A bibliometric analysis of recycled concrete research (1978–2019)

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Abstract

Purpose – The use of recycled concrete (RC) can reduce the greenhouse emissions associated with the production of cement, which is one of the primary materials used for the execution of construction projects. This research aims to review the state of knowledge in the field of RC research. An understanding of the state of the art in the RC domain justifies future research in this field.

Design/methodology/approach – A systematic and comprehensive search of RC-related literature was conducted using the Scopus database. In this research, the bibliometrix R-package was used for the analysis of bibliometric information of the selected papers. The software was used to create a map, which highlights the trends and gaps in the RC knowledge domain.

Findings – The results reveal the research themes, clusters, collaboration networks and advancement of knowledge in the field of RC research. The study integrates the literature focussed on RC research and provides a platform for progression of knowledge in this field.

Originality/value – The study contributes to the growing body of knowledge by providing an up-to-date RC knowledge map based on an analysis of bibliographic data. Information gleaned from previous studies suggests that bibliometric review can strengthen and complement the findings emerging from other forms of literature reviews. The study reported here is one of the first studies to provide insights into the evolution of RC research.

Keywords Bibliometric analysis, Bibliometrix, Circular construction, Recycled concrete

Paper type Research paper

Introduction

Concrete is one of the most widely used materials for the construction of infrastructure projects. The process of producing concrete generates a large amount of greenhouse gases (GHGs), which has been linked to climate change. Recently, there have been calls for the adoption of sustainable construction practices due to the rise in the number of extreme climatic events. The circular economy model is one of such concepts associated with sustainability, and it is premised on the principles of resource recovery and reuse (Greyson, 2007; Geissdoerfer *et al.*, 2017; Schroeder *et al.*, 2019). As such, an increasing advocacy for sectoral transitions from linear to circular economy production happens to have necessitated a corresponding rise in research interest within the academia.

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The need to embed circular economy models in construction business stems from its impact on the environment. On a global scale, it has been estimated that about 40% of GHGs are emitted from the activities in the construction sector (Azzi *et al.*, 2015). Also, reports (Bolin and Smith, 2011) have shown that a significant amount of GHG is generated when producing cement and concrete. Due to these challenges, industry stakeholders are continuously striving towards the embedding sustainability in their business operations (Kibert, 2013; Abuzeinab *et al.*, 2016; Heeren and Hellweg, 2019). Furthermore, research shows that large quantities of demolition wastes are transported from construction sites to landfills (Rao *et al.*, 2007). Therefore, the recycling of waste from construction sites is an integral part of the transformation, that is, the shift towards embedding circularity and sustainability in construction business processes.

The volume of research focussed on recycled concrete has grown in recent years. This growth has made it increasingly difficult for researchers and practitioners to update their knowledge of developments in different knowledge domains. In recent years, literature review has been used to synthesise and integrate previous literature into an understandable whole (Aria and Cuccurullo, 2017). The existence of previous reviews on recycled concrete is acknowledged. For instance, Tam *et al.* (2018) reviewed the amount and usage of recycled aggregate in the production of concrete in several countries. Also, Safiuddin *et al.* (2013) reviewed the properties (mechanical, chemical and physical) of recycled concrete. However, these reviews are typically qualitative, not replicable (the method used for selecting the papers is not adequately described), and limited number of papers were selected. In contrast, bibliometrics is a replicable and objective approach for analysis of literature (Linnenluecke *et al.*, 2020). The study extends the current knowledge on recycled concrete research through the application of bibliometrics. This study presents a comprehensive review of recycled concrete research. The study maps the evolution and trends in recycled concrete research. It identifies the key contributors, research themes, key publication outlets and themes (topics) in recycled concrete research. Furthermore, this paper holds salient implications for researchers working within the recycled concrete research domain as it will assist them in identifying possible gaps within the corpus of extant research. This is the gap which this study seeks to bridge relying on the utility of a bibliometric analysis of relevant literature. Subsequent parts of this review paper will comprise the following: a justification of the research method adopted; a results presentation and discussion section and the conclusion.

Research method

There are several review methods used for the analysis of existing literature. Systematic review, meta-analysis and bibliometric analysis are three main methods used for the synthesis of previous research (Gradeci *et al.*, 2017; Schmidt, 2008; Zupic and Čater, 2015). These methods are popular due to transparency and the reproducibility of the process. In this study, the bibliometric method was used to map the structure and evolution of knowledge relating to recycled concrete. There are two main advantages associated with the use of bibliometric method, namely: (1) objective analysis of previous research and (2) replicable – an audit trail makes it easy to reproduce findings emerging from bibliometric review. Thus, bibliometric review was used to analyse previous research on recycled concrete.

Bibliometric analysis has been used to synthesise knowledge in various academic disciplines. Previously, this method has been used to map the published research on corporate social responsibility (Feng *et al.*, 2017) and biodiesel (Zhang *et al.*, 2018), among others. Bibliometric analysis is well suited for identifying the evolution of topics (themes) and knowledge in a particular area. This information is useful for identifying gaps in the current knowledge and suggesting the pathway for future research. In this study, the approach adopted is similar to the process suggested and utilised in previous studies (Zupic and Čater, 2015; Aria and Cuccurullo, 2017; Ekanayake *et al.*, 2019). The standard workflow suggested in

these studies (Zupic and Čater, 2015; Aria and Cuccurullo, 2017) is carried out in five stages: conceptualisation of research, collection of bibliometric data, analysis of collected data, visualisation and interpretation.

As stated earlier, a five-stage process was used in this research. Firstly, the research objectives were defined. Secondly, the bibliographic information was collected via searches conducted on the Scopus and WoS (Web of Science) databases. These two databases are comprehensive sources for articles published in academic journals (Visser *et al.*, 2020). In this study, data was retrieved from Scopus and WoS databases. The search was limited to journal papers, and this is because the peer-review process is part of the quality assurance process for these publication outlets. The identification of search keywords is an important stage in the search process. An initial search was carried out on the database of *Construction and Building Materials* Journal. This initial search was conducted using two terms "recycled concrete" and "recycled aggregate concrete". The focus of the search was to identify review papers. Review papers are good sources for identifying search terms. A total of nine relevant publications were found at the end of this initial search.

As suggested in Ananiadou *et al.* (2009), term extraction is a critical tool for identifying keywords for systematic literature search. In current study, the term extraction process was implemented using the TerMine Software (Frantzi *et al.*, 2000). The title and abstract of the nine publications from the *Construction and Building Materials* database were used to create a corpus for the process of term extraction. Although terms [such as aggregate concrete, mechanical property, recycled aggregate and natural resource, among others] emerged from the extraction process, the suitable keywords were limited to "*recycled concrete*", "*waste concrete*" and "*recycled aggregate concrete*". The three keywords were used for the main database search. This approach was used to ensure that all relevant studies are captured in the search process.

These terms ("*recycled concrete*"), ("*recycl**" AND "*waste concrete*") and ("*recycled aggregate concrete*") were used for main search. The search filtered through all publications till 2019. These terms were used for title and abstract search. Papers published in 2020 were excluded. This is because the publications for 2020 are still work in progress. The search results are summarised and presented in Table 1. The final data set used for the analysis in this paper contains 2,462 publications. For the third and fourth stage, the metadata collected from Scopus and WoS were visualised and analysed using Bibliometrix (Aria and Cuccurullo, 2017) and CiteSpace (Chen, 2006). Bibliometrix is a package within the R-programming environment (R Core Team, 2016). Also, Bibliometrix (Di Vaio *et al.*, 2020) and CiteSpace (Ekanayake *et al.*, 2019) have been used as a tool for bibliometric analysis in previous research. The capabilities make these software ideal tools for the analysis of bibliometric information. Finally, the findings emerging from the analysis of data are interpreted.

Process	Description	SCOPUS search results	WoS search results
Search in Scopus and WoS database	Initial search results	3,208	2,440
Filtering	Removing articles published in other languages apart from English	2,439 (769 articles excluded)	2,411 (29 articles excluded)
Merge	Articles common in both databases	4,850	
Common articles	Articles common in both databases	2,462 (2,388 articles excluded)	
Final	The articles used for final analysis	2,462 articles	

Table 1. Search results from WoS and Scopus database

Results and discussion

Number of publications per year

The temporal distribution of recycled concrete publications is summarised and presented in Figure 1. The first paper on recycled concrete was published in 1978. Figure 1 shows that the number of publications per annum on this subject matter grew from 1 in 1978 to 463 by the end of 2019. Figure 1 provides insights into the evolution of interest in recycled concrete. Figure 1 can be divided into three periods: (1) initial stage from 1978 to 1999 [less than 9 publications per year]; (2) slow growth stage from 2000 to 2005 [between 7 and 16 publications per year]; and (3) rapid growth stage [between 25 and 463 publications per year]. The number of publications grew exponentially in the third stage. As suggested in van Nunen *et al.* (2018), the number of publications is an indicator of the level of interest in a topic. The growth in the number of recycled concrete publications from 2001 could be due to the signing of the Kyoto Protocol in 1998 as part of the strategies for combating climate change. In addition, the cumulative number of publications grew from 1 in 1978 to 2,462 at the end of 2019.

Recycled concrete research: publication and journal outlet

The details of the top-five most cited publications are presented in Table 2. This manuscript was authored by González-Fonteboa and Martínez-Abella (2008). In the article, the authors carried out laboratory experiments to quantify the physical (density and water absorption) and mechanical properties (compressive and tensile splitting strength and static modulus of elasticity) of recycled concrete. The performance of conventional concrete was compared with recycled concrete. The inclusion of recycled aggregates reduced the strength of the concrete. However, the addition of silica fume improved the performance of the recycled concrete. Poon and Chan (2006) investigated the potential of using recycled concrete aggregate and crushed clay bricks to produce paving blocks. On the overall, in four of the top-five publications (González-Fonteboa and Martínez-Abella, 2008; Poon and Chan, 2006; Shayan and Xu, 2003; Poon and Chan, 2007), experiments were conducted to examine the properties of concrete produced with recycled concrete aggregate. In contrast, Fathifazl *et al.* (2009) explored the effect of using mixture proportioning to produce recycled concrete. In the article, the findings showed that the use of mixture proportioning resulted in the production of concrete which has better performance when compared with the conventional method.

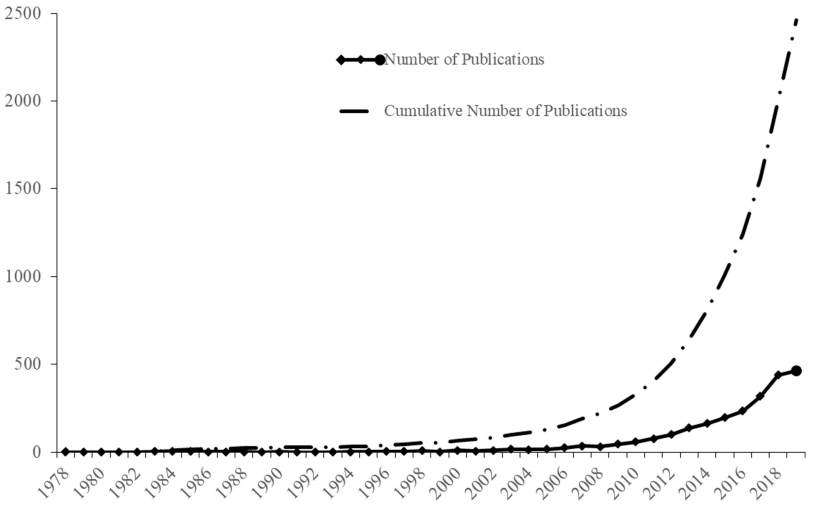

Figure 1.
Number of recycled concrete publications and cumulative number of recycled concrete publications per year

No	Author name	Title	Year
1	González-Fonteboa and Martínez-Abella	Concretes with aggregates from demolition waste and silica fume. Materials and mechanical properties	2008
2	Poon and Chan	Paving blocks made with recycled concrete aggregate and crushed clay brick	2006
3	Shayan and Xu	Performance and properties of structural concrete made with recycled concrete aggregate	2003
4	Fathifazl *et al.*	New mixture proportioning method for concrete made with coarse recycled concrete aggregate	2009
5	Poon and Chan	The use of recycled aggregate in concrete in Hong Kong	2007
No	*Journal*	*Number of publications*	*IF*
1	Construction and Building Materials	557	4.419
2	Journal of Cleaner Production	113	7.246
3	Journal of Materials in Civil Engineering	96	2.169
4	Cement and Concrete Composites	61	6.257
5	Magazine of Concrete Research	60	2.088

Note(s): IF = Impact factor (2019 Journal Citation Reports®)

Table 2.
Descriptive analysis – top-five most cited publications and top-five journal outlets

Recycled concrete research was published in 444 journals. The high number of outlets suggest that recycled concrete research is multidisciplinary in nature. Table 2 provides information on the top-five journals that actively published recycled concrete research. These top-five journals published 887 articles (36% of the total research output). Among these journals, *Construction and Building Materials* published the highest number of articles on recycled concrete (22.6%; $n = 557/2{,}462$). The impact factors [IFs] of these top-five journals ranged between 2.088 and 7.246. The journals used for disseminating recycled concrete have high impact factors (IF > 2). Based on JCR rankings, these outlets are the top-tier journals in the "*Construction and Building Technology*" and "*Environmental Sciences*" section. The scope of the top-five journals and JCR classification indicates that recycled concrete research is domiciled within the construction technology and material science body of knowledge.

Unearthing the underlying structures of knowledge

As stated previously, bibliometric analysis is well suited for condensing large volume of literature into an easy-to-understand whole. Aria and Cuccurullo (2017) assert that bibliometric analysis provides insights into "social structure" [collaborative network – researchers, countries and universities], "intellectual structure" (the impact of an author's research on a knowledge base] and "conceptual structure" [trending research themes].

Social structure: country collaboration

To gain an understanding of the geographical coverage of publications related to recycled concrete research, the co-authorship network was analysed using the VOSviewer (van Eck and Waltman, 2013). Countries that are not connected to other countries were not included in this network (i.e. countries that do not collaborate). The colour is an indicator of collaboration clusters. The collaboration network among countries is presented in Figure 2. Based on information available in Figure 2, there are four clusters (purple, blue, green and red). The green cluster is largely made up of Asian countries (Malaysia, Korea, Saudi Arabia and Pakistan). European, Asian and South American countries are within the blue cluster.

The purple and blue cluster indicates that European and South American countries are working as teams on recycled concrete research. This finding could be due to similarities in languages spoken in these counties, for example, Spanish and Portuguese. The red cluster encompasses countries located in North America, Europe, Asia and Oceania. Similar to the findings in previous studies, collaborators tend to be located within the same geographical location (van Nunen *et al.*, 2018).

Conceptual structure: identification and interpretation of clusters

In this section, the clusters of recycled concrete publications are analysed to identify outliers in the body of knowledge. Similar to the approach adopted by Ekanayake *et al.* (2019), cluster labels are selected from the noun phrases of each cluster, and the noun phrases are extracted from titles, keywords and the abstracts of the publications. Therefore, the top-ranked noun phrases have been selected as the cluster label. Three specialised metrics, namely, log likelihood ratio (LLR), mutual information (MI) test and the latent semantic index (LSI), are used to identify the most significant clusters of RC research and their most significant terms. The uniqueness of a term to a specific cluster was identified using the LLR test while LSI and MI tests recognise the most representative words in each dimension and the most salient aspect of the clusters.

The clusters generated in this study along with their cluster labels are shown in Figure 3. Typically, the size of the cluster label depends on the total number of publications in a cluster, that is, the higher the number of publications, the larger the size of the cluster label and vice

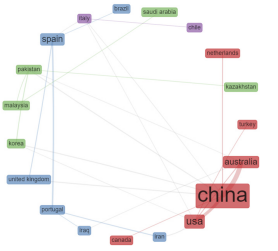

Figure 2.
Collaboration network among countries contributing to recycled concrete research

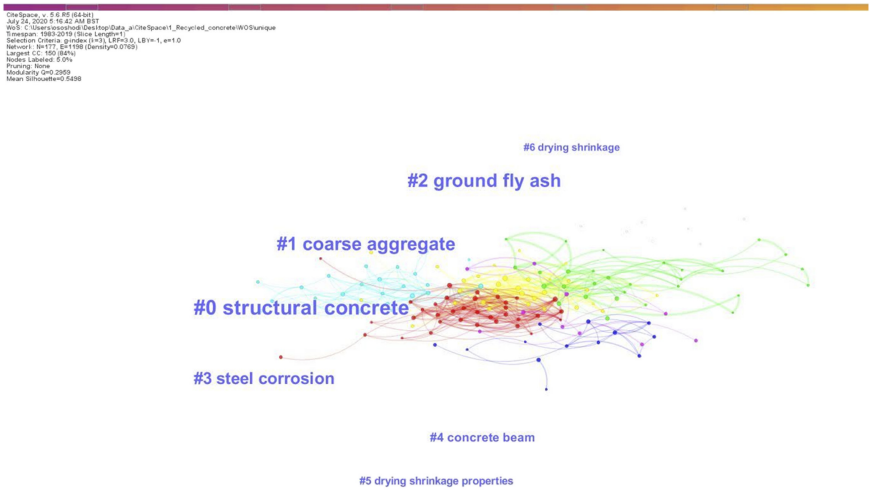

Figure 3.
Cluster of knowledge within recycled concrete research

versa. Here, the largest cluster, which is numbered as #0, is structural concrete while the smallest cluster (#6) is drying shrinkage. The most significant and largest cluster in this study is structural concrete (#0), which includes 35 publications. The articles in this cluster mainly focussed on the mechanical properties such as durability, carbonation resistance, microstructure, permeability and time-dependent behaviour of the recycled concrete. This observation is very important since there is a very strong desire within the discipline to match the overall performance of recycled concrete to those of virgin concrete in order to make a strong case for the use of the material within the construction industry.

The second most important cluster relates to the coarse aggregate (#1). The articles in this cluster present details about the use of waste concrete as coarse recycled concrete aggregate (RCA) in place of natural coarse aggregate. The article by Lye *et al.* (2016) presented a comparison of the modulus of elasticity of natural aggregate concrete and recycled aggregate concrete. The authors concluded that the modulus of elasticity of recycled concrete reduces as the percentage of coarse RCA increases. Other factors that influence the strength of recycled aggregate concrete include the low density, low specific gravity, high water absorption, high porosity and shape of the RCA as well as the water–cement ratio of the mix (Tabsh and Abdelfatah, 2009; Somna *et al.*, 2012).

The third-ranked (#2) cluster is ground fly ash. The 29 articles in this cluster focus the production and mechanical properties of sustainable concrete through the use of industrial and/or agricultural wastes. In this cluster, the studies seek to reduce the global CO_2 emission associated with the use of virgin materials by partially replacing cement with other cementitious or pozzolanic materials such as ground fly ash. Also, the use of pozzolanic materials has been found to improve strength and durability of recycled aggregate concrete, that is, reduced water permeability, improved chloride penetration resistance and reduced expansion due to sulfate attack (Somna *et al.*, 2012). Furthermore, the remaining major clusters (for instance, steel corrosion, concrete beam and drying shrinkage) are also strongly related to the mechanical and flexural performances of recycled aggregate concrete.

Conceptual structure: trending topics

The trending topic for each year is generated based on the keywords analysed. The trending topics are summarised and presented in Figure 4. Based on the topics, recycled concrete research can be grouped into three phases, that is, first [pre-1990s], second [1990–2000] and third (post-2000). In the first phase, the identified topics related to economic benefits. For instance, Chase and Lane (1986) explored the use of RCA as a material for sub-base in a highway project. In contrast, other authors (such as Hansen and Naryd, 1983; Sri Ravindrarajah and Tam, 1985) conducted experiments targeted at understanding the properties of concrete produced from RCAs. The results of these previous studies highlight the potential benefits of utilising recycled concrete. Based on the findings of studies in the first period, the focus shifted towards exploring the use of recycled concrete in non-structural components, for example, highway pavements, in the second phase. In the third phase, researchers have investigated the effects of using new mixing methods on the properties of recycled concrete. For example, Tam and Tam (2008) showed that the use of two-stage missing approach for the production of recycled concrete improved its strength. Collectively, the evidence emerging from previous research provides stakeholders with information on the properties of recycled concrete. These studies highlight the potential use of recycled concrete for non-structural components.

Intellectual structure: analysis of citation bursts

In this section, we present an analysis of the timeline of the most cited publications that received strong citation burst, which helps to identify the articles that received particular attention from the relevant research communities within a certain period of time. Figure 5

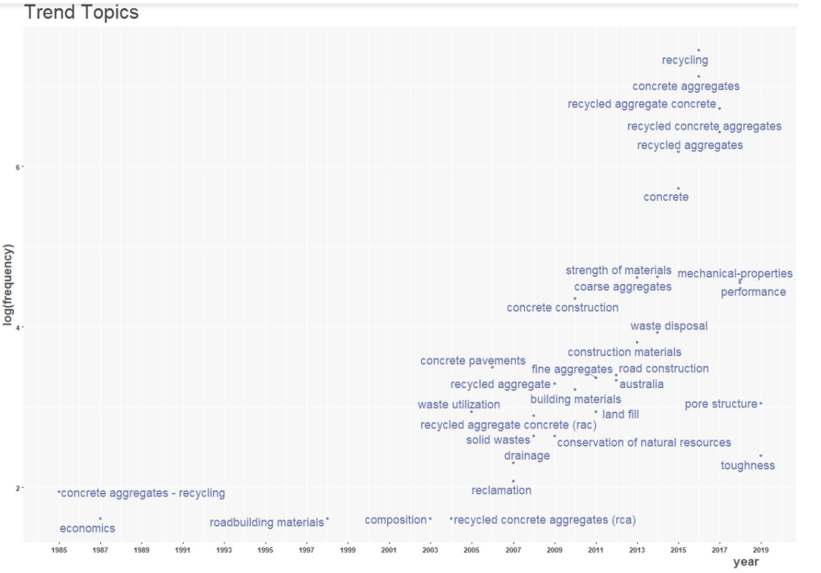

Figure 4.
Trending topics within recycled concrete research

Figure 5.
Top ten references with strong citation bursts

illustrates the top ten references with the strongest citation bursts. In the last column, the length of the line represents the period between 1983 and 2019, in which the red line means the time period of the citation bursts. The earliest citation burst started in 2003, which corresponds with the growth in the number of recycled concrete publications from 2001 in line with the signing of the Kyoto Protocol in 1998 and the United Nations Millennium Declaration in September 2000.

The study by Olorunsogo and Padayachee (2002) on the performance of recycled aggregate concrete has the strongest citation burst with a strength of 17.9 from 2004 to 2015. Their study provided the much-needed indicators for quantifying the mechanical properties of RC in comparison to concretes made from virgin materials. It is also interesting to note that the article by Poon *et al.* (2002) has the second strongest citation burst in the period between 2004 and 2011. In their work, the authors presented a technique for producing concrete bricks and paving blocks using recycled aggregates with a focus on their compressive strength, transverse strengths, shrinkage, skid resistance and density.

The third strongest citation burst was in relation to the work by Sagoe-Crentsil *et al.* (2001), which also focussed on the mechanical properties of fresh and hardened concrete made with commercially produced coarse RCA and natural fine sand. Furthermore, the other seven (7) articles in the strongest citation burst list also focussed on the mechanical properties and performance of recycled concrete. Taken together, the studies, which have the strongest

citation burst, provide insights into the properties and performance of recycled concrete. This information is essential for assessing the suitability of using recycled concrete in construction projects. Also, it can be used to evaluate the impact of interventions, such as introduction of additives or the use of new mixing methods, on the strength of recycled concrete.

As mentioned previously, review studies on recycled concrete were found to exist in the literature. The review of literature has shown that the incorporation of recycled aggregate significantly reduces the strength of the recycled concrete (Safiuddin *et al.*, 2013). In contrast, Tam *et al.* (2018) found that the use of recycled aggregate for non-structural applications was prevalent within the construction sector. The citation burst (Figure 5) in the current study indicates that a significant number of studies have investigated the properties and performance of recycled concrete. The prevalence of experimental studies in recycled concrete research was also observed. However, little attention has been paid to the possibility of replicating these experiments in the real world. Hence, there is a need to explore the potential of producing recycled concrete meeting various specifications using field experiments.

Conclusion

Recycled concrete has received growing interest from researchers in the engineering, construction and other allied academic disciplines. This study conducted a bibliometric analysis of the recycled concrete research to provide a macroscopic perspective of research trends based on journal articles available on the WoS and Scopus database between 1978 and 2019. A total of 2,462 publications were identified and used for the study. The data was analysed according to the key themes such as the number of publications per annum, collaboration and trending topics. Also, publications that have "contributed highly" to the recycled concrete knowledge base were identified.

Recycled concrete research has received growing attention due to its economic and environmental benefits. In the early years, the strength of concrete produced from new and recycled aggregates was compared. Subsequently, researchers evaluated the effect of pozzolan on the performance of recycled concrete. Recently, the effect of mixing methods on the strength of recycled concrete is being examined. This finding suggests that recycled concrete research has evolved over time. Also, the findings emanating from the current study highlight the need for studies focussed on: (1) real-world application of recycled concrete, (2) the use of models, such as machine learning, for quantifying the properties of recycled concrete and (3) the effects of using innovative mixing methods and admixtures on the strength of recycled concrete. These new processes and materials would provide opportunities for improving the strength and properties of recycled concrete.

The findings of this study are subject to certain limitations. For instance, in terms of scope, the database search focussed on papers published in journals and English language. Publications in other languages are not included in the sample analysed in this study. Notwithstanding these limitations, this study offers valuable insights into the current state of knowledge on recycled concrete. This study's findings hold salient implications for the recycled concrete research community. For instance, following from the review, it is evident that recycled concrete research remains focussed on an understanding of the mechanical, chemical and physical properties of the material. Also, it was observed that limited publications have emanated from Africa – a continent wherein the lack of infrastructure has necessitated massive infrastructure investments. The review further revealed the prevalence of collaborations between authors within the same geographical location, thereby highlighting the absence of knowledge sharing on the topic between researchers situated in the Global South and the Global North.

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