A BIBLIOMETRIC ANALYSIS OF RECYCLED CONCRETE RESEARCH (1983-2018)

# Abstract

**Purpose:** The use of recycled concrete 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 recycled concrete (RC) research. An understanding of the state-of-the-art in the RC domain justifies future research in this field.

**Design:** A systematic and comprehensive search of RC-related literature was conducted using the SCOPUS database. In this research, VOSviewer software 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 findings reveal the research themes, clusters, collaboration networks and advancement of knowledge in the field of RC research. The study integrates the literature focused 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 suggest 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. Also, there is a need for multi and interdisciplinary studies focused on RC.

**Keywords:** Bibliometric Analysis, Circular Construction, Recycled Concrete, VOSviewer

# Introduction

Evidence indicates that the construction sector produces a significant amount of greenhouse emissions, which is associated with climate change. In recent years, the rise in the number of extreme weather event has led to increased calls for the adoption of sustainable practices. The circular economy model is one of concepts associated with sustainability, and it is premised on the principles of resource recovery and re-use (Robinson 2004, Greyson 2007, Geissdoerfer et al. 2017, Winans et al. 2017, Schroeder et al. 2019, Bruel 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.

There is a growing body of literature that recognises the importance of incorporating circular economy business models in business within the construction sector. Concrete is one of the main materials used for the execution of projects in the construction sector. On the global scale, it has been estimated that about 40% of the greenhouse emission has been attributed to the activities in the construction sector (Azzi et al., 2017). Also, a significant amount of non-renewable materials and greenhouse emissions have been associated with the production of cement and concrete (Bolin and Smith, 2011; Liu, 2013). Due to these challenges, industry stakeholders are continuously striving to ensure that the industry transitions from the high levels of unsustainable resource consumption patterns associated with it towards a state which depicts optimal sustainability (Kibert 2013, Abuzeinab et al., 2016, Heeren and Hellweg, 2019). Also, 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, i.e. the shift towards embedding circularity and sustainability, of the construction sector.

In recent years, there has been increased number of studies focused on recycled concrete. However, only a few studies have been undertaken to review the state of knowledge on recycled concrete. 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. (2003) reviewed the properties (mechanical, chemical and physical) of recycled concrete. However, these reviews are typically qualitative, not replicable (the method for selecting papers were not described), and limited number of papers were selected. Thus, the nature and state of recycled concrete research remains unclear.

This study present 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 with 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 of the following: A justification of the research method adopted; a results presentation and discussion section and the conclusion.

# Research Method

In recent years, the number of manuscripts published in academic journals has been increasing. Integrating the empirical findings of past research is essential for creating knowledge required for improving practice. Systematic review, meta-analysis and bibliometric analysis are three main methods used for synthesizing previous research (Gradeci et al., 2017; Schmidt, 2008; Zupic and Čater, 2015). 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: (i) objective analysis of previous research and (ii) 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 methods have been used to synthesize knowledge in various academic disciplines. Previously, this method has been used to map the published research on corporate social responsibility (Feng et al., 2017), green building (Zhao et al., 2018), flexible pavement (Chang et al., 2020) 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, an approach adopted in similar previous studies was utilised (Zupic and Čater, 2015; Ekanayake et al., 2019). According to these authors, a five-stage approach for conducting bibliometric reviews is suggested. This 5-stage process consists of: conceptualization of research, collection of bibliometric data, analysis of collected data, visualization and interpretation.

As mentioned previously, this 5-step process was used for this bibliometric review. At the first stage, the research objectives and an appropriate method for addressing the research objectives was identified. Second, bibliographic information was collected based on searches conducted using the SCOPUS database. A comparison of SCOPUS and Web of Science (WoS) databases indicates that SCOPUS serves as a more comprehensive source of indexed journal articles (Falagas et al., 2008). The selection of appropriate keywords is essential for ensuring that relevant journal papers are identified from the SCOPUS search. In this study, two combinations [(i) "*recycled concrete*", and (ii) "*recycle\**" AND "*concrete*"] of keywords were used for the SCOPUS search. The search results were filtered to exclude the following: (i) duplicates, and (ii) papers published in other languages apart from English. Also, the search results were limited to journal papers. A total of 1018 relevant publications were identified at the end of the search process. The bibliometric data relating to these publications were downloaded and stored for further analysis.

The third and fourth stage (i.e. data analysis and visualization) was carried out using the VOSViewer software. VOSViewer (van Eck and Waltman, 2013) is a proven software that can be used for analysis and visualization of bibliometric data. The VOSViewer has been applied in numerous published studies (Cancino et al., 2017; Krauskopf, 2018). Finally, the findings emerging from the bibliometric analysis were analyzed.

# 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 1983. Figure 1 shows that the number of publications on this subject matter grew from 1 in 1983 to 226 by the end of 2018. Figure 1 provides insights into the evolution of interest in recycled concrete. Figure 1 can be divided into three periods: (1) initial stage from 1983 to 2000 [less than 2 publications per year]; (2) slow growth stage from 2001 to 2006 [between 3 to 9 publications per year]; and (3) rapid growth stage [between 11 to 226 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 emergence of topical subject area. The growth in the number of recycled concrete publications from 2001 could be due signing of the Kyoto Protocol in 1998 as part of the strategies for combating climate change. Also, the cumulative number of publications grew from 1 in 1983 to 1018 at the end of 2018.

**‘Insert Figure 1 here’**

## Distribution of authors and collaboration pattern

These 1018 publications were written by 2114 different authors. A large proportion of authors have published only one paper focused on recycled concrete (73.32%, n= 1,550/2114). One hundred and nineteen authors (5.63%, n=119/2114) had published at least three papers, and twenty authors (0.95%) had published at least ten or more journal articles. These findings are consistent with observations presented in previous studies (Goyal, 2017; van Nunen et al., 2018) which showed that a small group of authors published a significant proportion of journal articles on a topic.

Out of the 2114 authors, the top-10 most productive authors in terms of the numbers of journal papers published on the recycled concrete were identified. See Table 1.

**‘Insert Table 1 here’**

According to the information on Table 1, De Brito is the most productive author on the topic of recycled concrete with 42 publications. The second and third ranked authors are Arulrajah and Poon who have published 26 and 23 journal papers, respectively. In contrast, the top-3 most cited authors are De Brito, Evangelista and Poon with 1875, 1070 and 842 citations, respectively.

The collaboration pattern (i.e. authorship) among authors publishing journal papers on recycled concrete was analysed with VOSViewer. The authors included in the network published at least 5 papers on recycled concrete. Kindly note that authors who are not connected with other authors were not included in the network. The pattern of collaboration among authors is presented in Figure 2. The size of the nodes (i.e. circles) gives an indication of the number of published journal articles. The lines between the nodes represents collaboration between authors and the colours in the figure represents the collaboration cluster. Based on Figure 2, it is evident that De Brito and Gonzalez-Fonteboa are the main researcher in the network. Other researchers are linked to these main researchers.

From Figure 2 there are 5 main clusters (purple, blue, red, yellow and green) are evident. The authors in the blue and purple cluster are affiliated with institutions located in Portugal apart from Dhir who is affiliated with a university in the UK (i.e. University of Dundee). The authors in the red and green clusters are affiliated with Spanish institutions. The yellow cluster is made up of authors affiliation with institutions located in Italy except for Letelier who is affiliated with a university in Chile (i.e. Universidad de la Frontera, Temuco, Chile). Although Figure 2 suggests that authors are actively collaborating on recycled concrete research, it is evident that most of the authors are affiliated with institutions located in Europe. This finding highlights the need for a more international and interdisciplinary research focused on recycled concrete.

**‘Insert Figure 2 here’**

## Collaboration Network

### Institution

The authors contributing to knowledge on recycled concrete are affiliated with 835 institutions (one author can be affiliated to more than one institution or several authors working at various institutions can contribute to the same manuscript). The use of fractional counting was recommended for analysis of co-authorship network (Perianes-Rodriguez et al. 2016) and this approach was utilised in this study. The top 10 most active institutions in terms of numbers of published studies on recycled concrete are presented in Table 2. The most productive institution is in Spain. This university published 43 journal papers. Interestingly, all the top-10 institutions are universities. This is indicative of the roles of universities in shaping the evolving discourse around recycled concrete.

**‘Insert Table 2 here’**

### Countries

To gain an understanding of the geographical coverage of publications related to recycled concrete research, the co-authorship network was analysed using the VOSViewer. This analysis revealed that authors from 70 countries had contributed to recycled concrete research within the period under review. The countries included in this map published at least 15 papers on recycled concrete (18 countries met this threshold). Countries that are not connected to other countries were not included in this network (i.e. countries that do not collaborate). The size of the circle is an indicator of the number of papers published. The thickness of the link represents the number of collaborations among counties. The colour is an indicator of collaboration clusters. The collaboration network among countries is presented in Figure 3. Based on information available in Figure 3, there are four clusters (blue, yellow, red and green). The green cluster is made up of mainly European Nations. The Red cluster contains countries located in Asia. The clusters tend to be centered around the most productive countries in recycled concrete research. Similar to the findings in previous studies, collaborators tend to be located within the same geographical location (van Nunen et al. 2018).

**‘Insert Figure 3 here’**

## Journals that publish recycled concrete research

In total, these 1018 publications were published in 208 journals. The high number of outlets suggest that recycled concrete research is multidisciplinary in nature. Of the 208 journals, 106 journals published only one article culminating in 10.41% of the 1018 journal papers reviewed, whereas 40 journals published only 2 articles on recycled concrete (7.86% of 1018 journal papers). 16 journals published ten or more articles on this topic (61.20% of all papers).

Table 3 gives information about the top 10 peer-reviewed journals actively publishing recycled concrete research. These top-10 journals published 543 articles hence accounting for 53.34% of the global outputs. Among these journals*, Construction and Building Materials* published the highest number of articles on recycled concrete (25.25%; n = 257/1018). The other key journals in the field are *Journal of Cleaner Production* and *Journal of Materials in Civil Engineering* with 56 and 51 articles on the topic, respectively. The subject categories: '*Construction & Building Technology*' and '*Materials Science, Multidisciplinary'* appear 7 times for the top-10 active journal focused on recycled concrete. As expected, recycled concrete research is domiciled within the construction technology and material science body of knowledge.

**‘Insert Table 3 here’**

## Term analysis

The title and abstract of a journal paper give a concise insight into its content. An overview of the trends in recycled concrete research emerged from an analysis of the title and abstract of the selected journal papers using VOSViewer. The dataset contains 538 terms that occur in 10 or more times in the titles or abstracts. The most occurring terms were: "concrete aggregate" (548 documents), "construction" (240 documents) and "mixture" (204 documents). To discern the evolution of key issues discussed in recycled concrete research, a term map of terms that occur in 50 or more publications was created. The terms occurred in the 1018 journal articles published between 1983 and 2018. Three main clusters were identified.

Due to the relatedness of the terms, there is an overlap between the clusters at the center of Figure 4. The red cluster represents properties of recycled concrete. The property of a material is strongly related to the possibility of its usage in the real world. Generally, research focused on concrete seeks to understand its properties and, to explore extant know-how for managing the quantity of cement utilized to achieve carbon footprint reduction associated with concrete production, and microstructure (Narayanan and Ramamurthy, 2000). The key terms in the red cluster includes modulus, flexural strength, compressive strength, shrinkage, splitting tensile strength, elasticity and workability. The green cluster represents the material being investigated and process of extracting the material. The terms in this cluster includes recycled concrete aggregate, demolition, waste and recycled material. The blue cluster represents the methods for data collection and analysis used in recycled concrete research. This cluster includes terms, such as experimental results, experimental study, specimen and model.

**‘Insert Figure 4 here’**

To highlight the trends in recycled concrete research over time, temporal variation of terms (content of research papers) can be used to gauge the focus of research in a particular field. The journal articles were grouped into three periods of twelve years: (i) 1983-1994 (5 papers); (ii) 1995-2006 (38 papers); and 2007-2018 (975 papers). The frequency of occurrence of terms over these three periods are summarised and presented in Table 3. Looking at the time period between 1983 and 1994, the most frequent terms are cement, concrete and calcium silicate. Subsequently, the most frequent terms between 1995 and 2006 are recycled concrete, recycled aggregate, effect and performance. In recent times, the most frequent terms are recycled concrete, concrete and compressive strength. A scan of the frequently occurring terms in the titles and abstracts of the selected journal papers indicates that the understanding of the properties of recycled concrete has been the focus of a significant portion of studies in this area.

**‘Insert Table 4 here’**

# 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 SCOPUS data base between 1983 and 2018 (a 35-year-period). A total of 1018 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, the distribution of authors and collaborating partners, the nature of the extant collaborative network, journals publishing recycled concrete research, and, term analysis.

Findings from the study indicate a year-on-year increase in the number of recycled concrete publications from 1983 (1) to 2018 (226). Also, the review revealed that 10 authors out of 2114 authors were most productive as they shared 208 publications out of 1018 identified publications-approximately 20% of the entire publications within the SCOPUS database. The 1018 articles were published across 208 journals. Whereas 106 journals published one article on recycled concrete research, 40 journals published 2 articles only. However, 16 journals published 10 articles and above. The term analysis carried out highlighted the focus on engendering increased understanding of the properties of recycled concrete. Data from the term analysis was delineated according to three different time intervals, namely; 1983-1994, 1995-2006, and 2007-2018. It was discovered that terms like cement, concrete and calcium silicate were prevalent in the first era (1983-1994), the second era (1995-2006) recorded an increase in the use of terms like recycled concrete, recycled aggregate, effects and performance. The most recent era (2007-2018) witnessed a surge in the use of terms like recycled concrete, concrete and compressive strength.

The findings of this study are subject to certain limitations. For instance, in term of scope, the database search focused 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 focused on an understanding of the 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. From the review Research on recycled concrete has continued to be viewed from a mono-disciplinary perspective judging from the description of the journals wherein they are published. Impliedly, there is a need for engagement with multi-, and interdisciplinary journals.

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