the thermal performance by minimising the thermal conductivity of earth blocks when natural fibers (0.4%) and cement (5%) were incorporated into the earthen bricks. Additionally, the energy utilisation in a building can be optimised and energy conserved by adopting innovative measures, such as the inclusion of insulation material either within the masonry brick mix or by filling the holes of the masonry bricks with insulating material (Al-Hadhrami & Ahmad, 2009). Brick surfaces could also be modified to improve the performance properties of the brick. For instance, Cheraghcheshm & Javanbakht (2021) improved the hydrophobic, photocatalytic, and antibacterial properties of bricks by coating the surface with zinc oxide-silver

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nanoparticles. The results indicated a 1.8-fold improvement in flexural strength and a reduction in efflorescence on the surface of the brick coated with ZnO/Ag compared to the non-coated brick.

OBJECTIVES

Over the last few decades, researchers worldwide have conducted extensive research on brick-related topics. Discovering trends and knowledge gaps in the research field might be challenging due to the vast volume of publications. In this regard, this study aims to assess the evolutionary trend in publications, citations, and collaborative networks, and explore the prevalent themes in bricks and brick modification-related research

METHODS

The bibliometric data were collected using the Web of Science (WoS) Core Collection database. A comprehensive search of bricks and brick modification articles published between 2003 and 2025 was conducted on June 6, 2025, using the following search strategies (title, abstract, keywords) = ["bricks" AND "brick modification"]. A total of 10,535 publications were identified (fig.1). The literature type was filtered to "Article," and the language was restricted to English, resulting in 9,542 articles. The bibliometric and visualization analysis was conducted using VOSviewer (version 1.6.20). In this study, the VOSviewer was used to investigate the influential authors, organisations, journals, countries, and their collaborative efforts, as well as the common schools of thought among scholars in the bricks and brick modification research domain.

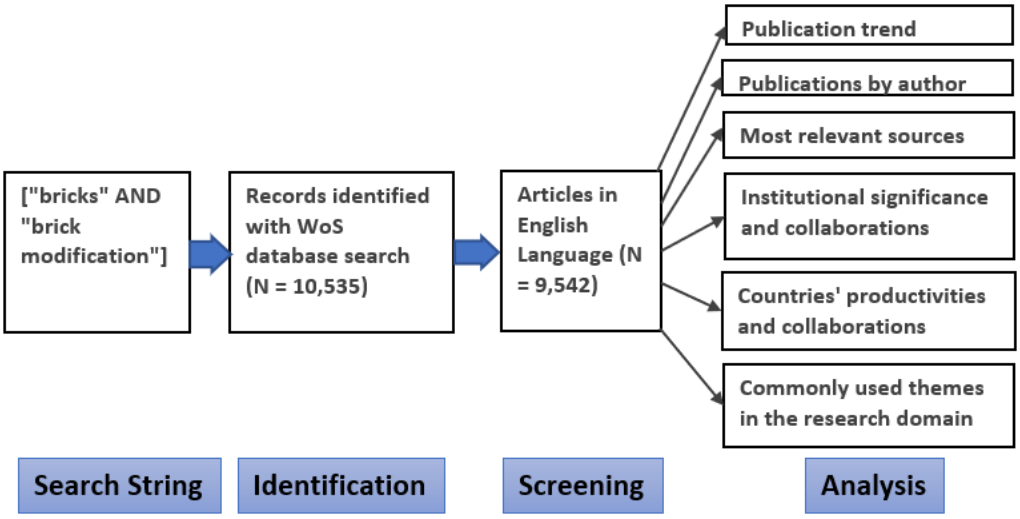

Fig.1. Flowchart illustrating the methodology

RESULTS

In this section, the findings are discussed, taking into account various considerations, including publication years, impactful authors, countries, and institutions, in terms of publications, total citations, and collaboration. The prevalent themes in brick and brick modification publications, as identified through keyword co-occurrences, were also presented.

DISCUSSION

Descriptive statistics

Upon screening the database collection from the WoS, a total of 9,542 publications, comprising only journal articles, were obtained. The publications in the dataset used for the study were published in 2,399 journals by 31,564 authors affiliated with 7,601 organizations from 141 countries. The database collection has 31,642 keywords.

Historical progress

An excellent measure of growth in a research topic is the number of publications it receives each year. Over time, there have been an increasing number of publications on brick and its modification, indicating a growth in scholarly

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interest in brick-related research. Fig. 2 presents the annual trends of publications on the topic from 2003 to June 2025. There has been a gradual increase in the publication number since 2003, till 2019, after which a sharp increase was observed between 2019 and 2021, followed by a gradual increase till 2024. Although a decrease in publication numbers was observed in 2025, it is essential to note that the data were collected up to 2 June 2025, meaning that the 2025 data included in the study were incomplete compared to other years, which could have contributed to the drop in 2025.

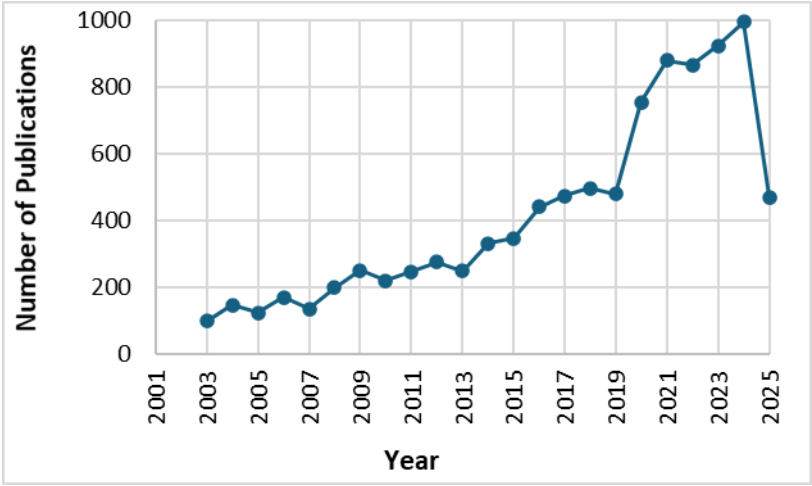

Fig. 2. Publications by year

Authorship

The study indicated that 31,564 authors were involved in brick and brick modification research. The top nine researchers in this research field are shown in Fig. 3. Based on the publication counts and total citations from the collected dataset, Sutcu, M., took the lead with 41 publications and 1,870 citations, followed by Gencel, O., with 39 publications and 1,506 citations. Based on publication count, Cultrone, G. took the third position with 32 publications; however, considering total citations received, the third position was shifted to Eliche-quesada, D., with 1,249 citations.

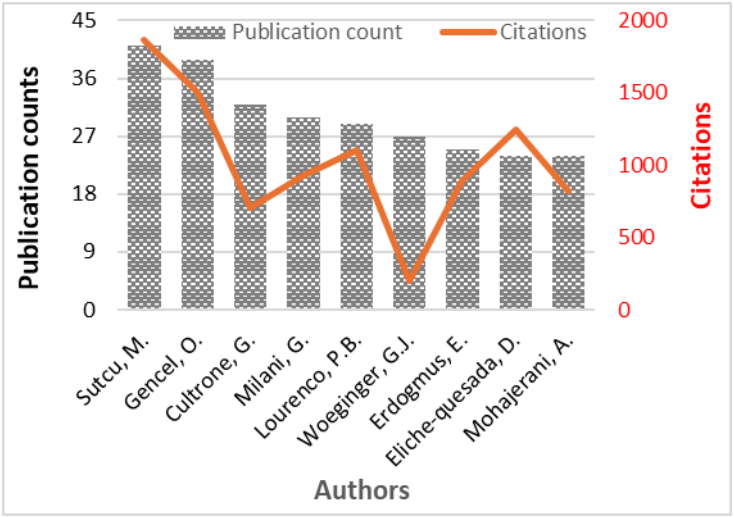

Fig. 3. Number of publications by author in the brick and brick modification research domain

Publication Sources

The dataset used for the study showed that 2,399 journals were used for publications related to brick and brick modification. The top 10 relevant sources, based on the number of publications and total citations received in this

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research domain, are presented in Fig. 4a and b. Findings revealed the Journal of Construction and Building Materials as the most impactful journal in brick and brick modification research, with 786 publications and 29,549 citations. Based on publication count, the Journal of Building Engineering and Ceramic International Journal took the second and third positions with 242 and 203 publications, respectively. On the other hand, the Journal of Cleaner Production and the Journal of the American Chemical Society took second and third positions, based on total citations received, with 7,000 and 6,905 citations, respectively.

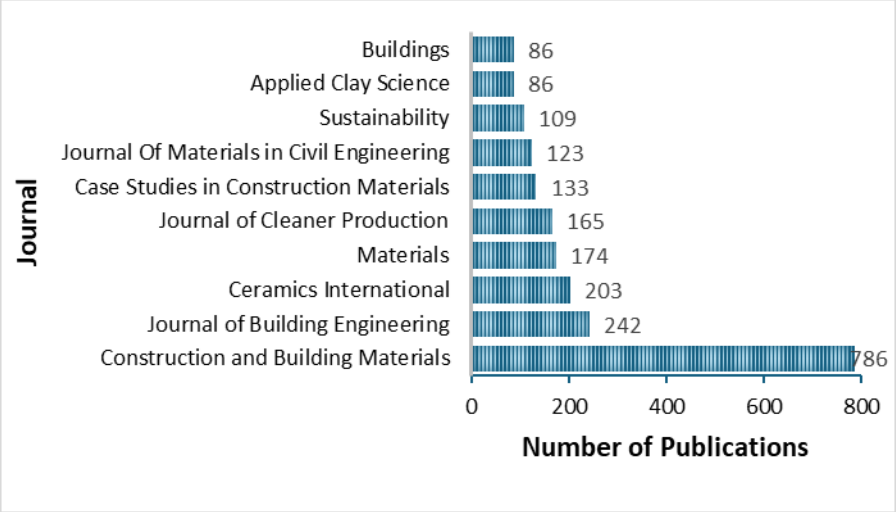

Fig 4a. The top 10 relevant sources based on the number of publications and total citations

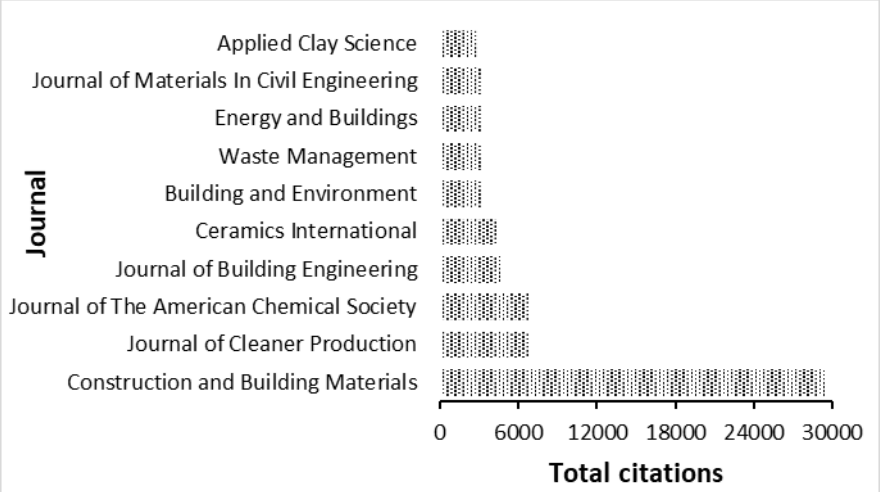

Fig 4b. The top 10 relevant sources based on total citations

Country participation and collaboration in brick and brick modification-related research.

This section discusses the contributions and collaborative efforts of countries in brick and brick modification research. A total of 141 countries were involved in the research (Fig. 5a). The participating countries are indicated in blue on the map, with a deeper hue of blue representing countries with a high number of publications in bricks and brick modification-related research, and vice versa. It is important to note that the countries not involved in the research are the ones presented in ash colour. Based on the number of publications and total citations in the relevant research field, the People's Republic of China, the United States of America, and Italy took the lead with publication and citation counts of 1,716 and 34,389, 928 and 26,739, and 818 and 24,725, respectively (Table 1). Fig. 5b further illustrates the countries' participation in research related to bricks and brick modification. The nodes represent the publication counts of the countries, where the size of each node is determined by its corresponding publication count (Aniyikaiye & Ikudayisi, 2025). Invariably, higher publication counts are

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represented by larger nodes, and vice versa. In addition, the edges represent the collaboration between countries; the thicker the edges, the greater the extent of collaboration between the countries they connect. For investigating the collaborative significance of countries, factors such as Links and Total link strength (TLS) were considered. Link is the number of countries with which a country is associated in collaborative research. On the other hand, TLS refers to the total number of times a country is linked with others in collaborative research within a given field (Jan van Eck & Waltman, 2023). Considering collaborative significance based on the total link strength, the USA took the lead with TLS of 725, followed by China and England with TLS of 556 and 537, respectively.

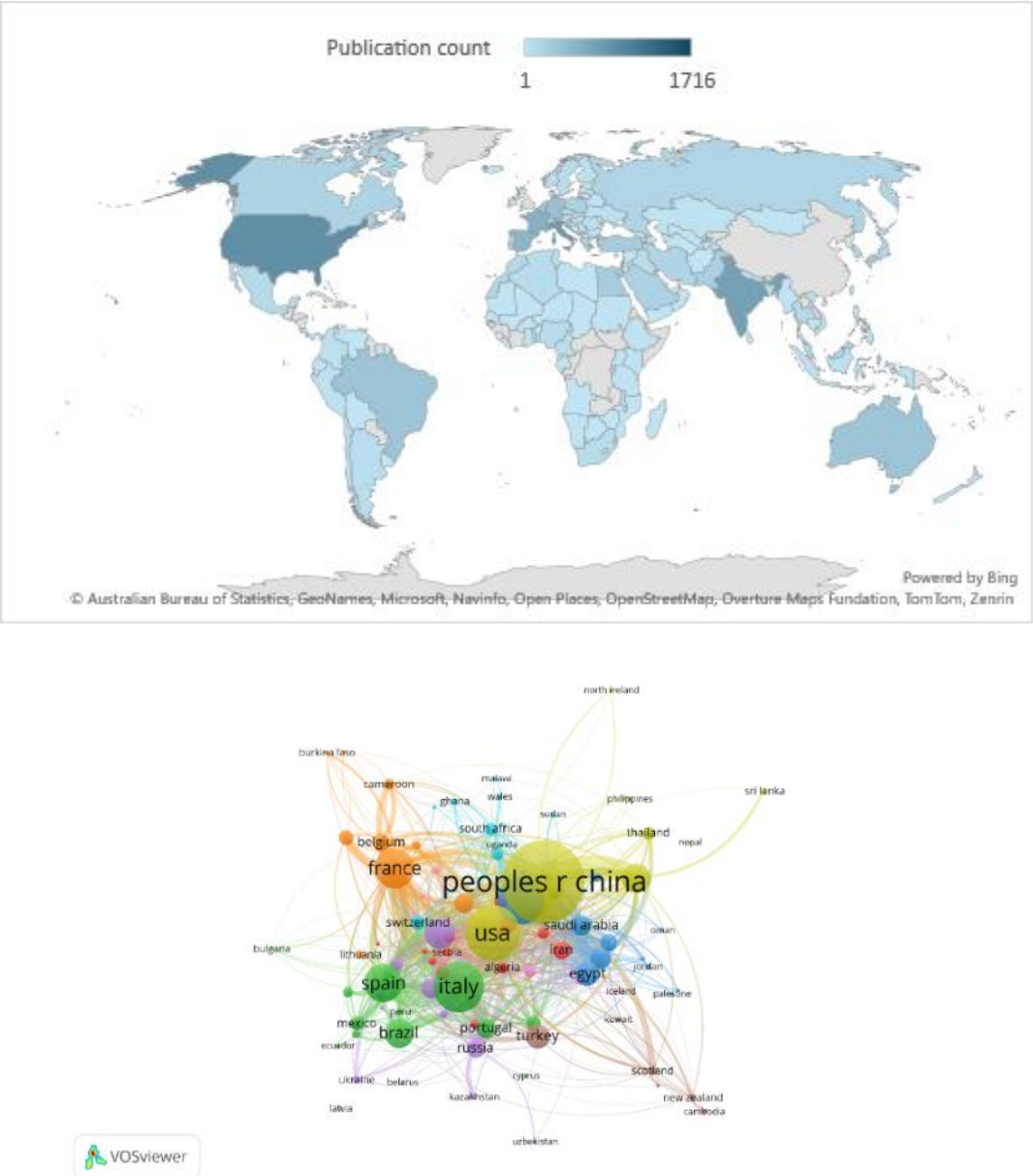

Fig. 5: Countries' participation (a) based on publication count (b) collaborative impact

Table 1: The most influential countries in brick and brick modification research

Country	Publication count	Citations	Links	Total link strength (TLS)	TLS rank
Peoples R. China	1716	34389	63	556	2
USA	928	26739	74	725	1

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Italy	818	24725	73	515	4
India	730	14122	54	244	9
France	569	19530	68	488	5
Spain	525	13327	56	396	7
England	489	13240	81	537	3
Germany	392	9136	70	433	6
Australia	351	9279	48	321	8
Brazil	350	6542	37	152	10

Productivity and Collaboration among Institutions

Findings from this bibliometric study indicated that 7,601 were involved in bricks and brick modification-related research from 2003 to June 02, 2025. The Chinese Academy of Sciences was found to top the list of institutions with 106 publications. This was followed by University Science and Technology Beijing, Wuhan University of Science and Technology, and Tongji University with 79, 70, and 70 publications, respectively (Fig. 6a)). Based on the collaborative significance of the institutions in bricks and brick modification-related research, findings from this review have shown the Chinese Academy of Science to be the leading institution (Fig. 6b). However, the other top nine institutions based on publication count were not actively involved in collaborative research with other institutions, since they were not found among the top ten institutions based on the total link strength, as shown in Table 2.

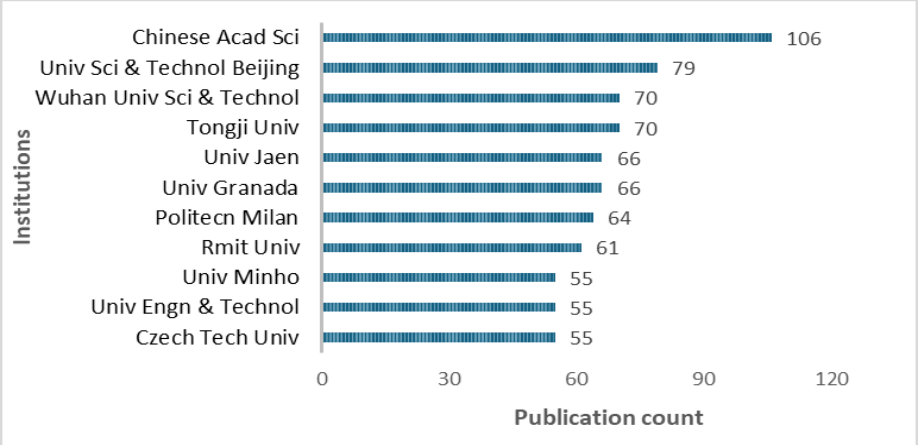

Fig. 6a: Institutional significance in bricks and brick-modification research in terms of publication counts

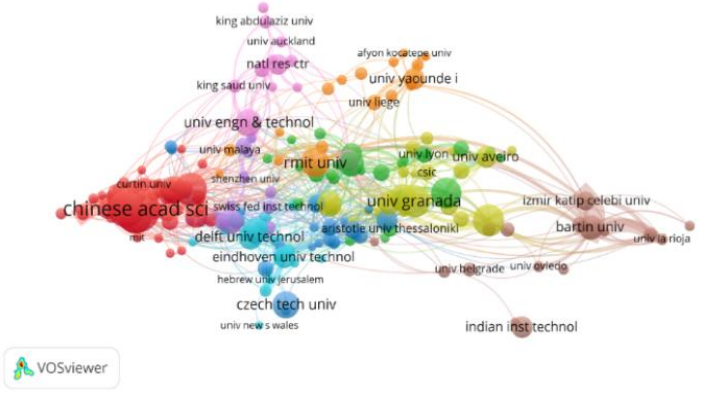

Fig. 6b: Institutional significance in bricks and brick-modification research in terms of collaborative strength

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Table 2: The most influential institutions in brick and brick modification research

Institution	Links	Total link strength (TLS)	TLS rank	Publication count	Citations
Chinese Acad Sci	34	77	1	106	2746
Bartin Univ	14	71	2	50	1687
Izmir Katip Celebi Univ	11	54	3	37	1369
Univ Autonoma Chile	8	50	4	27	595
Univ Padua	22	44	5	42	1242
Univ Jaen	13	41	6	66	2503
Univ Engn & Technol	21	39	7	55	1151
Univ Naples Federico Ii	24	39	7	46	1535
Cnr	22	39	7	42	799
Univ Granada	13	38	10	66	2116

Themes in the bricks and brick modification research

Themes in brick and brick modification-related research encompass the prevailing schools of thought among scholars in this field. Using VOSviewer, keyword co-occurrence analysis was conducted with a threshold frequency of 40. A co-occurrence network with 6 clusters was generated (Fig. 7). Each cluster comprises closely related words commonly used by authors in the bricks and brick modification research domain.

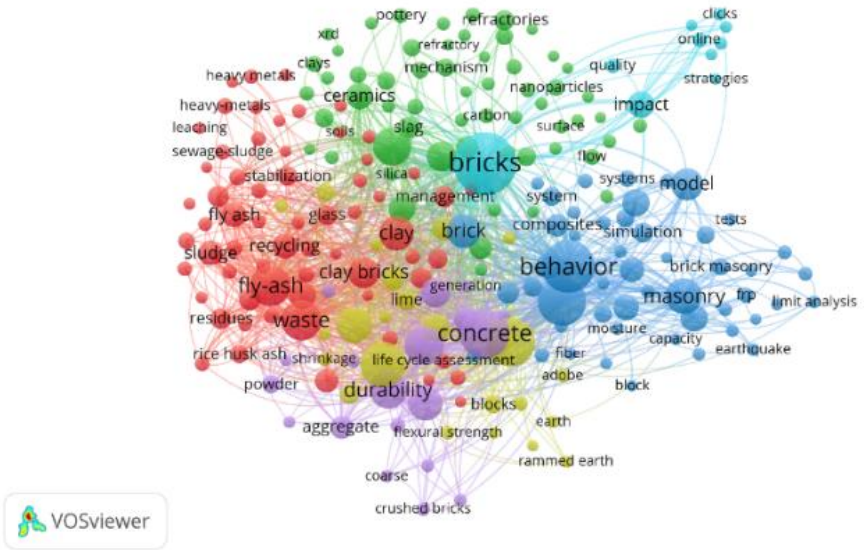

Fig. 7. Co-occurrence of keywords

The summary of the themes used in the research domain, subdivided into six clusters, is as follows:

Red cluster: The red cluster comprises keywords such as “waste,” “clay,” “clay bricks,” “ash,” “ recycling,” “ sludge,” “fly ash,” “sustainability,” “fired clay bricks,” and “geopolymer”. This cluster primarily focuses on the development of sustainable construction materials by partially replacing soil (used in brick production) with agricultural and industrial waste products. The use of these waste products in brick production helps reduce the extent of environmental degradation caused by soil depletion and the high energy required for firing (Aniyikaiye, 2024). Additionally, the inclusion of these waste products in brick improves the mechanical properties and promotes the recycling of agricultural and industrial wastes, thereby enhancing the production of sustainable construction materials (Zhang, 2013).

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Green cluster: In the green cluster, terminologies such as “microstructure,”, “temperature”, “ceramics”, “porosity”, “mortars”, “slag”, “refractories”, “firing temperature”, “resistance”, “evolution”, “nanoparticles”, “clays”, “quartz”, “minerology”, “pottery”, “fabrication” were used. The cluster explores the evolution of brick production, from ancient pottery techniques to advanced ceramic processing. The mineralogy of clay, such as quartz, which influences characteristics like porosity, microstructure, and the thermal resistance of the final product, is a key factor in determining brick performance. Additionally, the firing temperature in brick production plays a crucial role in phase transitions and densification, influencing the structure and durability of the final brick (Coletti et al., 2016). Incorporating industrial residues such as slag and refractories improves the mechanical strength and corrosion resistance of bricks (Oti & Kinuthia, 2012).

Blue cluster: Keywords such as “behaviour,“ ”performance,” “masonry,” “brick,” “model,” “walls,” “design optimization,” “buildings,” “mortar,” “composites,” “energy,” “simulation,” “ conductivity,” thermal performance,“ heat-transfer,” “brick masonry systems,” “frp,” “insulation,” “composite homogenization,” “fracture,” and “thermal insulation” were used. This cluster addresses the behavior and performance of brick masonry in modern buildings. Building design, material composition, and the interaction between brick and mortar are key factors influencing how brick masonry behaves and performs in modern buildings. Advancements in composites and fiber-reinforced polymers (FRP) have improved the mechanical integrity and fracture resistance of walls, particularly in seismic regions (Triantafillou & Fardis, 1995). Another crucial component of masonry systems is their thermal performance, which emphasises conductivity, heat transmission, and thermal insulation. Energy-efficient solutions can be developed to reduce heat loss in buildings by utilising composite materials and improved insulation techniques (Al-Hadhrami & Ahmad, 2009).

Orange cluster: It comprises the keywords such as “strength,” “compressive strength,” “cement,” “thermal conductivity,” “adobe bricks,” “soil thermal-conductivity,” “lime,” “water absorption,” “hydration blocks,” “flexural strength,” “fibers,” “adobe,” “gypsum,” “phosphogypsum,” “density,” “shrinkage,” “mechanical strength,” “physical properties,” “earth,” “rammed earth,” “hygrothermal properties” amongst others. The cluster focuses on earthen construction materials, including rammed earth, adobe bricks, and stabilised soil blocks, and explores how the mechanical strength and physical properties of these materials can be enhanced. Incorporating stabilizers such as phosphogypsum, lime, cement, and gypsum into these materials can improve their compressive strength and flexural strength, while minimizing shrinkage and water absorption, thereby enhancing durability (Murmu & Patel, 2018). The incorporation of synthetic or natural fibers has also been found to enhance the crack resistance and tensile behaviour (Aymerich et al., 2012; Jesudass et al., 2020).

Purple Cluster: The school of thought in this cluster deals with the reuse of crushed bricks and clay brick powder derived from demolition activities for partial replacement of natural coarse aggregate and sand in mortar and concrete production. Authors with this school of thought used keywords such as “concrete,” “durability,” “construction,” “mechanical properties,” “aggregate,” “clay brick powder,” “demolition waste,” “sand,” “construction and demolition waste,” “crushed bricks,” “coarse aggregate,” “thermal properties,” “coarse recycled aggregate,” “physical properties,” and “replacement”. It is recommended that the replacement of natural aggregate with brick aggregate should not exceed 20%, so that the durability performance of the concrete is maintained. This innovation not only minimises waste generation but also promotes the circular economy in the construction industry by producing durable and structurally sound concrete mixtures with modified aggregate properties (Wong et al., 2018).

Sky blue cluster: Keywords such as “bricks,” “impact,” “quality,” “online internet clicks,” “competition,” “e-commerce strategies,” and “coordination” were used. This school of thought primarily deals with the online sales of physical products.

CONCLUSION

Bricks have evolved significantly from their rudimentary forms to advanced units that are well-suited for contemporary construction requirements. Although traditional clay bricks are still widely used, their reliance on natural resources and environmental impact has prompted the quest for more sustainable alternatives. Modified bricks incorporating agricultural or industrial by-products have demonstrated considerable potential in reducing

greenhouse gas emissions, conserving natural resources, and enhancing overall material performance. In this study, a bibliometric analysis of bricks and brick modification was conducted to investigate the evolutionary trend with respect to publication years, as well as the impact of authors, institutions, and countries. The prevalent schools of thought in this research domain were also explored using the VOSviewer software. Findings from the study showed a continual growth in publications in the research domain, indicating high scholarly interest in brick and brick modification-related research. The results also indicated that China was the most influential country in the research domain, based on publication counts and total citations received, with four institutions from China taking the lead globally. However, considering collaborative research with other countries, the United States of America took the lead, followed by China, England, and Italy. Using the VOSviewer, six clusters of keywords were generated, signifying the common themes among authors in the research domains. The popular themes among scholars in this research domain are: the development of sustainable construction materials through the partial replacement of soil with wastes; the evolution of brick production from rudimentary pottery techniques to advanced ceramics innovation; the behaviour and performance of brick masonry in modern buildings; earthen construction materials as sustainable substitute to fired clay and how the mechanical and physical characteristics of these materials could be improved; the reuse of crushed bricks from demolition activities; and the online sales of bricks.

The innovations explored in this study align well with the Sustainable Development Goals (SDG) 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). As research progresses in refining the composition and manufacturing techniques of modified bricks, the widespread application can significantly enhance economically viable and sustainable construction. Future initiatives should focus on standardising performance metrics, raising stakeholder awareness, and reinforcing legislative frameworks that would enable the adoption of sustainable brick technologies.

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