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Review

Evaluating research on the utilization of recycled Brick aggregates in concrete

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Abstract
Considering the substantial production of concrete and the significant generation of demolition waste resulting from the dismantling of old concrete structures, the reuse of construction and demolition waste (CDW) has become crucial. Numerous studies have been conducted to assess the adequacy of the mechanical behavior of concrete incorporating CDW within the last two decades. However, there is a dearth of scientometric reviews on studies examining the environmental impacts of CDW. To address this gap, science mapping methods were utilized to conduct a bibliometric analysis of research on the environmental impacts of CDW. To conduct a comprehensive scientometric assessment of the utilization of recycled brick aggregates in concrete (RBAC) production, a search was performed in the Scopus database. The search primarily focused on the keywords "recycled bricks" and "concrete" to retrieve relevant papers. The objective of this study was to conduct a scientometric analysis of the bibliometric data on recycled bricks to identify its key components. The findings of this study included the following: (1) identifying the mostly focused area on the use of recycled bricks in concrete, (2) identifying authors with the greatest contribution, (3) journals with the most publications, (4) countries that contributed most in terms of publications, and (5) publications with highest number of citations. The findings suggest that the mechanical properties of RBAC have been the core of existing research. Existing studies have focused on the behavior of RBAC under monotonic loading only. The application of RBAC in structural contexts requires considerable attention, as prior research has yet to concentrate on this specific domain. No empirical research has yet explored the incorporation of recycled brick aggregate concrete in the presence of lap splices or within shear-dominated regions. Existing research has revealed substandard mechanical properties of RBAC that induce concerns for its structural applications. Given the state-of-the-art of RBAC and its applications, its behavior needs to be examined for reinforced concrete structural members. Moreover, the provisions of modern codes for RBAC also require significant attention. Moreover, the behavior of RBAC concrete under reverse cyclic loading needs attention.

Article highlights

- This study endeavors to chart the scope of research on recycled brick aggregate concrete within the last two decades.
- The current research on recycled brick aggregate concrete (RBAC) was reviewed using scientometric-based analysis.
- The majority of research on RBAC has focused on evaluating and enhancing their mechanical properties.

Keywords Scientometric · Recycled bricks · Top contributing authors · Countries · Sources · Mechanical properties · Concrete

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1 Introduction

The demand for concrete has risen due to the expansion of urbanization and industrialization [1–3]. It is a highly prevalent construction material worldwide [4], and is the second most utilized resource on the planet, following water [5]. The production of concrete worldwide was estimated to be about 30 billion tonnes annually [6]. The yearly global production of concrete is estimated to surpass 12 billion tonnes [7]. However, this manufacturing and consumption process has a considerable environmental impact, rendering the current concrete industry unsustainable. Specifically, over 2.1 billion tonnes of human-related greenhouse gases are generated annually due to global concrete production, accounting for more than five percent of such emissions [8].

It is believed that the present concrete approach is unsuitable since it entails substantial consumption of cement, sand, and aggregate, leading to the depletion of natural resources [9]. With aggregates accounting for 60–75% of the concrete volume, there is immense pressure on quarries that are quickly depleting [10]. In EU countries, the combined requirement for raw aggregate is roughly 2.7 billion tonnes per year [11]. Similarly, the USA requires approximately 900 million tonnes per year, while Brazil consumes around 700 million tonnes per year [12]. This indicates that there is a pressing need to find an alternative approach to meet the increasing demands of the construction sector. Annually, a significant amount of construction and demolition waste (CDW) is produced worldwide, leading to severe environmental repercussions that have sparked significant research efforts over the last two decades. According to reports, the global annual production of CDW surpasses 10 billion tonnes, with the United States generating around 530 million tonnes and the European Union producing over 850 million tonnes [13]. Due to rapid urbanization and extensive urban renewal initiatives, China generates over 2.3 billion tonnes of CDW annually, accounting for approximately 40% of the total solid waste produced [14]. The environmental consequences of CDW are a global concern [15]. Despite recycling being a viable alternative, landfills remain the primary CDW treatment method in many regions, with roughly 35% of CDW worldwide being sent to landfills [16]. The largest global producer of CDW is China, which generates approximately 2 billion tonnes of such waste each year. Of this amount, it is estimated that 65% comprises waste concrete, while 80% is a combination of concrete and brick waste [17]. It is not easy to determine the exact quantity of brick waste generated due to the manufacturing rejection of non-conforming and unmarketable bricks, but it still accounts for a significant proportion [18]. Concrete is the most common construction material, with brick being the second most commonly used building material. In China, brick waste generation reaches 0.4 billion tonnes yearly [19]. According to sources [20, 21], India ranks as the world's second-largest brick manufacturer, and the estimated amount of brick waste it produces constitutes 32% of the total CDW, which is greater than 28% of concrete waste. It is estimated that approximately 315 tonnes of brick waste is generated by demolishing an area of 50,000 m^2 [22]. The United States environmental data fact sheet reveals that CDW produced around 44 million tonnes of brick waste during 2012–2014, requiring significant landfill space to dispose of it. Therefore, recycling brick waste becomes crucial.

The previous discussion highlights two primary concerns regarding the construction sector: (1) the quick escalation in demand for concrete caused by a rapidly expanding population and (2) the equally concerning issue arising from the significant generation of CDW. The predominant approach for disposing of construction waste in numerous regions, which involves underground landfills, has adverse effects on the surrounding environment [23]. Considering the substantial production of concrete and the significant generation of demolition waste resulting from the dismantling of old concrete structures, the reuse of CDW has become crucial. It is crucial to explore the feasibility of incorporating different waste materials as supplementary cementitious materials to address the depletion of natural resources and enhance the strength of concrete, as indicated by research [24]. This trend is fueled not only by the imperative to protect the environment but also by the pressing necessity to conserve precious natural aggregate resources, and the shortage of available land for waste disposal coupled with the escalating expenses associated with waste treatment preceding disposal, [25]. Waste materials have the potential to serve as a substitute for aggregates [26–30] or cement [31–35] in concrete. Several investigations have been conducted on using bricks as a partial substitute for natural aggregates in concrete and highlighted the potential of recycled aggregate concrete in structural and non-structural applications [36–43]. RBAC boasts several key advantages, primarily attributable to its lower density compared to stone [44]. This characteristic results in a relatively lighter weight. Additionally, RBAC demonstrates enhanced resistance to fire, owing to the excellent refractory properties inherent in bricks, as observed by Khalaf and DeVenny [45]. The primary drawbacks associated with RBAC stem from its subpar mechanical and durability characteristics. Notably, RBAC exhibits lower strength and elastic modulus [42, 46]. Moreover, it displays larger creep, and a deformation under sustained load [47]. Additionally, RBAC shows weaker resistance to carbonization and chloride penetration [48]. The drawbacks of RBAC primarily stem from the brick materials' porous structure, resulting in relatively low strength and higher water absorption [44]. These limitations have predominantly confined the application of RBAC to nonstructural uses, such as road sub-base and paving blocks [49].

This study undertook a scientometric assessment of bibliometric data spanning the previous two decades regarding the utilization of recycled bricks in concrete. The application of scientometric analysis allowed for the handling of voluminous datasets without engendering further complications. The process of scientific mapping and visually representing bibliographic co-occurrence, co-citation, and co-citations poses significant technical challenges [50]. The present study utilizes scientometric analysis to overcome the inherent limitations of conventional manual reviews. The scientometric analysis is a quantitative approach that examines various aspects of science, including science policy, communication, and the scientific process. While its scope is broad, one of its primary objectives is to assess the influence of authors, articles, journals, and institutions, as well as analyze the citations associated with them. Additionally, it involves visualizing and mapping scientific domains and evaluating indicators to inform future policy and management strategies [51]. In summary, a meticulous scientometric review of recycled brick aggregate concrete is crucial for understanding the research landscape, identifying knowledge gaps, fostering innovation, and evaluating research quality. A recent study highlights the extensive annual consumption of about 13.2 billion metric tons of natural aggregates for concrete production [52]. Identifying research gaps by performing a comprehensive scientometric review would be useful in recognizing areas that are yet to be explored for the utilization of recycled brick aggregates. As discussed in the literature review, RBAC has substandard mechanical properties as compared to natural aggregate concrete. To be specific, the present study entailed the identification of sources that have published a substantial number of articles, investigation of keyword co-occurrence, analysis of author collaboration, determination of frequently cited authors and articles, and examination of the regions that are actively engaged in employing brick waste for sustainable construction of concrete. The outline of this work is as stated: Sect. 2 will provide the research significance, Sect. 3 will provide the methodology adopted for this analysis, and Sect. 4 will provide a detailed discussion on results.

2 Research significance

Numerous research studies have been carried out in the past to identify various factors that affect the sustainable production of concrete, particularly with the inclusion of reused brick aggregates, yielding notable inferences. Previously, scientometric analysis has been conducted in the field of recycled aggregate concrete. Nevertheless, the domain associated with the utilization of reused brick aggregates remains unexplored and requires particular focus. Thus, this study endeavors to thoroughly chart the scope of research conducted on recycled brick aggregate concrete (RBAC) within the last two decades. Further, the present study aims to identify the primary academic institutions, researchers, research collaborations, and country collaborations in this area of investigation. Lastly, it aims to recognize the emerging areas of interest, as well as the areas that have been neglected in prior research.

3 Methodology

The current research on RBAC was reviewed using scientometric-based analysis [41]. The study included a thorough examination of the research areas that are currently being explored in this field. The rationale behind the adoption of the scientometric assessment approach is that several previous studies in the field of construction have revealed that relying solely on subjective judgments may lead to unreliable outcomes. This underscores the importance of using a more objective and systematic approach to review studies [39]. Several studies have highlighted that subjectivity and unbiasedness could be prevented by adopting scientometric analysis [42, 43]. The current study aims to provide a comprehensive summary and synthesis of the research conducted in the past two decades on the topic under investigation. To achieve this objective, the study utilizes maps and bibliometric data to quantify research progress and establish connections between different studies, resulting in a rigorous quantitative assessment.

It is to be noted that abundant research has been conducted on RBAC, targeting its various aspects, and yielding useful inferences. A comprehensive scientometric assessment was performed by conducting a search in the Scopus database for papers about the utilization of recycled brick aggregates in the production of concrete. Scopus was selected for this search due to its extensive coverage of filtered abstracts and citations, which makes it one of the largest and most comprehensive databases available for scholarly literature [44]. Accordingly, this review has utilized Scopus as the primary tool to construct a bibliometric database to examine the research related to RBAC. The search query employed to retrieve

Table 1 Documents searched in Scopus database and resulting documents on 29th January 2024

Result refine function	Limitations	Document results
Title-Abs-Key	–	1212
Year	2003–2023	1155
Subject area	Engineering, Material Science, Environmental Science, Earth and Planetary Science,	801
Document type	Article, Conference Paper, Review, Book Chapter, Conference Review	791
Language	English	627

Keywords: Best keyword combination for recycled bricks in concrete—TITLE-ABS-KEY (recycled AND bricks AND concrete)

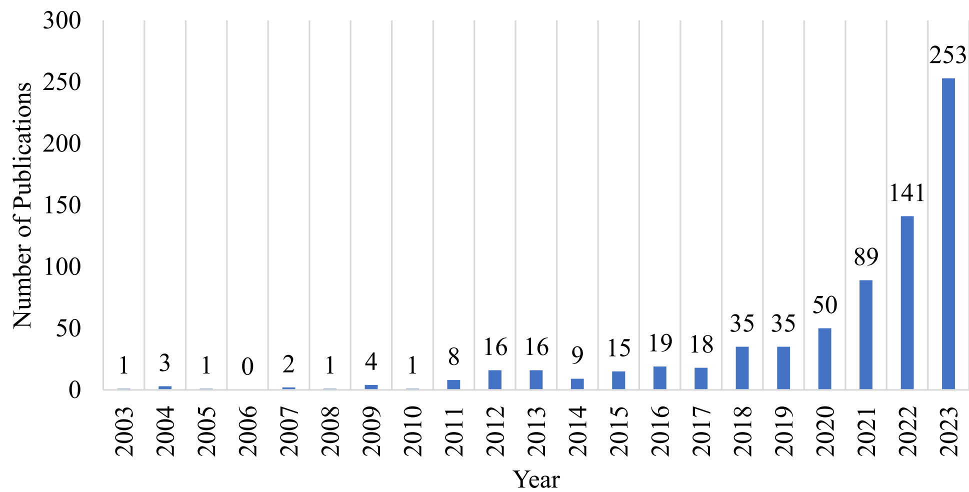


Fig. 1 The annual publication trend with keywords "recycled bricks AND concrete"

relevant papers from the Scopus database was the highly visible and relevant keywords "recycled bricks" AND "concrete". The search resulted in a total of 1212 documents. This was narrowed down to the period of the last two decades, i.e., from 2003 to 2023, reducing the search to 1155 documents. This highlights that a major chunk of the research related to RBAC was conducted within the last two decades. After applying a few other filters such as subject area, and document type, and restricting the language to English only, the remaining number was 627. Table 1 presents the process of narrowing the search and the corresponding number of documents.

Once a comprehensive, all-encompassing, and impartial database was compiled and saved in a standardized file format, multiple analyses were carried out to explore diverse aspects of the provided bibliographic information. These analyses were performed by using the map-generating software free VOSviewer. VOSviewer's unique feature is its versatility as a multi-functional data processing tool capable of producing, visualizing, exploring, and presenting bibliometric data-driven maps in a clear and easily understandable manner [45]. In VOSviewer, the input "type of data" was set to "create a map from bibliographic data". Finally, parameters like annual publication trends, top publication sources, and mostly used keywords were estimated and analyzed.

4 Results and discussions on scientometric analysis

4.1 Annual publication trend

The annual publication trend with the selected keywords is presented in Fig. 1. Interestingly, the years 2003–2010 observed a mild interest in the use of clay bricks and this period can be regarded as the emerging period in this research field. As the years progressed towards the year 2015, the number of publications gradually increased, indicating a rise in the interest in the use of recycled bricks in concrete. One possible explanation for this rise is the growing recognition of the positive impact on environmental sustainability, along with other contributing factors. Towards the end of this second decade, the number of yearly publications rose to 50 in total. This number signifies the mounting inclination of researchers to alleviate the swiftly disappearing natural resources in preference for reused bricks. In the year 2023, a total of 253 publications have been documented, implying yet another escalating year for research on clay bricks. Additionally, the distribution of documents by research area is shown in Fig. 2. It is interesting to observe that more than 48% of documents related to the use of recycled bricks in concrete belong to the Engineering category, followed by Materials Science at 23%. This identifies that recycled bricks have found their use in engineering applications and researchers have identified the potential of recycled bricks in this domain.

4.2 Frequent significant keywords

Keywords serve as a means to showcase and encapsulate the focal points of a research domain, demonstrating the content that is at its core [46]. For this particular study, the most used keywords were identified by VOSviewer and subsequently summarized in Table 2. It is to be noted that recycling, compressive strength, concrete aggregates, and bricks were among the notable keywords. Previous research on utilizing recycled clay bricks as a substitute for natural aggregates in concrete has consistently revealed inferior mechanical characteristics, such as diminished compressive strength and altered strain response [47–50].

This can mainly be attributed to the mortar that is adhered to the recycled aggregates, resulting in an increased water absorption potential of recycled aggregates [51]. It is corroborated from Table 2 that mortar was also among the most used keywords. The visualization of the most used keywords in terms of their occurrence, frequency, and link strength is shown in Fig. 3a. The size and location of each node represent its frequency and occurrence, whereas the thickness of the line joining two nodes depicts their link strength. The visualization confirms the frequency of each keyword shown in Table 2. For example, the keywords "brick," "compressive strength," and "clay bricks" were assigned higher degrees of centrality than the other keywords in the network. Identifying the most used keywords in a particular field or topic can help future authors in selecting appropriate and effective keywords for their research. This can aid in improving the discoverability and visibility of their work, making it easier for others to find and cite their publications. Additionally, analyzing the frequency and distribution of keywords in a particular field can also provide insights into the current research trends and interests of researchers in that field. In Fig. 3a, in the network, distinct clusters of keywords have been assigned different colors to visually represent their co-occurrence patterns across various publications. For instance, brick, compressive strength, and recycling were represented with blue, green, and red colors, respectively. However, there are several links connecting each node in the network, indicating that incorporating recycled bricks into concrete must be done with caution, as it can have significant effects on the resulting concrete. Figure 3b is another representation of the density of keywords in each cluster, where a darker part represents a higher frequency and vice versa. Figure 3b is an alternative representation of the keyword density in each cluster, where a darker shade corresponds to a higher frequency of occurrence, and a lighter shade represents a lower frequency of occurrence.

Fig. 2 Pie chart showing the distribution of documents on recycled bricks in concrete by research area

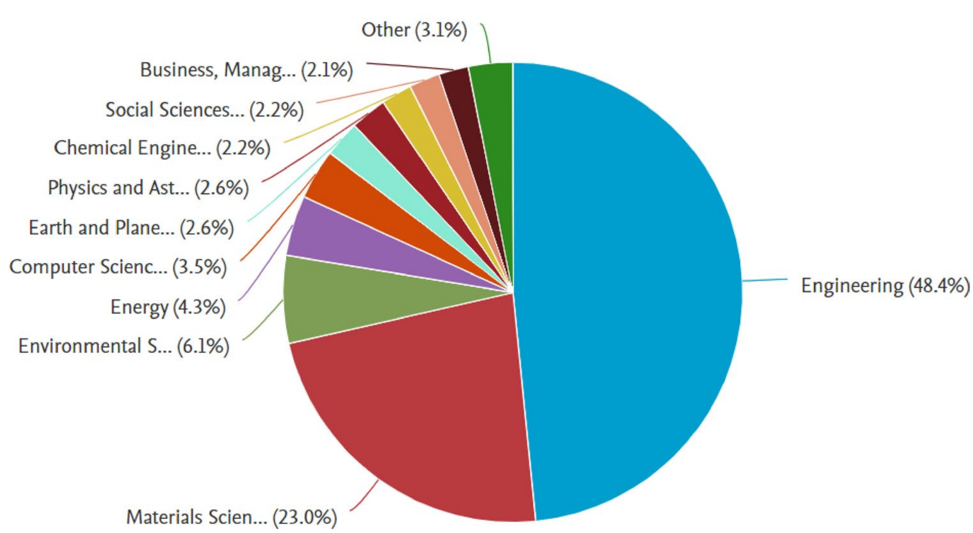


Table 2 Summary of mostly used keywords

No	Keyword	Occurrences	Total link strength
1	Recycling	470	1884
2	Compressive strength	445	1599
3	Concrete aggregates	370	1539
4	Bricks	309	1388
5	Aggregates	190	820
6	Concrete	186	758
7	Recycled bricks	169	809
8	Cement	164	695
9	Tensile strength	146	565
10	Mechanical properties	129	476
11	Recycled aggregates	124	597
12	Water absorption	124	550
13	Demolition	122	572
14	Mortar	117	465
15	Fly Ash	111	347
16	Construction waste	105	451
17	Sustainable development	104	358

4.3 Top publication sources

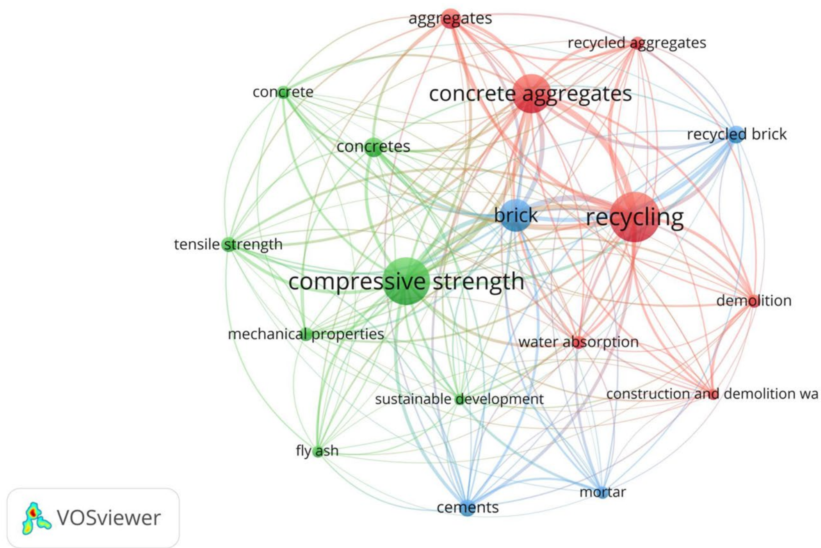
Evaluating a journal's impact in a specific field enables readers to access the most reliable information and easily identify the journals that may be suitable for publication [52]. The combined link strength of a scholarly journal to other peer-reviewed journals, along with the number of published documents and its citation count, collectively demonstrate the journal's impact.

Table 3 contains data regarding the aforementioned metrics. Notably, the Construction and Building Materials journal exhibits the highest number of documents, citations, and total link strength on the list. Table 3 presents sources in chronological order based on the number of published documents in the given field. The top three sources were Construction and Building Materials, Journal of Building Engineering, and Materials with 204, 75, and 67 documents, respectively. In terms of citations, Construction and Building Materials remained the most highly cited, followed by the Journal of Cleaner Production and Journal of Materials in Civil Engineering with 4578, 1192, and 911 citations, respectively.

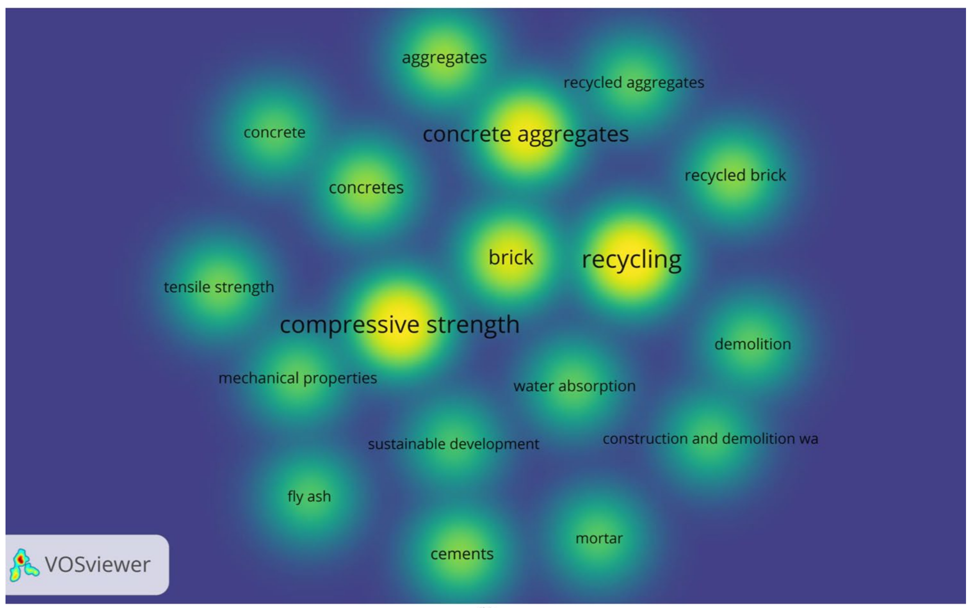
Figure 4 showcases a network visualization of the top journals, where each node's size corresponds to the total number of articles published by the respective journal. The larger nodes, such as those for Construction and Building Materials, Journal of Building Engineering, and Materials, indicate a more considerable contribution and impact in the current field of study in comparison to the other journals. Clusters are formed by analyzing the scope of research outlets or the frequency of their co-citations in scholarly publications [53]. The number of articles in the present research domain that feature co-citations is indicated by the links connecting the research source [54]. A higher link strength between two nodes implies that the respective sources have been frequently cited together in the same scholarly publication. Further, the proximity of the two nodes indicates that the two sources have been cited together frequently. For instance, Construction and Building Materials and the Journal of Building Engineering exhibit proximity in the present research field.

Figure 5 showcases a timeline visualization that represents the co-occurrence of sources regarding recycled brick aggregates. The absence of darker hues in the figure indicates that the sources have been publishing content on recycled brick aggregates recently. Notably, Construction and Building Materials are among the oldest sources in this field.

Fig. 3 Science mapping **a** visualization of keywords and **b** Cluster Density Visualization



(a)



(b)

4.4 Top contributing authors

The act of citing sources indicates a researcher's significance and contribution to a particular area of study [55]. The least number of publications for each author was kept at 10 and the resulting scientific map is shown in Fig. 6. The node size indicates the contribution of the corresponding author in terms of the number of publications. It is interesting to observe that four authors are found to have co-authorship, that is, all ten authors in Fig. 6 have no links. It is to be noted that the largest node size corresponded to Ziao J., followed by Huang W. and Ma Z., respectively. The work by Xiao J. was mostly related to the mechanical properties of concrete made with recycled bricks [56, 57], and evaluating the properties of powder obtained from recycled bricks [58]. Based on the darker shade of the node, it can be inferred that the researcher began working on recycled bricks at an earlier point in time, Huang W., and Ma Z., with a minimum of 10 publications, can be regarded as pioneers in this area of research. The contribution of authors in terms of their number of publications, citations, total link strength, and average citations is presented in Table 4.

Table 3 List of top 17 publication sources with the greatest number of documents with their citations and total link strength within the years range of 2003–2023

No	Source	Documents	Citations	Total link strength
1	Construction and building Materials	204	4578	156
2	Journal of building Engineering	75	897	32
3	Materials	67	483	32
4	Case studies in construction Materials	35	322	16
5	journal of cleaner production	32	1192	51
6	Sustainability (Switzerland)	28	201	19
7	Buildings	26	129	8
8	Journal of materials in civil engineering	24	911	20
9	Bulletin of the Chinese ceramic society	20	22	5
10	Cement and concrete composites	18	658	10
11	Applied sciences (Switzerland)	17	153	8
12	Materials today: proceedings	15	48	11
13	Polymers	15	75	2
14	Advances in materials science and engineering	12	91	11
15	Jianzhu cailiao xuebao/journal of building materials	12	43	7
16	Advances in materials science and engineering	12	91	11
17	AIP conference proceedings	11	7	6

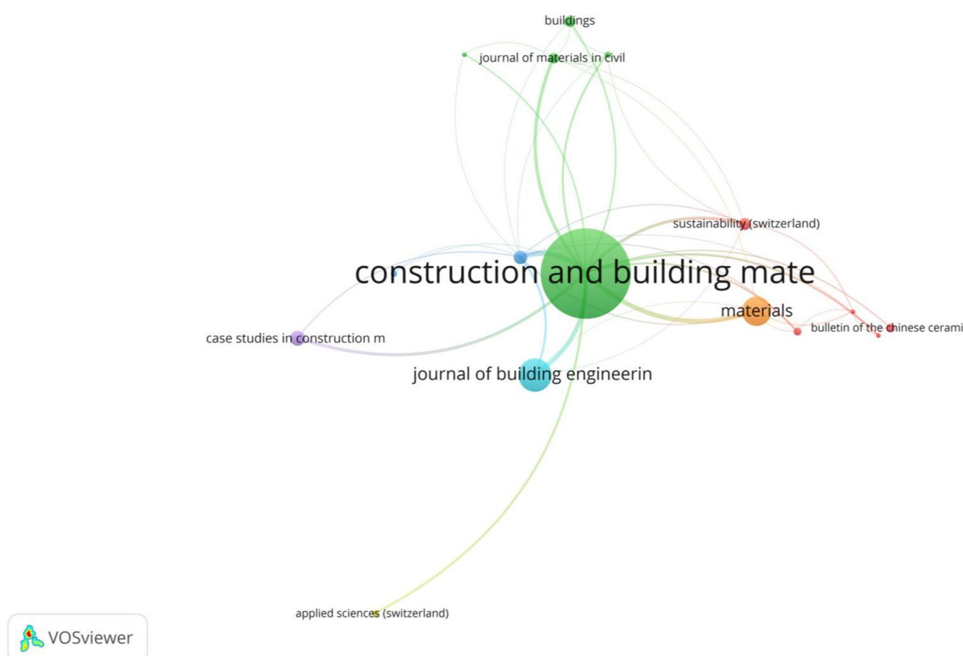


Fig. 4 Top Publication Sources Visualization

Assessing a researcher's effectiveness based on multiple indicators, including the number of publications and total citations, can be challenging. Therefore, it may be necessary to evaluate each factor separately to determine the scientist's overall performance accurately. It is to be noted that Xiao J. tops the list with the most publications, i.e., 24, followed by Huang W. and Ma Z. with 20 and 17 publications, respectively. Similarly, the most citations were received by Ma Z., followed by Wu H. and Xiao J., respectively. These researchers received total citations of 535, 480, and 372, respectively. Table 4 also presents the average number of citations for each researcher, which was calculated by dividing the total citations by the number of publications. It is interesting to note that Ma Z. was the highest-cited researcher. However, the highest number of average citations were received by Wu H., i.e., an average number of 44 citations per document.

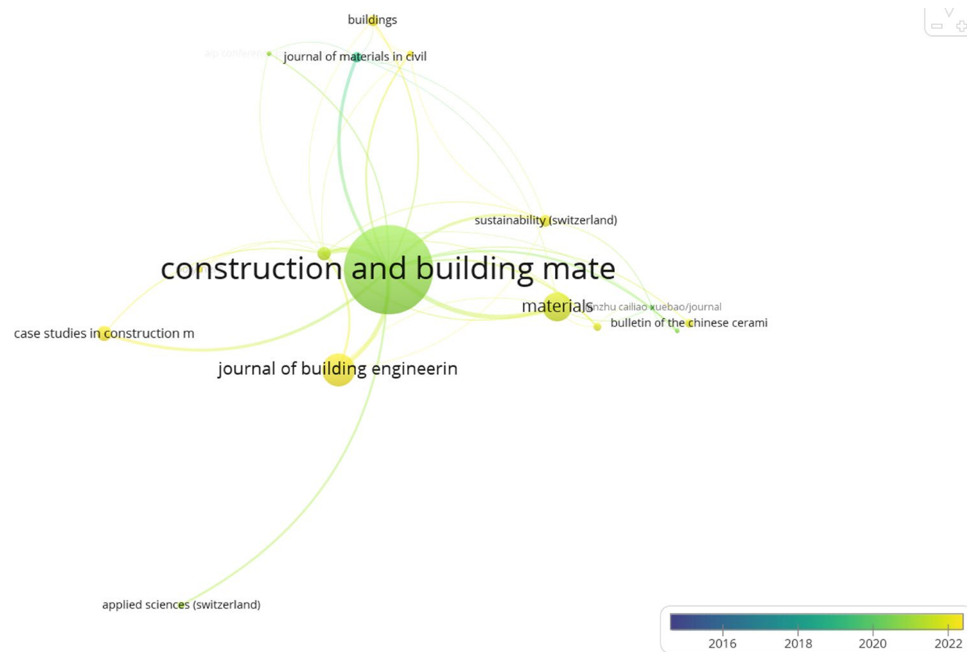


Fig. 5 Top Publication Sources timeline visualization

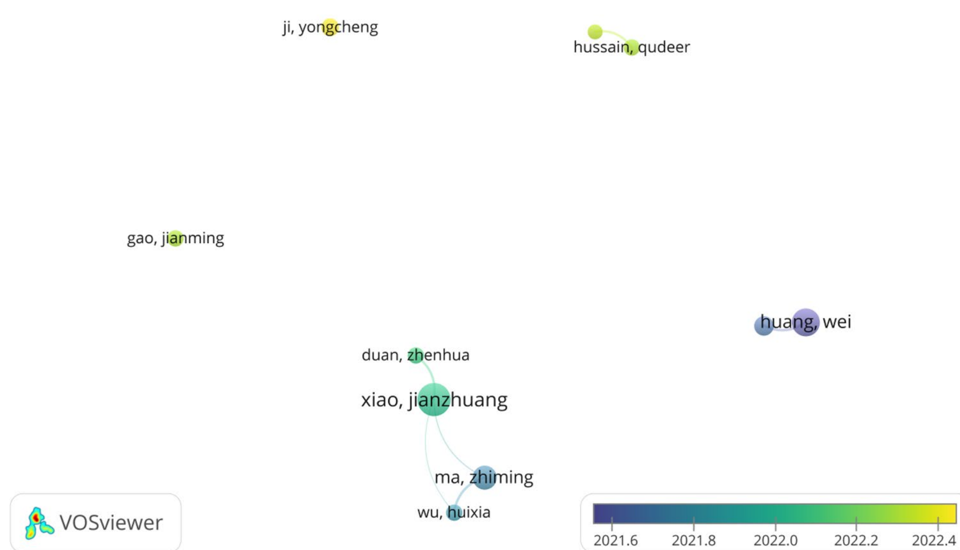


Fig. 6 Science mapping of top contributing authors

Table 4 List of authors with at least 15 publications presented in chronological order of their number of publications within the years range of 2003–2023

No	Author	No. of documents	Citations	Average citations	Total link strength
1	Ma Z	17	535	32	13
2	Xiao J	24	372	16	13
3	Wu H	11	480	44	12
4	Ge P	13	52	4	11
5	Huang W	20	133	7	11
6	Duan Z	11	244	22	10
7	Hussain Q	11	93	9	9
8	Joyklad P	10	97	10	9
9	Gao J	11	118	11	0
	Ji Y	12	35	3	0

4.5 Top cited articles

Table 5 enlists documents with the greatest number of citations related to the recycling of waste bricks in concrete.It is to be noted that the article Arulrajah et al. [59], with the title of "Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications", received the greatest number of citations, i.e., 355. In addition, the document Tang et al. [60] with the title "The utilization of eco-friendly recycled powder from concrete and brick waste in new concrete: A critical review" has received 216 citations.

4.6 Countries with most research on recycled bricks

A list of countries with the greatest number of research articles utilizing recycled bricks is shown in Table 6. This list was obtained by keeping the minimum number of articles and citations to each article at 25. The top three countries were China, India, and Australia with 552, 116, and 66 research articles, respectively. By examining the number of documents, citations, and total link strength, it could be gauged the degree of impact that each country has had on the progress of recycled bricks. The total link strength reflects the interconnectivity between countries in terms of how their research has influenced one another, with China and Pakistan emerging as the countries with the highest total link strength of 73 and 51, respectively. Figure 7 displays a visualization that represents the co-citation relationship among countries, whereas Fig. 8 visualizes this data.

5 Discussion on utilization of recycled brick aggregates in Concrete

The production of concrete is an environmentally unfriendly process due to the adverse effects of the constituent materials on the surrounding environment. The manufacturing of cement, a key component of concrete, is particularly problematic, as the production of one ton of cement typically releases approximately one ton of CO_2 into the atmosphere [69]. Over the past decade, there has been a consistent upward trend in cement consumption, and it currently represents 5.8% of the total global CO_2 emissions [70]. Aggregate mining processes can result in the scarring and transformation of land use, leading to the loss of habitat and agricultural land, as well as generating issues such as noise, blasting effects, and problems related to erosion and sedimentation. In the United States, the construction industry consumes approximately 2–7 billion tons of natural aggregates each year. The production of such vast quantities of natural aggregate demands a significant amount of energy, adversely impacting the ecology of forests and aquatic environments [71]. The conventional reliance on natural resources for concrete production poses a significant environmental threat. Recycling and reusing brick waste in concrete offer eco-friendly alternatives, addressing waste disposal issues and decreasing dependence on natural raw materials. Bricks, manufactured without the use of chemicals, serve as stable and safe building materials. Research has explored incorporating recycled bricks into concrete, considering options such as partial replacements for aggregates and cement. This approach aims to reduce brick waste while promoting sustainable construction practices [72]. Several studies have also highlighted the potential of brick waste as a partial replacement of cement in mortar [73, 74].

This study employed bibliometric data to conduct a quantitative analysis and scientific mapping of research on the use of recycled bricks in the production of concrete. Unlike previous traditional review studies that suffered from insufficient interconnectivity between various areas of the literature, this bibliometric analysis successfully identified the most prolific publication outlets in terms of the number of published papers, frequently occurring keywords in published articles, articles and authors with the highest citation counts, and regions actively engaged in this area. The yearly trend analysis indicates that recycling of bricks has emerged as a significant research area over the past two decades. The number of publications on this topic has increased steadily during this period. Nonetheless, the greater trend towards the research on RBAC particularly in some countries can be related to the limitations related to the funding or general interest of researchers. The generation of brick waste in the residing country of the researcher could also induce more interest in its reuse, hence, attracting more attention in the research field.

Despite the promising potential of using recycled brick aggregates in concrete, their application has been primarily limited to non-structural purposes. According to a scientometric analysis of keywords, most of the research in this field has focused on investigating the mechanical properties of concrete produced from recycled bricks, particularly

Table 5 Documents with the greatest number of citations within the years range of 2003–2023

No	References	Title	Journal	Citations
1	Arulrajah et al. [59]	Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications	Journal of Materials in Civil Engineering	355
2	Tang et al. [60]	The utilization of eco-friendly recycled powder from concrete and brick waste in new concrete: A critical review	Cement and Concrete Composites	216
3	Amin [61]	Effect of using mineral admixtures and ceramic wastes as coarse aggregates on properties of ultrahigh-performance concrete	Journal of Cleaner Production	205
4	Khlaf [62]	Recycling of demolished masonry rubble as coarse aggregate in concrete: Review	Journal of Materials in Civil Engineering	196
5	Corinaldesi and Moriconi [63]	Behaviour of cementitious mortars containing different kinds of recycled aggregate	Construction and Building Materials	184
6	Chen et al. [64]	Utilization of recycled brick powder as alternative filler in asphalt mixture	Construction and Building Materials	181
7	Modarres and Hamedi [65]	Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes	Materials & Design	169
8	Das et al. [66]	Performance evaluation of polypropylene fibre reinforced recycled aggregate concrete	Construction and Building Materials	161
9	Ukhurebor et al. [67]	Effect of hexavalent chromium on the environment and removal techniques: A review	Journal of Environmental Management	155
10	Alves et al. [68]	Mechanical properties of structural concrete with fine recycled ceramic aggregates	Construction and Building Materials	148

Table 6 Countries with the greatest number of documents

No	Country	Documents	Citations	Total link strength
1	China	552	5181	73
2	India	116	1031	31
3	Australia	66	1441	41
4	Iran	49	1104	12
5	Turkey	46	526	11
6	United States	46	866	38
7	Pakistan	41	393	51
8	United Kingdom	40	946	39
9	Malaysia	39	507	39
10	Italy	37	569	19
11	Spain	36	771	7
12	Bangladesh	34	416	7
13	Iraq	31	126	23
14	Saudi Arabia	29	258	38
15	Thailand	27	137	31

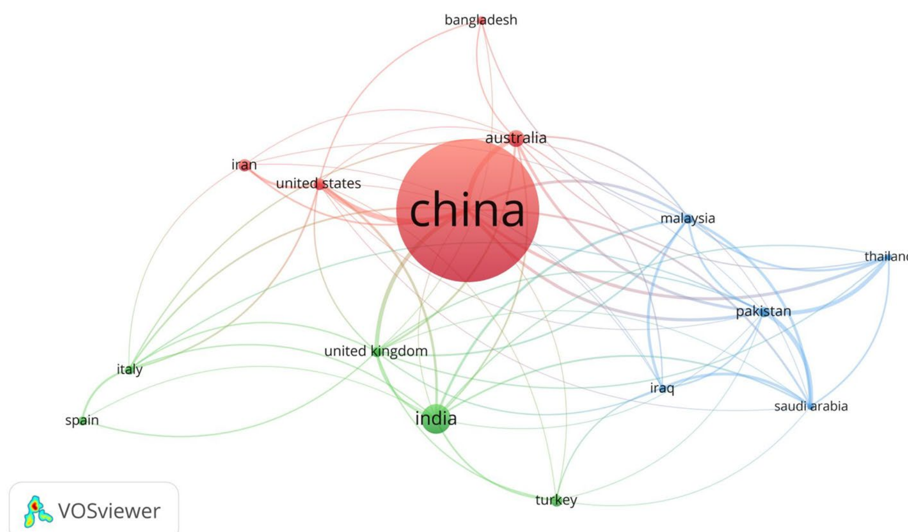


Fig. 7 Scientific mapping of countries with greatest number of documents

the compressive strength. This is because previous research on utilizing recycled clay bricks as a substitute for natural aggregates in concrete has consistently revealed inferior mechanical characteristics, such as diminished compressive strength and altered strain response [47–50]. This can mainly be attributed to the mortar that is adhered to the recycled aggregates, resulting in an increased water absorption potential of recycled aggregates [51, 75].

Currently, most of the research is conducted in assessing and improving the mechanical properties of concrete with recycled brick aggregates. This is evident from the scientometric analysis results, especially from the keyword analysis. So far, researchers have mainly focused on improving the mechanical properties of recycled brick aggregate concrete [25, 26, 76–79]. The mechanical response of recycled brick aggregate concrete subjected to various loading configurations has not yet been investigated. Although there are reports of enhanced mechanical properties of recycled brick aggregate concrete when subjected to external confinement [24, 76, 77, 80], no empirical studies have been conducted to examine the impact of incorporating recycled brick aggregate concrete in the presence of lap splices. Furthermore, the behavior of recycled brick aggregate concrete under conditions where shear-dominated behavior is prevalent remains unexplored. Several existing studies have performed experiments on substandard lap splices [81–85] and proposed expressions for the design of external confinement. Similar methodologies can be adopted in the case of RBAC by incorporating lap splices. One such study could be used to develop expressions for the development length of steel bars [86–88].

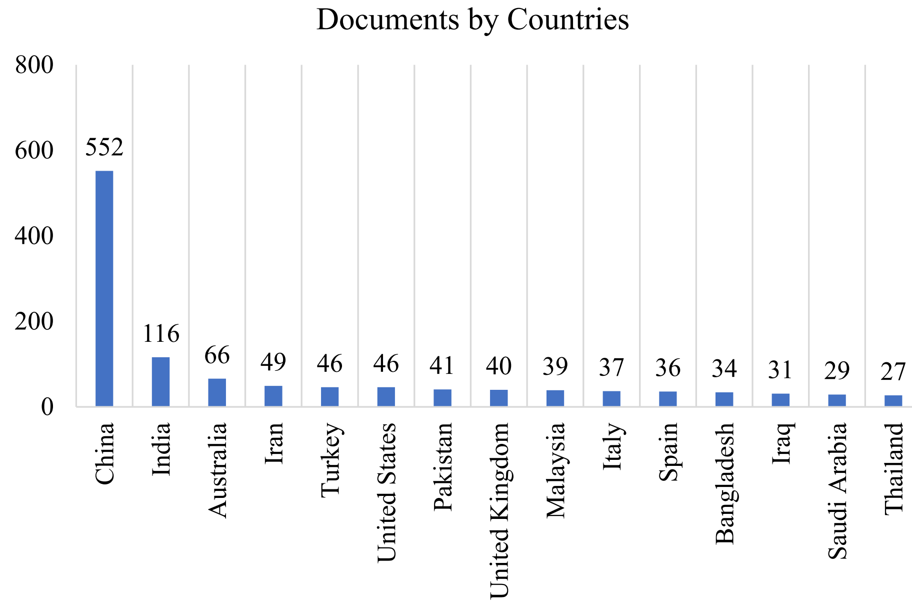


Fig. 8 Number of documents with keywords "recycled bricks AND concrete" by countries

Recent trends toward sustainable construction practices have already gained significant importance. In the present study, the core research areas related to the use of recycled brick aggregates were highlighted. The massive production of brick waste worldwide requires a comprehensive approach to reduce their carbon footprint. The handling of this waste is not a straightforward process and consumes significant energy resources. It has been highlighted that the reuse of this brick waste in the production of concrete achieves bifold objectives: it eases the requirements of its proper handling while reducing the demand for natural resources. However, RBAC possesses substandard mechanical properties that have mainly limited its use to non-structural applications. The current study identifies that a major junk of existing research has targeted improving the mechanical properties of RBAC. Aiming at more sustainable construction, the use of RBAC needs to be extended to structural applications. Having identified this, more studies are needed to assess the performance of RBAC in the presence of reinforcement steel bars [89, 90].

Though recycled bricks possess the potential to be used as a partial replacement for concrete ingredients, it also involves certain challenges. The presence of mortar adhered to the surface of bricks is notoriously known to absorb water in concrete. This may reduce the water available for the hydration process in concrete. As a result, the unbalanced water-to-cement ratio can influence the mix design adopted. Moreover, the properties of brick samples during recycling may vary, posing a challenge in utilizing existing models developed for bricks with certain types. With substandard mechanical properties, the use of recycled bricks in concrete for structural applications is a major concern. Therefore, solutions need to be devised to enhance the mechanical properties of the resulting concrete to meet the standards [91].

6 Conclusions

This investigation aimed to conduct a scientometric evaluation of the existing literature on recycled brick research, to examine its fundamental elements. To achieve this objective, the Scopus database was explored for 4614 relevant publications, and utilized the VOSviewer software to analyze the data. Our primary findings are as follows:

1. In this study, VOSviewer was used to identify the most commonly used keywords, which included compressive strength, water absorption, recycling, mortar, and walls. Previous research has consistently shown that using recycled clay bricks as a replacement for natural aggregates in concrete leads to reduced mechanical properties, such as lower compressive strength and altered strain response. This is largely due to the presence of mortar on the recycled aggregates, which increases their water absorption potential.
2. The Construction and Building Materials journal has the most significant number of documents, citations, and total link strength among all sources examined. The top three sources are Construction and Building Materials, Journal of Building Engineering, and Materials, with 204, 75, and 67 documents, respectively. In terms of citations, Construction

and Building Materials maintains the highest citation count, followed by Journal of Cleaner Production and Journal of Materials in Civil Engineering, with 4578, 1192, and 911 citations, respectively.

3. The maximum number of publications was related to the author Xiao J., followed by Huang W. and Ma Z., respectively. Notably, Xiao J. has the highest number of publications on the list, with 24 papers, followed by Huang W. and Ma Z., with 20 and 17 publications, respectively. In terms of citations, Ma Z. has the most with a total citation count of 535, followed by Wu H. and Xiao J. with 480 and 372 citations, respectively.
4. The article titled "Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications" by Arulrajah [59] received the highest number of citations, with 355 citations. Furthermore, the paper authored by Tang [60], titled "A critical review on the utilization of eco-friendly recycled powder from concrete and brick waste in new concrete," has garnered 216 citations.
5. Thus far, the majority of research on recycled brick aggregates in concrete has focused on evaluating and enhancing their mechanical properties. However, the mechanical behavior of recycled brick aggregate concrete under different loading configurations has not been thoroughly investigated. While studies are reporting improved mechanical properties of recycled brick aggregate concrete when externally confined, no empirical research has been conducted to examine the effect of incorporating recycled brick aggregate concrete in the presence of lap splices. Additionally, the behavior of recycled brick aggregate concrete under conditions where shear-dominated behavior prevails has yet to be explored.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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