Materiales de Construcción
Vol. 72, Issue 345, January-March 2022, e277
ISSN-L: 0465-2746
https://doi.org/10.3989/mc.2022.07421

The use of recycled aggregates in the construction sector: a scientific bibliometric analysis

Z. Sánchez-Roldán[a], M. Zamorano[b], M. Martín-Morales[a]✉

a. Department of Building Construction, University of Granada, ETS de Ingeniería de Edificación, (Granada, Spain)
b. Department of Civil Engineering, ETS Ingeniería de Caminos, Canales y Puertos. University of Granada, (Granada, Spain)
✉: mariam@ugr.es

Received 12 May 2021
Accepted 27 July 2021
Available on line 22 March 2022

ABSTRACT: The environmental problems associated with the construction sector have promoted the worldwide scientific community to pay attention to the use of recycled aggregates from construction and demolition waste. SciMAT and VOSviewer bibliometric tools have been applied in order to analyse, quantify and visualise the conceptual and social aspects of this scientific field, as well as its evolution between 1973 and 2019. The study of 843 scientific papers in this field has shown that the most important thematic area has been *Recycling*. In general, the common objective of the published papers was to study the efficient use of resources contained in construction and demolition waste due to their treatment to produce recycled aggregates, particularly for use in concrete. Likewise, some lacks have been observed in other areas of the analysed field, e.g. the use recycled aggregates in applications subject to less demanding regulations (mortars, precast concrete products, or green roofs).

KEYWORDS: Waste treatment; Recycled aggregate; Construction sector; Bibliometric analysis; Science mapping analysis; Concrete.

Citation/Citar como: Sánchez-Roldán, Z.; Zamorano, M.; Martín-Morales M. (2022) The use of recycled aggregates in the construction sector: a scientific bibliometric analysis. Mater. Construcc. 72 [345], e277. https://doi.org/10.3989/mc.2022.07421.

RESUMEN: *Empleo de áridos reciclados en el sector de la construcción: un análisis bibliométrico científico.* Los problemas medioambientales asociados al sector de la construcción han promovido que la comunidad científica mundial preste una mayor atención al uso de áridos reciclados procedentes de residuos de construcción y demolición. Para analizar, cuantificar y visualizar los aspectos más relevantes de este campo científico, así como su evolución entre 1973 y 2019, se han aplicado las herramientas bibliométricas SciMAT y VOSviewer. La revisión bibliométrica de 843 trabajos científicos publicados en este campo ha mostrado que el área temática más importante ha sido el *Reciclaje*. El objetivo común de los mismos ha sido el estudio del uso eficiente de los recursos contenidos en los residuos de construcción y demolición para producir áridos reciclados y ser usados en hormigón. Asimismo, se han observado algunas carencias en otros ámbitos del campo analizado, como el uso de áridos reciclados en aplicaciones sujetas a normativas menos exigentes (morteros, prefabricados no estructurales o cubiertas verdes).

PALABRAS CLAVE: Tratamiento de residuos; Áridos reciclados; Sector de la construcción; Análisis bibliométrico; Análisis de mapas científicos; Hormigón.

1. INTRODUCTION

In Europe, the construction industry consumes about half of all extracted raw materials, in addition to being an important source of waste production (1). According to the latest data published by Eurostat, the European Union (EU) produced 924 million tons of construction and demolition waste (C&DW) in 2016 (2); this value represented around one third of the total waste generated. Approximately 294 million tons of the non-hazardous mineral fraction of the C&DW were treated. The construction sector contributes to significant environmental problems along the different phases of the life cycle (material extraction, product production, construction, use, maintenance and demolition) which includes the generation of waste (3, 4).

C&DWs are mainly composed of concrete, ceramics, stone, asphalt and/or excavation soil, although they may also contain a small amount of impurities (gypsum, wood, plastics, steel or paper) (5). Most of them are classified as inert because they are neither chemically nor biologically reactive, will not decompose and do not have dangerous characteristics in their original form. Therefore, C&DW recycling through the conversion of waste into secondary raw materials is considered to be fundamental, since it could lead to significant environmental, economic and social benefits (6–8). In this context, and in accordance with a framework for sustainable development, this type of waste has received widespread attention around the world, resulting in a significant number of scientific documents published in recent years. The growth in scientific publications has been quick and it has been motivated by the important environmental impacts generated by C&DW (9), focussing on possible applications of recycled aggregates (RA) such as concrete (10–13), prefabricated concrete (14), non-structural concrete (15), masonry mortars (16–18) and road or pavement applications (19–21), among others of the most representative.

On the other hand, studying the development of a cross-section of studies on a specific subject is of great scientific interest in the search for new trends or, even, to identify possible weaknesses and shortcomings. In the sense of the wealth of scientific information available in a certain field, the application of bibliometric science could be a good way of analysing it. This science examines the bibliographic material from an objective and quantitative viewpoint and is useful for organising information in a specific field (22, 23). In order to do this, it uses two principal resources: performance analysis and content analysis (24–27). The first one is based on bibliometric indicators and it is used to measure the quality of the publications and their impact on the scientific community (survey of publications and citations). The second resource is developed by scientific maps that spatially represent the structure of the scientific research; they also try to represent the social (relationship between authors) and conceptual connections (network of co-words) in the investigated area, as well as their temporal evolution.

Software tools are usually used for this purpose (28, 29), examples are: Bibexcel (30), CiteSpace II (31), IN-SPIRE (32), Science of Science (Sci2) Tool (33), SciMAT (34) and VOSviewer (35). Despite the fact that each of them implements different analysis techniques and algorithms to the data, they have complementary characteristics and, therefore, it could be convenient to take advantage of their synergies to perform a complete analysis of the scientific field that is to be analysed (28).

Some studies have been developed through the bibliometric analysis of indexed scientific papers relating to different topics in the construction sector, for example: concrete segmental bridges (36); self-compacting concrete (37); construction safety management (38); analysis of the construction life cycle (39, 40), construction and building technology (41–43), green roof research (44) or even on building information modelling (45, 46). Key issues for the progress of the sector itself include the evolution of the Circular Economy (47, 48). Other studies combined quantitative and visual processes to measure the performance of global research in the framework of the management of C&DW (49, 50), related research on the reuse and recycling of urban solid waste (including C&DW) have also been developed during recent decades (51–53) or bibliometric review in the domain of 'sustainable construction' over the past 25 years (54).

Accordingly, the scientific community has considered this type of study to be of real interest, as it facilitates the management of a large amount of information and validates the knowledge of existing data in a specific field. The findings of bibliometric studies could prove useful for the scientific community in identifying the gaps and potential opportunities in the current knowledge and suggesting the pathway for future research. However, knowledge about the use of RA in construction, from a systematic perspective, is non-existent.

As a consequence, it is necessary to carry out an analysis through the use of intelligent bibliometric tools to evaluate the changes in existing research and establish the direction of future research. Therefore, the objective of this work has been to analyse, quantify (through bibliometric indicators) and visualise the social (co-author analysis) and conceptual (co-word analysis) aspects of the scientific field "A*pplications of RA in the construction sector"*. In addition, the evolution of conceptual aspects has been studied over three periods to predict their future trends. In order to do this, the most used tool, SciMAT and VOSviewer, have already been used in different scientific articles (55–59).

2. MATERIALS AND METHODS

To achieve the established objective for this research, a systematic review of the published literature on applications of RA in construction was carried out; it was then analysed from a bibliometric perspective. Both procedures are described in the sections below.

2.1. Systematic literature review

A systematic literature review has been used as a methodological approach for exploring the useful findings in the related literature that are relevant to a specific investigation, according to PRISMA methodology (60). Figure 1 shows the flow chart of the review process carried out, showing the number of documents included as well as those excluded after applying the selection criteria at each stage.

Web of Science (by Clarivate Analytics) and Scopus (by Elsevier) are the most widely used databases worldwide for the search of scientific documents. They were used to collect the publications focused on "*applications of RA in the construction sector*", between the 1970s and 2019. Specifically, an intense search on the scientific production in the field of "*construction and demolition waste*" has been done. Later, this search was refined towards the application in the "*construction sector*" and, in turn, on "*recycled aggregates*", which are the granular material obtained from inert waste from the construction and demolition of buildings and infrastructures. This search was refined based on the "Article title, Abstract, Keywords" of papers published in international journals relating to this field.

Firstly, and after the aforementioned filters were applied, 1295 documents were identified through an initial search from the data repository. These documents were then exported into SciMAT, where this software finds the duplicate documents and one of them is removed. This elimination was done manually, specifically from Web of Science, as a comparative analysis has found that Scopus offers more comprehensive coverage of sources than Web of Science (54, 61). Aspects referring to the document type, journal tittle, country, affiliation, keywords, and impact indicators (sum of citations and h-index) were all analysed and standardised using SciMAT mapping tools.

Therefore, after eliminating duplicates, repeated or unwanted information (such as manuscripts and patents), reviews and methodological papers (given that they may distort the impact (62, 63)), as well as studies that were not related to the main theme of this work, the final number was reduced to 843 documents (Figure 1).

2.2. Bibliometric analysis

Based on the information obtained from the documents selected after the systematic review, the bibliometric performance analysis has been combined with

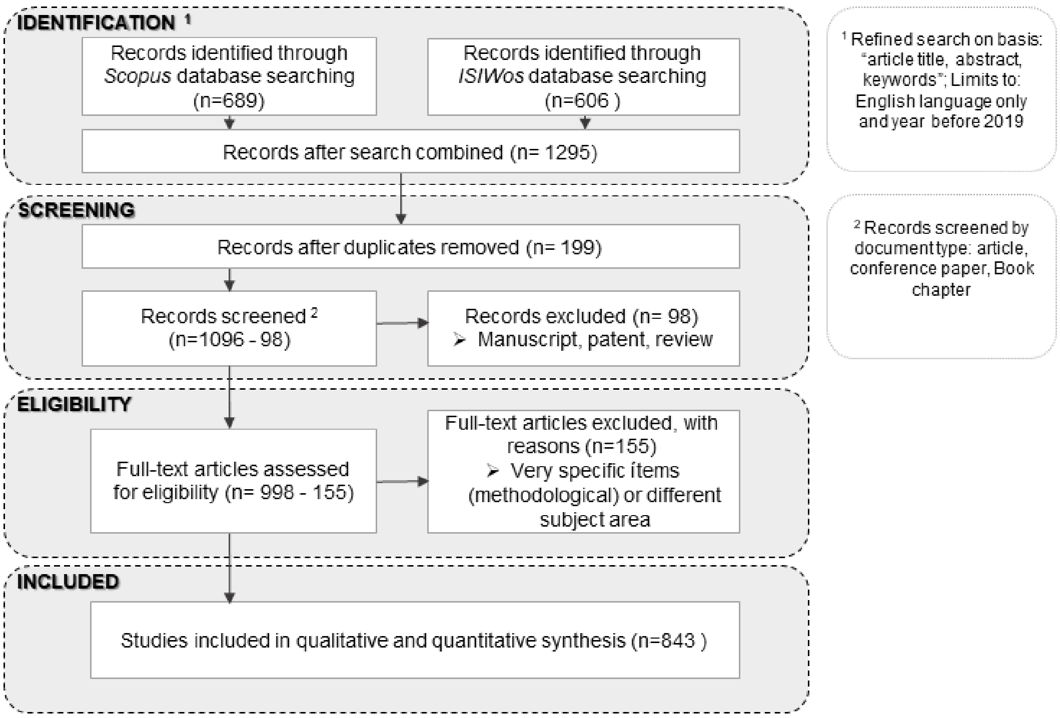

Figure 1. Flow of information through the different phases of a systematic review by PRISMA.

the bibliometric analysis of the content of these documents using SciMAT and VOSviewer mapping tools. In this way, the following questions related to the field of research have been addressed: (i) How many articles have been published and how have they been distributed over time?; (ii) Who are the most prolific authors?; (iii) Which magazines and conferences lead this issue?; (iv) What is the most influential work?; (v) What is the current state of this field of study?; (vi) What are the main thematic areas?; and (vii) What are the new topics for future research?

Bibliometric performance analysis has provided a response to the four questions and the last three have been answered using the cited scientific mapping software.

2.2.1. Bibliometric performance analysis

In particular, bibliometric performance studies use several bibliometric indicators to analyse and quantify the influence of diverse aspects relating to scientific productivity (55, 64, 65). It should be noted that bibliometric indicators objectively and numerically assess the production, activity and quality or impact in the field of science and technology, using scientific knowledge published. These indicators are grouped into three main categories (63): (i) production indicators, which measure the amount of results or publication count (number of publications or percentage of works indexed in a repository); (ii) visibility and impact indicators, either based on the number of citations received by documents (h-index (64), g-index (66), hg-index (67), q^2-index (68), etc.) or by journal in which they were published (Impact Factor of *Journal Citation Reports* - JCR); and (iii) collaboration indicators that measure the collaboration of the authors or institutions in scientific production (co-authorship index, similarity measures, etc.).

The bibliometric analysis carried out in this research evaluated the performance of the field *"Applications of recycled aggregate in the construction sector"* from an objective and quantitative perspective, taking into account the scientific output produced by authors and journals; in addition, the highly cited papers in this research field have been studied.

2.2.2. Bibliometric content analysis

Other types of bibliometric indicators are known as relational indicators, which generate graphic scientific representations through the use of relational information (34). In this case, scientific mapping has been developed using VOSviewer and SciMAT, which are considered two of the most widely used tools in scientific articles (55–57). The most important facets of the analysis of scientific mapping have been described below.

2.2.2.1. VOSviewer

VOSviewer software (version 1.6.15) is a free-to-use tool developed by the Center for Science and Technology Studies of Leiden University (Netherlands) in 2010. It has been designed for constructing and visualising bibliometric networks through the use of the VOS mapping technique, where VOS stands for visualisation of similarities (35). The main advantage of this program over most other available bibliometric mapping software is that it focuses on the graphic representation of large maps, due to its powerful graphic interface, which allows examination of the created maps in an intuitive way.

The analysis developed in this study has been aimed at understanding the collaboration among researchers who have worked on RA in construction. To do this, the most cited authors have been considered, i.e. authors with more than three published documents. Based on this information, a two-dimensional map of authors was created based on a co-occurrence data matrix and using the *author* entity as the analysis unit. According to the indicated methodology (35), the frequency of occurrence of a particular term is represented by a circle and it is defined by its size on the map, so that the more important the element, the greater the associated circle. Due to an intelligent algorithm at each zoom level, only the most important (or most frequent) elements are displayed, thus avoiding overlap. In addition, VOSviewer selects a different and random colour for each group of elements (according to the strength of association) and the circles in the same group should be displayed in the same colour. Likewise, the distance between two elements is related to their degree of relationship or similarity; in consequence, the shorter distance, the stronger the author's relationship is.

2.2.2.2. SciMAT

Science Mapping Analysis software Tool – SciMAT (version 1.1.04) is an open source software tool (GPLv3) developed by a group of researchers from the University of Granada (34). SciMAT integrates everything necessary to analyse the scientific maps generated under a longitudinal framework and study the evolution of the conceptual aspects of a research field over consecutive time periods. In addition, this tool improves the maps with the integration of visibility and impact bibliometric measures (citations), such as h-index, g-index, hg-index, q2-index, etc. As result, the conceptual subdomains (particular topics or general thematic areas) of a specific field can be detected and visualised (29).

On the basis of the methodology developed by Cobo and his collaborators (29, 34), the applied analysis has been developed according to the following steps:

- In order to improve the quality of the data, once the knowledge base (Web of Science and SCO-

PUS data) was constructed and the data collected were imported, this base was edited to remove possible mistakes in titles, authors or references etc. The words that represented a similar concept were also unified into a single group.

- To detect the most important, productive and impactful topics, the analysis of scientific maps was configured using an assistant designed for this purpose (29, 34, 69). In particular, the entity used in the analysis was words and the co-occurrence of keywords was used for the construction of the bibliometric network (relation co-occurrence is when two elements appear together in the same document).
- The results obtained were displayed graphically using four different instruments (29): (i) Strategic diagram (Figure 2a); (ii) Thematic network or cluster (Figure 2b); (iii) Temporal evolution map (Figure 2c); y (iv) Overlap map (Figure 2d).
  1. Strategic diagram (Figure 2a). This represents the main themes of a scientific field in a two-dimensional space, which includes four categories, one in each quadrant. The measure of centrality (X axis) represents the scale of relevance of the topics for the research area; the density scale (Y axis) represents the frequency of appearance (24, 70). Finally, each topic is represented with a sphere or node; the number of associated documents is included in the node, whose size is proportional to this number.
  2. Thematic network or cluster (Figure 2b). In the case of each topic included in the strategic diagram, the keywords concerning the topic and their interrelationships allow the construction of a thematic network. This is labelled with the name of the most significant node or keyword and includes a series of keywords related to each other through links between their nodes; the value included in the node is the number of documents associated with the keyword of the topic and it is proportional to the size of the sphere. Finally, the nodes are connected to each other when two keywords co-appear in a set of documents; in this case the thickness of the union lines depend on the equivalence index of the keyword pair (24).
  3. Temporal evolution map (Figure 2c). This is used to represent the analysed documents grouped into consecutive periods of years, thus displaying the evolution of the scientific field studied. The methodology used was based on the Jaccard index; this measures the degree of similarity between two sets or clusters that represent the keywords associated with the topic (71). The joining lines between each cluster can be continuous or discontinuous. A continuous line means that the linked cluster shares the main item (usually the most significant one); in the case of dashed lines, the themes share elements that are not the main item. In addition, the thickness of the links is proportional to the similarity between the two topics and the volume of the spheres is in relation to the number of documents associated with the topic (28).
  4. Overlap map (Figure 2d). The stability between two consecutive periods can be represented with a graph of overlapping elements where the circles are used to represent the periods studied and the inside number (Nº words) shows the total keywords of each one. The union between periods is carried out with a horizontal arrow including the number of keywords shared between both periods and the degree of overlap or corresponding stability index (Ei). The incoming arrows to each circle represent the number of new words in each period, while an outgoing one is used to show the new ones.

Finally, the performance measures obtained for the most important themes detected in each period are shown. Among all the quality measures that can be selected in SciMAT, the most commonly used ones were chosen, according to Cobo´s methodology (28, 29): sum of citations and h-index. Accordingly, the quantitative values obtained from the analysis were the total number of core documents analysed, the sum of citations received, the corresponding h-index, and values of centrality and density. These bibliometric measures give information about the interest in and impact on the specialised research community of each detected cluster or evolution area (29).

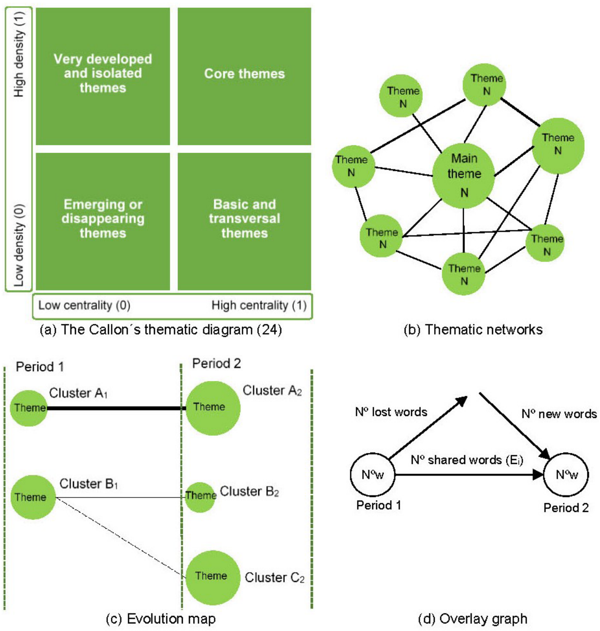

FIGURE 2. SciMAT visualisation maps (24, 29).

3. RESULTS AND DISCUSSION

This section summarised the analysis of the performance of the scientific activity taking into account the bibliometric data extracted from the SciMAT software and the co-word analysis. In the first case, the results have been organised in five subsections that include the quantification of the articles per year and period studied (Figure 3); the authors' contributions (Table 1); the distribution of documents analysed by journals (Table 2); and lastly, the analysis of the most cited documents (Table 3).

Finally, the results of the co-word analysis have made it possible to obtain scientific maps constructed with SciMAT (Figure 5 - Figure 7) and the performance measures associated with the most important themes for each established period (Table 4), as well as the structure of the scientific evolution of the studied field (Figure 8 and Figure 10).

3.1. Scientific activity performance

3.1.1. Article quantification by year and period

Although the first indexed paper in Web of Science and Scopus that published the results of research on applications of RA ("*Recycled concrete*" by Buck (72)) dates back to 1973, the number of scientific documents published on this subject has grown substantially since 2000, particularly in the last ten years (2009-2019). For this reason, the study has been conducted in 3 periods: before 2000, 2000-2009 and 2010-2019. Figure 3 shows the number of documents published per year (Figure 3a) and for each period, including the sum citations received for documents published by period (Figure 3b). An exponential growth of the number of publications, both per year and per period, has been observed; however, in the case of the number of citations, a lineal growth has been noticed. It can be seen that over 75% of total citations are concentrated in less than 16% of total analysed papers and located in the second period; this is because the assessment of the impact of works through the citations they receive is not an immediate measure, but can only be applied years after the publication of the documents. In 2019, 192 documents were identified with a total of 616 citations; this number of papers represents almost doubling of all documents published in the previous period (112 articles published between 2000 - 2009 have been cited 15174 times). Specifically, 85% of the associated literature with the analysed field was published in the study's last time period; this leads to the conclusion that this is a literature that is continuing to grow, and whose recognition by the scientific community will increase over time (as the number of citations received increases). This is due to the fact that more attention is paid to this topic in social, economic, and scientific contexts, in an attempt to reduce the use of natural resources, enhance economic benefits, and encourage conscientious respect for the environment (73–75). All of this is associated with the approach of the construction sector to the paradigm of sustainable development which has been integral to the European Strategy 2020 (since 2010) to promote a Circular Economy.

3.1.2. Contribution of authors and collaborations

The top 10 authors (from a list of 1828) with the highest contribution to the field studied have been summarised in Table 1. This table also includes the number of documents published, the total and average value of citations received, the average publications per year, the university and the country where they came from, and the author links according to the VOSviewer data. In this ranking, the Portuguese researcher *Jorge de Brito* leads the list with 110 documents and a total of 5745 citations received; he is followed at an important distance by the Hong Kong-born *Chi-Sun Poon* and his compatriot *Luis Evangelista*, with 57 and 35 publications and with 5086 and 2439 citations, respectively. It is important to point out that *Ravindra K. Dhir* held 10th position on the list, with only 11 articles published in the field under investigation, but received a large

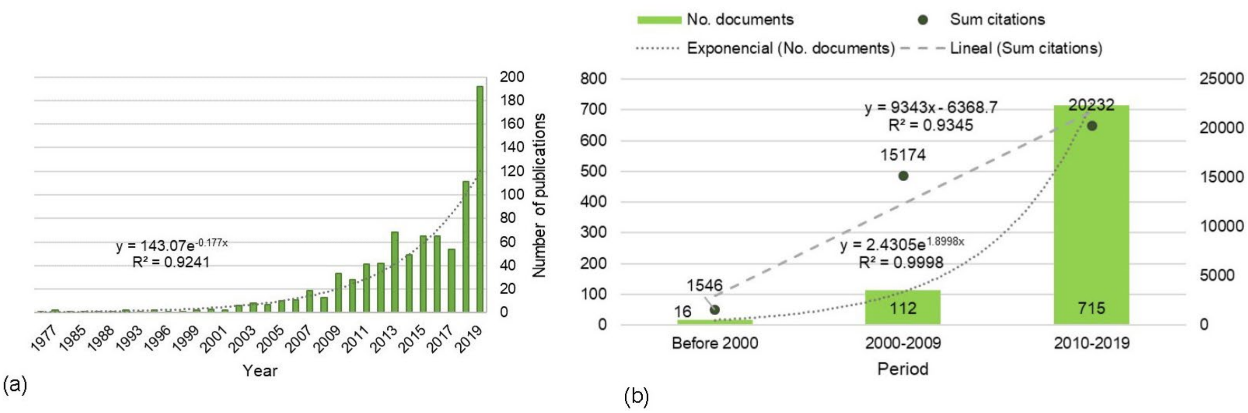

FIGURE 3. Number of published documents by year (a) and by period, including the corresponding sum citations (b).

TABLE 1. Top 10 authors with the highest number of documents published (from a total of 1828 authors) in the period studied (1970s - 2019).

Rank	Authors	No. of documents	Sum citations[1]	Average citations	Mean year	Author links (VOSviewer data)	Institution (Country)
1	de Brito, Jorge	110	5745	52	2015	23	Technical University of Lisbon (Portugal)
2	Poon, Chi-Sun	57	5086	89	2011	12	The Hong Kong Polytechnic University (China)
3	Evangelista, Luis	35	2439	70	2015	12	Lisbon's Polytechnic Institute (Portugal)
4	Kou, Shi-Cong	30	2872	96	2011	3	The Hong Kong Polytechnic University (China)
5	Agrela, Francisco	20	625	31	2015	12	University of Córdoba (Spain)
6	Jiménez, José Ramón	18	700	39	2014	11	University of Córdoba (Spain)
7	Ayuso, Jesús	17	622	37	2015	10	University of Córdoba (Spain)
8	Etxeberria, Miren	16	1443	90	2013	5	Polytechnic University of Catalonia (Spain)
9	Silva, Rui Vasco	15	1004	67	2016	3	ICIST, Instituto Superior Técnico (Portugal)
10	Dhir, Ravindra K.	11	1286	117	2013	3	University of Birmingham (UK)

(1) Citations have been update in June 2020

number of citations (1286), with an average of 117 citations per document. This author's impact is associated with collaboration with highly productive scientists, which helps to increase his scientific output, such as by his collaboration with the Portuguese *Jorge de Brito.* As a consequence, it can be asserted that the measure of the impact of the number of citations is not always related to the quantity of production itself. Likewise, the average period of distribution of the most productive authors' research time has been estimated between 2011 and 2016, showing a greater concentration of published documents in the third period studied (2010-2019) (Figure 3b).

On the other hand, the "intellectual structure" of the studied field knowledge base has been represented with the help of VOSviewer software. Figure 4 shows the connections between the 45 authors with the most significant associations in this network (with more than seven published articles), distributed into ten clusters with 113 links; and it reveals two predominant different but interrelated schools of thought in the used of RA. The largest group of collaborators is led by the Portuguese researcher *Jorge de Brito* (blue) who, in turn, shows the relationship with other smaller groups, amoung a total of 23 author links, such as *José Ramón Jiménez, Jesús Ayuso and Francisco Agrela* (red), *Iris Gónzalez-Taboada and Belén González-Fonteboa* (purple) or *María I. Sánchez de Rojas and Moises Frias,* among others (green). The subject investigated by J*orge De Brito* and his colleagues focused on the use of RA in a wide variety of applications, including structural concrete (76–78), non-structural use (79, 80), self-compacting (81–83) and high strength concrete (84), mortars (85–87) and geotechnical applications (20). The benefits of incorporating different types of chemical (88–90) or mineral additives (84, 91–93) were analysed in many of these studies, with the objective of improving the properties of recycled aggregate concrete (RAC). The replacement of natural sand by recycled material has also been a recurring theme for this author and collaborators, both in concrete (76, 88, 94, 95) and in masonry mortars (85, 86, 96).

Likewise, the research developed by *Chi-Sun Poon's* group (related by means of 12 author links) have also been focused on different applications of RA, such as structural concrete types (97, 98), self-compacting concrete (99) and high strength concrete (100) or previous concrete us-

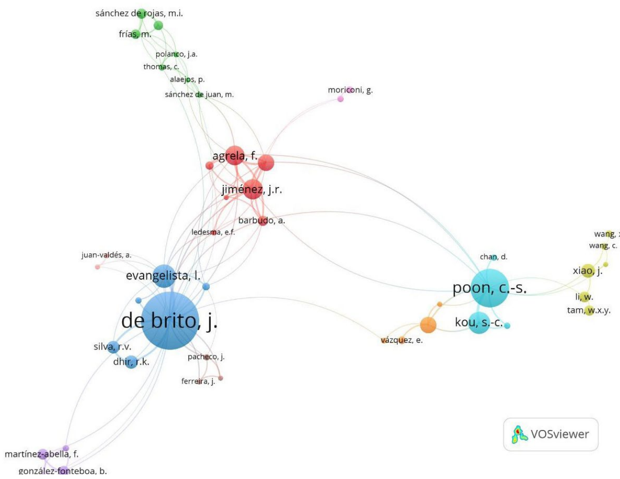

FIGURE 4. Network visualisation of the largest set of connected items. Source: VOSviewer.

ing waste glass and RA (101). However, the production of precast concrete using different types of RA has been the most important contribution of this author's research (102–106). The manufacture of concrete using RA with different humidity (107, 108), even, using carbonated RAs to understand their effects on the durability of RAC (109) or the study of the environmental consequences of the production of RA through the analysis of the life cycle (110) are other topics addressed by these authors.

At the collaboration level, Jorge De Brito has mainly collaborated with Portuguese authors, such as Luis Evangelista (76, 78, 111) or Rui V. Silva (85, 112–114), and he is also linked to Spanish research, such as that of José Ramón Jiménez, Francisco Agrela and Jesús Ayuso group (80, 86, 115) or with Belén González Fonteboa group (13, 81). In the case of Chi-Sun Poon, he has collaborated with Asian authors, such as Shi-Cong Kou (99, 102, 116) and Jian-Zhuang Xiao (97, 117), as well as with the Spaniards Miren Etxeberria (106, 118) and Francisco Agrela (119).

3.1.3. Distribution of journals

In this study, a total of 843 documents were analysed in the field under investigation; due to its interdisciplinary nature these documents had been published in 219 international journals, conferences and handbooks. The 10 top sources of information (Table 2), in respect of the number of documents published, include approximately 55% of all the articles collected in the database. The *Construction and Building Materials* journal stands out from the rest with 221 documents published in the research field, 26% of the total of the documents. The *Cement and Concrete Composites* and *Journal of Cleaner Production* ranked second and third, respectively with 49 (6%) and 41 (5%) documents from each one. Likewise, most of the journals have been included in the first quartile (Q1) of the following four JCR categories: Multidisciplinary, Construction and Building Technology, Civil Engineering and Materials Science; some of them are also included in the Engineering, Environmental and Environmental Science categories.

In relation to the cites received as an indicator of the impact or visibility, *Construction and Building Materials* is also the journal with a higher number of citations; a total of 12432 citations and an average value of citations per document of 56 was quantified. In contrast, journals such as *Cement and Concrete Research* (position 7) and *Cement and Concrete Composites* (position 2) with a lower number of doc-

Table 2. Top 10 journals with the highest number of papers published in the period studied (1970s - 2019).

Rank	Title	No. of papers	Papers by period[1]	Sum citations[2]	Average citations	Categories (Quartile /Rank in 2019). *JCR Impact Factor (http://jcr.fecyt.es)*
1	Construction and Building Materials	221	2/21/197	12432	56	Construction & Building Technology (Q1/10/63); Engineering Civil (Q1/11/134); Materials Science, Multidisciplinary (Q2/86/314)
2	Cement and Concrete Composites	49	0/10/39	4806	98	Construction & Building Technology (Q1/3/63); Materials Science, Composites (Q1/4/26)
3	Journal of Cleaner Production	41	0/0/41	2000	49	Engineering, environmental (Q1/8/53); Environmental sciences (Q1/19/265); Green & Sustainable Science & Technology (Q1/6/41)
4	Materials and Structures/Materiaux et Constructions	29	0/9/20	1956	67	Construction & Building Technology (Q2/17/63); Engineering Civil (Q1/29/134); Materials Science, Multidisciplinary (Q2/142/314)
5	Journal of Materials in Civil Engineering	26	0/5/24	1033	40	Construction & Building Technology (Q2/27/63); Engineering Civil (Q2/51/134); Materials Science, Multidisciplinary (Q3/179/314)
6	Materials	20	0/0/20	152	8	Materials Science, Multidisciplinary (Q2/132/314)
7	Cement and Concrete Research	20	0/13/6	4302	215	Construction & Building Technology (Q1/2/63); Materials Science, Multidisciplinary (Q1/36/314)
8	Waste Management	18	1/6/11	1415	79	Engineering, Environmental (Q1/11/53); Environmental Science (Q1/35/265)
9	Resources Conservation and Recycling	18	1/6/11	1590	88	Engineering, Environmental (Q1/5/53); Environmental Science (Q1/13/265)
10	Materiales de Construccion	17	0/5/12	319	18	Construction & Building Technology (Q3/39/63); Materials Science, Multidisciplinary (Q4/246/314)

(1) Publications by period: first /second/ third period
(2) Citations have been update in June 2020

uments published in the studied field (20 and 49, respectively), have received the next highest numbers of citations (4302 and 4806 citations, respectively - 215 and 98 average citations per document - Table 2). It can be seen that the number of publications and the total number of citations have not been related, it follows that the most prolific sources do not always have the greatest impact in the field of research.

On the other hand, it is very interesting to note that the number of articles published in *Construction and Building Materials* has increased dramatically in the last period (Table 2). In particular, the most cited documents in this journal were mainly focused on the influence of the mortar-adherence properties of coarse RA (depending on its applications (120)), and the influence of different types of RAs on the microstructure of the interfacial transition zone, besides the implications of the microstructure on the strength development of the RAC (121). Instead, papers published in *Cement and Concrete Composites* were fundamentally focused on the effect of the partial or total replacement of natural sand by fine RA on the structural concrete behaviour, in mechanical terms (76), or durability, in the long term (78). Finally, *Cement and Concrete Research* published high impact scientific papers focusing on the study of the influence of the amount of RA on the mechanical properties of RAC for structural use (122, 123). The effect of partially hydrated residual concrete on the properties of the RAs and those of the concrete manufactured with these aggregates (124) was also analysed.

3.1.4. Highly cited papers analysis

The analysis of citations could be used to ascertain the influence of a certain document in a field of research, as well as the importance that the authors have acquired through it. For each period studied, Table 3 includes the most cited publication among the 843 documents analysed by SciMAT.

For the period between 1973 and 1999, research about the use of RA in concrete was led by *Torben C. Hansen*; in fact his papers are still a scientific reference for researchers. In the first of the most cited articles (125) was published a comprehensive and extensive work about the production of RA from mixed debris, its quality and the behavior of the RAC produced, both in the fresh and hardened state; the regulations applicable in different countries were also analysed and the article concluded with a total of 34 recommendations.

In the period 2000-2009, the first of the most cited papers (123) had 730 citations and were published in *Cement and Concrete Research* by *Miren Etxeberria* and his collaborators in 2007. The article evaluated the influence of the amount of coarse concrete, the order of materials used in concrete production and the mechanical properties of the RAC, in order to check the numerical models proposed by several researchers.

Finally, during the third period studied (from 2010 to 2019), the document published by *Rui Vasco Silva* and his colleagues was highlighted (112). These authors focused on examining the factors affecting the physical, chemical, mechanical, permeation and compositional properties of RAs sourced from C&DW, intended for concrete production. The results obtained allowed producing a practical means of measuring the quality of RAs, which can be used to produce concrete with predictable performance.

The published researches mainly focused on the use of recycled granular materials in concrete applications and how this approach has evolved, in terms of material testing or the quantity and type of fraction replaced. However, knowledge gaps in other areas of the field, such as in applications where there are no restrictions on RA use, such as mortars, non-structural prefabricated concrete or green roofs.

TABLE 3. Most cited publications in each period (out of 843 documents).

Ref.	Period	Title	Authors	Journal title (abbreviated)	No. of cited[1]	Publication year
Hansen, 1986 (125)	1973-1999	Recycled aggregates and recycled aggregate concrete second state-of-the-art report developments 1945-1985	Hansen, T.C.	MATER STRUCT	283	1986
Etxeberria et al. 2007 (123)	2000-2009	Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete	Etxeberria, M., Vázquez, E., Marí, A., Barra, M.	CEMENT CONCRETE RES	730	2007
Silva et al. 2014 (112)	2010-2019	Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production	Silva, R.V., de Brito, J., Dhir, R.K.	CONSTR BUILD MATER	356	2014

(1) Citations have been update in June 2020

3.2. Co-words analysis

The keywords included in the 843 selected papers were compiled with the SciMAT software, applying the co-occurrence analysis. As a result, 84 thematic groups of keywords were obtained and used to proceed with the bibliometric study. In this process, more than 3000 words were not included because they did not contribute to the study (they were used by the authors in less than 10 documents). Table 4 shows the main thematic groups detected after analysis of the co-occurrence of words for each period studied. For each subject investigated it lists the total number of core documents analysed, the sum citations received, the corresponding h-index, and values of centrality and density. These issues have been positioned in the strategic diagrams generated by SciMAT according to their centrality and density measures, which allows them to be categorised according to their importance in the analysed field, these are presented in Figure 5a, Figure 6a and Figure 7a. The thematic network of the topics whose evolution has been more representative for the scientific field "*Applications of recycled concrete in the construction sector*" is presented between Figure 5b, Figure 6b and Figure 7b. Finally, the evolution of the main themes is shown in Figure 8 and Figure 9, according to documents count and to h-index, respectively. In addition, the stability or continuity of keywords between the periods studied is shown in Figure 10.

3.2.1. Content analysis. Strategic diagrams

The most significant results obtained after the word analysis for each period studied are then developed and discussed.

3.2.1.1. Period before 2000

The first analysed period (from 1973 to 1999), the strategic diagram shows only two main themes, focusing on two areas: *Physical Properties* and *Recycled Aggregate* (Figure 5a). The first one is the motor theme and it refers to the physical properties of the aggregates as well as those of the concrete manufactured with them; its strong centrality and high density (1/1) indicates that it was a highly studied subject and co-appears quite frequently. The most cited articles related to this topic are focused on the investigation of RA properties and the concrete manufactured with this granular material; in consequence they serve as a guide for the production and

Table 4. Performance measures for the themes in each period.

No. Cluster	Research topics	No. papers[1]	Sum citations	h-index	Centrality /Density range	No. Cluster	Research topics	No. papers[1]	Sum citations	h-index	Centrality /Density range
					Period before 2000						
1	PHYSICAL PROPERTIES	8	910	8	1/1	*2*	RECYCLED AGGREGATE	7	829	7	0.5/0.5
					Period 2000-2009						
1	RECYCLING	107	14872	66	1/1	*4*	PHYSICAL-MECHANICAL PROPERTIES	31	5800	27	0.4/0.4
2	CONSTRUCTION MATERIALS	37	3991	29	0.8/0.8	*5*	NON-STRUCTURAL CONCRETES PRECAST	18	793	11	0.2/0.2
3	MASONRY MORTARS	49	6088	38	0.6/0.6						
					Period 2010-2019						
1	RECYCLING	674	19526	76	1/1	*5*	FINE AGGREGATES	92	3747	35	0.62/0.5
2	SUSTAINABLE DEVELOPMENT	254	7948	52	0.88/0.88	*6*	MICROSTRUCTURAL ANALYSIS	51	1052	16	0.5/0.12
3	DURABILITY PROPERTIES	258	10105	61	0.75/0.62	*7*	ENVIRONMENTAL IMPACT	53	1298	17	0.38/0.25
4	ROAD PAVEMENT	75	2393	29	0.25/0.75	*8*	LABORATORY TESTS	5	69	4	0.12/0.38

(1) Referred to core documents

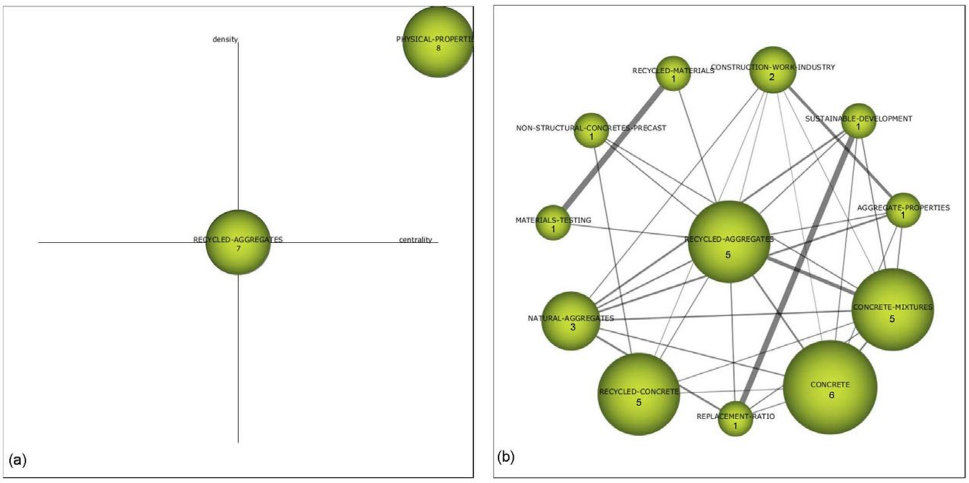

Figure 5. *Period before 2000: (a)* Strategic diagram. (b) Most representative cluster network for this period: *Recycled Aggregate*. Include number of associated documents. Source: SciMAT.

evaluation of the RA, as well as for the design, manufacture and use of RAC (125–127).

On the other hand, *Recycled Aggregate* is an issue that is becoming a motor theme and represents the beginning of the use of RA in construction sector applications, which slowly but certainly increasing in popularity. That is why the most cited studies pay special attention to RA research (125, 126, 128), focusing on the importance of RA quality (both physical and mechanical), especially in the strength of the original concrete, in order to obtain RAC of characteristic resistance suitable for a given use.

3.2.1.2. Period 2000-2009

During the second period, it can be seen how the scientific activity of the studied field has evolved, due to its growth compared to previous years in thematic diversity, as well as in the increase in its h-index and in the number of citations received for each new theme (Table 4). The strategic diagram in Figure 6a shows the detected issues, for example *Recycling, Construction Materials* and *Masonry Mortars* are well placed and have the largest number of associated documents (107, 37 and 49, respectively). For this reason, they have been categorised as motor issues. In addition, *Aggregate Properties* is an emerging topic that began to gain importance in the field studied; while *Non-Structural Concretes Precast* is a topic that in this period has not yet been developed.

Recycling has been the best developed and highest impact issue, with 107 associated items, a strong centrality and high density (1/1) (Table 4). It also has the highest biometric indexes (h-index of 66 and 14872 citations). This means that 107, of the 112 documents published in this period and related to the field of study (Figure 3b), were focused on recy-

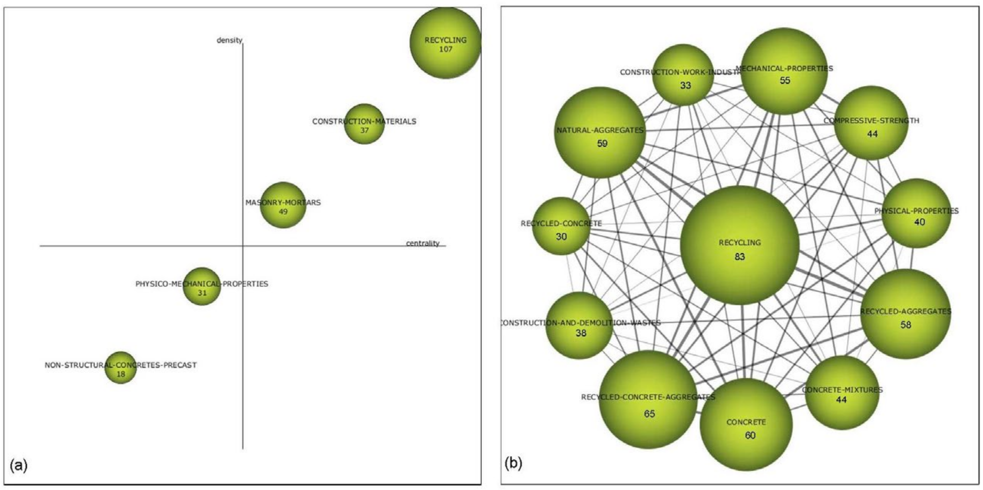

Figure 6. *Period 2000-2009: (a)* Strategic diagram. *(b)* Most representative cluster network for this period: *Recycling*. Include number of associated documents. Source: SciMAT.

cling. In related researches, great interest was given to the environmental benefits of C&DW recycling, thus creating an viable alternative to NA (76, 122, 123).

3.2.1.3. Period 2010-2019

Figure 7a shows the final time interval studied (2010 to 2019 inclusive), which includes a total of eight themes (Table 4). Three themes have been clearly identified as motor ones: *Recycling, Sustainable Development* and *Durability Properties*. In addition, the issue of *Fine Aggregates* has been considered as a basic theme that is becoming a well-developed one. In turn, several basic, peripheral and emerging or undeveloped themes have been identified in this period: these are *Microstructural Analysis, Environmental Impact* and *Laboratory Tests*, respectively. Finally, *Road Pavement* is a peripheral topic that, although relevant, has a poor relationship with the analysed field to date. The increase in the number of articles published in this period (Figure 3) is directly related to the development of a large number of legal and technical regulations that include the use of RA at a European level, with the publication of the Waste Framework Directive (129), the national Royal Decree 105/2008 (130) and Code on Structural Concrete EHE-08 (5), which did not exist until the end of the second period studied. Most of these regulations, together with the publication of Law 22/2011 on Waste (131), expect the minimisation and control of the generation of C&DW in the UE (132, 133) to fulfil the objectives for 2020 to become an intelligent, sustainable and inclusive economy, through a series of policies and actions aimed at moving towards a low carbon economy with an efficient use of resources (3, 134, 135). A greater importance has been given to the use of these types of granular materials in different applications (10, 136, 137) since the publication of this law.

Recycling has also been identified as the most important motor theme in this period; it has shown the highest number of publications (674), as well as a high density and strong centrality (1/1), meaning that it was a theme of great interest and impact, as reflected in Table 4, even more so than in the previous period. This fact indicates that recycling is not only a field of research but it is a practical reality (78, 112, 138), and where the quality of the recycling process has a considerable influence on the quality of the recycled material obtained (139).

3.2.2. Analysis of most significative thematic networks

Recycling is a theme what is worth mentioning as it is one of the most characteristic topics for the field studied, even more so if it is analysed from the point of view of its thematic network. From the beginning, and until its consolidation in the third period, this topic maintains a common thread with *Recycled Aggregate*; this fact reflects its scientific evolution.

Figure 5b shows the network built with the keywords associated with the *Recycled Aggregate* theme during the first period; it reflects the connection between the most significant nodes (thicker relationship lines). It can be further observed that the strongest internal relationships are not related to the central theme of the cluster but are established between the recycled materials and the tests that must be performed for them (127, 140), or between the sustainable development of the construction sector and how this has been influenced by the replacement percentage of natural material by recycling (141, 142).

After analysing the network of the *Recycling* cluster during the second period (Figure 6b), a significant relationship was observed between almost all nodes; this means that the keywords co-appear in most doc-

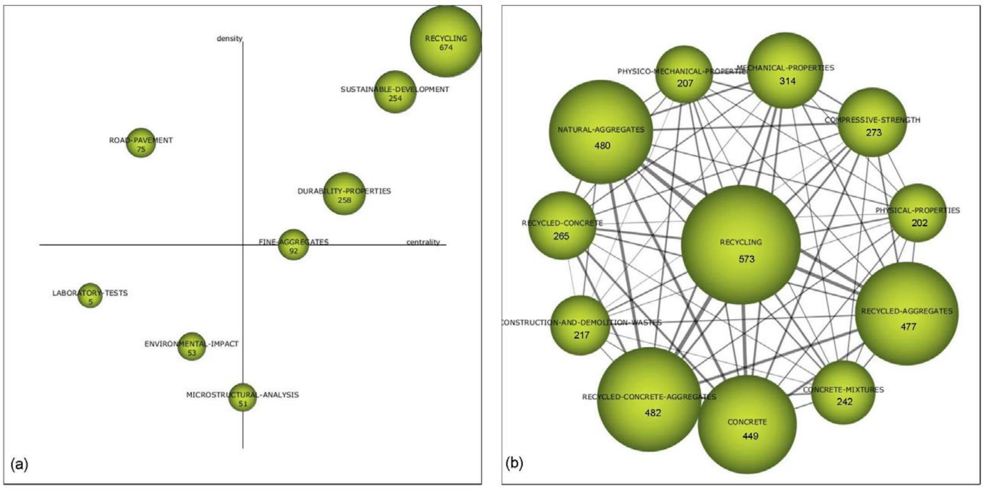

Figure 7. Period 2010-2019: (a) Strategic diagram. (b) Most representative cluster network for this period: *Recycling*. Include number of associated documents. Source: SciMAT.

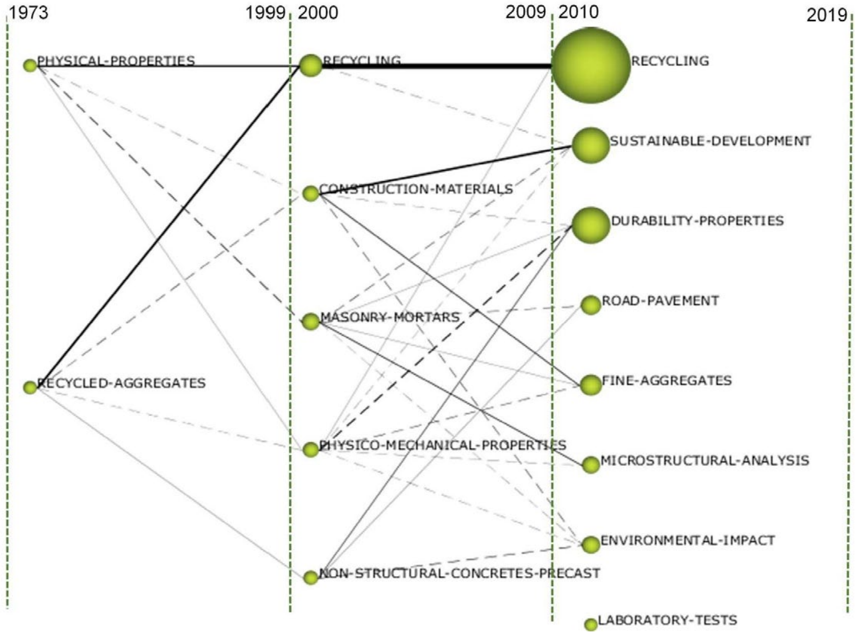

Figure 8. Evolution map (size of spheres according to documents count).

uments, thus providing great similarity between the elements. Despite this, the strong internal connection between the RA from concrete and its recycling reflects the fact that the recycling of concrete waste is beneficial and necessary from the point of view of environmental preservation and the efficient use of resources available (76, 122, 123).

3.2.3. Scientific evolution analysis

Evolution of the main themes in the scientific field are shown in Figure 8 and it is possible to observe that *Recycling* is the most dominant issue (in the period 2010-2019) as it has a larger sphere, according to documents count. In a conceptual way, the evolution of this thematic area can be understood to the extent that, until the year 2000, the few related documents (Table 4) focused on the recycling of concrete to be used as RA which, when evolving to the *Recycling* group in 2000-2009 and merging with *Physical Properties*, it became the most important topic in the entire field investigated in 2010-2019.

Between the first and second period it is observed that the conceptual nexus (greater thickness of continuous lines) is identified between *Physical Properties - Recycling* and between *Recycled Aggregates - Recycling*. While between 2000-2009 and 2010-2019 the strongest link is observed between the following topic: *Construction Materials – Sustainable Development,* in addition, *Recycling* remained the most predominant thematic area, maintaining the same designation in both periods, although with a greater number of documents published when passing from one period to another.

Among the groups in the second period, *Construction Materials* merged with *Sustainable Development*, based on a non-conceptual link with *Recycled Aggregate,* in addition to incorporating part of its content to *Fine Aggregates*. In other words, they share some keywords with others clusters but are not the main item (see Figure 8). In turn, *Masonry Mortars*, integrated with the *Physical Properties* theme (from the first period), merged with *Physical-Mechanical Properties* and *Non-Structural Concretes Precast* to evolve as a new motor theme, called *Durability Properties*, in the last period studied. On the other hand, *Construction Materials*, together with *Masonry Mortars*, created a new theme in the 2010-2019 period called *Fine Aggregates*, in addition to the influence of keywords provided by the *Physical Properties* and *Recycled Aggregates* groups. As for the *Non-Structural Concretes Precast* group, it gains little importance, since it incorporates terms of *Recycled Aggregates* but then it has evolved only a little. Nevertheless, this theme incorporated new elements from various groups in the last period, such as *Durability Properties, Road Pavement* and *Environmental Impact*, helping these themes to reach a better position (Figure 7).

In the last period, different groups emerged that share part of their elements with other themes from the previous period, such as *Road Pavement* and *Microstructural Analysis*. Finally, *Environmental Impact* appeared as a thematic group, with a weak contribution of several themes (*Construction Materials, Masonry Mortars, Non-Structural Concretes Precast* and *Physical-Mechanical Properties*), by means of a non-conceptual nexus (discontinuous

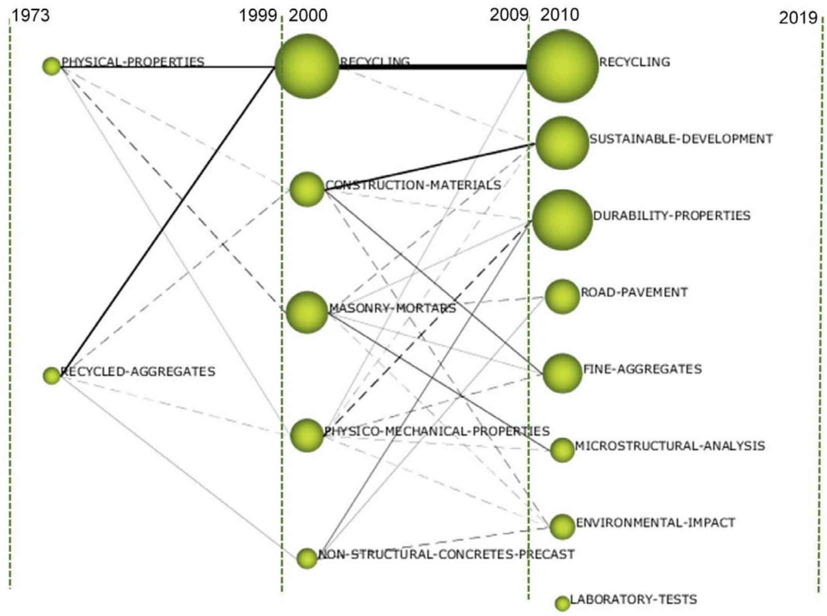

Figure 9. Evolution map (size of spheres according to h-index).

lines); even, a new cluster is created, *Laboratory Test,* without visible participation from other nodes.

Figure 9 shows the evolution of the main themes according to their h-index, where the size of the spheres or higher h-index of the themes *Recycling, Durability Properties* and *Sustainable Development* should be highlighted. *Recycling* is considered the thematic area with the greatest impact, as we have already seen, being central to the development of the field studied. The evolution of its h-index shows an upward trend, whose development stands out above the rest of the topics, with an h-index of 66 in the second period and 76 in the last period (Table 4). Although it started with low impact (*Recycled Aggregate*), it progressively became the origin of other research areas that are closely linked to Recycling, mainly in the last period (2010-2019), such as *Sustainable development* (h-index= 52) or *Environmental impact* (h-index=17).

Finally, Figure 10 shows the continuity of keywords shared between consecutive periods using a longitudinal map; that the keywords have increased considerably over the years, in parallel with an increase in the number of documents published (Figure 3). In fact, the field evolved from 31 word groups in the first period (1973 to 1999) to 96 in the second and 127 in the third. The increase in the number of keywords testifies to the growing thematic diversity discussed under the use of RA in different applications. Likewise, it is noticeable that the first and second periods share all of their words with the following period (31 and 96, respectively). 65 of the 96 words of the period 2000-2009 belong to the previous period; furthermore this one adds 31 new words to the next one (2010-2019). In addition, the index of stability between periods, whose value is 1, indicates that keywords do not disappear over time; this is a quite remarkable fact, which indicates that the field under investigation evolved in a solid way and is well consolidated.

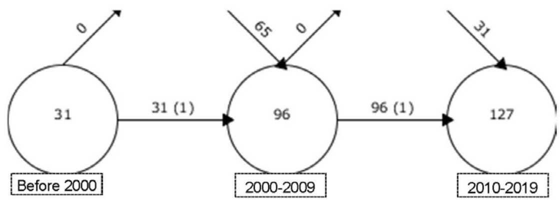

Figure 10. Overlapping map of keywords during the three consecutive periods.

4. CONCLUSIONS

This document combines bibliometric performance analysis with content analysis of the selected studies, after a prior systematic review and through the use of the SciMAT and VOSviewer tools. An exhaustive analysis of the field of *"Applications of recycled aggregates in the sector of construction*" in international research from 1973 to 2019 was developed. The methodology used has allowed us to obtain the conclusions summarised below:

- The analysis shows a remarkable growth of the field of study, in terms of the volume of documents and conceptual coherence, also, a lineal growth in matters of impact. *Jorge de Brito* and *Chi-Sun Poon* are the authors with the highest impacts, and have created a broad collaboration network with other researchers. *Construction and Building Materials* is the

journal with the best metrics, given its multidisciplinary nature.
- During the first two periods (until 2009), and as a consequence of the great importance of aggregate in the construction sector, the published studies focused mainly on RA recycling as an emerging theme, in view of the clear concern related to the environmental impacts associated with C&DW, among other issues. The research carried out in the last decade (2010–2019) highlights the interest in recycling as a result of the development of a large number of legal and technical regulations, but also because of more specific issues related to the treatment and management of C&DW. In relation to the conceptual evolution of the identified issues, the theme of *Recycled Aggregate* presented the greatest evolution over time, becoming part of the main group of the entire field under investigation: *Recycling*. In turn, the stability between periods is considered solid, because the keywords that describe the area under investigation reappear in their entirety in subsequent periods, indicating that the field is well consolidated and continues to evolve.

Therefore, it is possible to conclude that the most important thematic area is the recycling of C&DW to produce quality RA, giving priority not only to their type and origin, but also to the crushing and recycling process applied. Furthermore, although this issue is almost half a century old, it has not yet collapsed, showing an exponential growth trend. In addition, even if recycled material from the valorisation of C&DW is mainly used in the production of concrete, more and more applications have been found for it. Finally, it is anticipated that future research will be aimed at analysing the use of aggregates of a different nature than concrete (ceramic and mixed), as well as fine fraction in applications subject to less demanding regulations, such as, for example, masonry mortars, prefabricated non-structural, and green roofs.

DATA AVAILABILITY STATEMENT

All data, models, and code generated or used during the study appear in the submitted article.

ACKNOWLEDGEMENTS

The authors would like to thank Jose Miguel Lao-Egea from "Promoción de Empleo Joven e Implantación de la Garantía Juvenil en I+D+I" of Spanish Ministry for Science Innovation and Universities, the Departments of Building Construction and Civil Engineering and Research Group TEP-968 "Tecnologías para la Economía Circular" (Technologies for Circular Economy) of Granada University for their contribution to this research.

AUTHOR CONTRIBUTIONS:

Conceptualization: Z. Sánchéz-Roldán, M. Zamorano, M. Martín-Morales. Data curation: Z. Sánchéz-Roldán. Formal analysis: Z. Sánchéz-Roldán, M. Zamorano, M. Martín-Morales. Investigation: Z. Sánchéz-Roldán, M. Zamorano, M. Martín-Morales. Methodology: Z. Sánchéz-Roldán, M. Zamorano, M. Martín-Morales. Project administration: M. Martín-Morales. Software: Z. Sánchéz-Roldán. Supervision: M. Zamorano, M. Martín-Morales. Validation: M. Zamorano, M. Martín-Morales. Visualization: Z. Sánchéz-Roldán, M. Zamorano, M. Martín-Morales. Roles/Writing, original draft: Z. Sánchéz-Roldán. Writing, review & editing: Z. Sánchéz-Roldán, M. Zamorano, M. Martín-Morales.

ABBREVIATIONS:

C&DW: Construction and Demolition Waste; EU: European Union; JCR: Journal Citation Reports; RA: recycled aggregate; RAC: recycled aggregate concrete; SciMAT: Science Mapping Analysis software Tool; VOS: visualisation of similarities.

REFERENCES

1. UEPG. (2018) European aggregates association. A sustainable industry for a sustainable Europe. Annual Review 2017-2018. *Union Eur des Prod Granulats Brussels-Belgium*. 32.
2. Eurostat. (2018) Waste Statistics, gestión de residuos (env_wasgen) [Internet]. Eurostat. 2018. p. Date accesed: 20-11-2018. Retrieved from https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en.
3. Comisión Europea. (2014) COM 445. Comunicación de la comisión al parlamento europeo, el consejo, el comité económico y social europeo y el comité de las regiones. Oportunidades para un uso más eficiente de los recursos en el sector de la construcción. *Bruselas*. 1–29.
4. Comisión Europea. (2015) COM 614. Comunicación de la comisión al parlamento europeo, el consejo, el comité económico y social europeo y el comité de las regiones. Cerrar el círculo: Un plan de acción de la UE para la economía circular (COM 614). *Bruselas*. 24.
5. Ministerio de Fomento. (2008) EHE-08. Instrucción de Hormigón Estructual. *BOE*. 203, 35176–8.
6. Comisión Europea. (2014) COM 397. Propuesta de directiva del parlamento europeo y del consejo por la que se modifican las directivas 2008/98/CE sobre los residuos, 94/62/CE relativa a los envases y residuos de envases, 1999/31/CE relativa al vertido de residuos, 2000/53/CE relati. *Bruselas*. 35.
7. Parlamento Europeo. (2015) 2017/C 265/08. Resolución del Parlamento Europeo, de 9 de julio de 2015, sobre el uso eficiente de los recursos: avanzar hacia una economía circular (2014/2208(INI)). *DOUE*. C 295, 65–75.
8. Comisión Europea. (2017) COM 33. Informe de la comisión al parlamento europeo, al consejo, al comité económico y social europeo y al comité de las regiones sobre la aplicación del plan de acción para la economía circular. *Bruselas*. 1–15.
9. Chen, P.; Chen, X.; Wang, Y.; Wang, P. (2020) Preliminary study on the upcycle of non-structural construction and demolition waste for waste cleaning. *Mater. Construcc.* 70 [338], e220. https://doi.org/10.3989/mc.2020.13819.
10. Behera, M.; Bhattacharyya, S.K.; Minocha, A.K.; Deoliya, R.; Maiti, S. (2014) Recycled aggregate from C&D

waste & its use in concrete - A breakthrough towards sustainability in construction sector: A review. *Constr. Build. Mater.* 68, 501–516. http://doi.org/10.1016/j.conbuildmat.2014.07.003.
11. Saini, P.; Ashish, K.D. (2015) A review on recycled concrete aggregates. *SSRG Int J Civ Eng – EFES*. 71–75.
12. Kazmi, S.M.S.; Munir, M.J.; Wu, Y-F.; Patnaikuni, I.; Zhou, Y.; Xing, F. (2019) Influence of different treatment methods on the mechanical behavior of recycled aggregate concrete: A comparative study. *Cem. Concr. Compos*. 104, 103398. https://doi.org/10.1016/j.cemconcomp.2019.103398.
13. González-Fonteboa, B.; Seara-Paz, S.; de Brito, J.; González-Taboada, I.; Martínez-Abella, F.; Vasco Silva, R. (2018) Recycled concrete with coarse recycled aggregate. An overview and analysis. *Mater. Construcc*. 68 [330], e151. https://doi.org/10.3989/mc.2018.13317.
14. Rubio De Hita, P.; Pérez-Gálvez, F.; Morales-Conde, M.J.; Pedreño-Rojas, M.A. (2019) Characterisation of recycled ceramic mortars for use in prefabricated beam-filling pieces in structural floors. *Mater. Construcc.* 69 [334], e189. https://doi.org/10.3989/mc.2019.04518
15. Sánchez-Roldán, Z.; Martín-Morales, M.; Valverde-Espinosa, I.; Zamorano, M. (2020) Technical feasibility of using recycled aggregates to produce eco-friendly urban furniture. *Constr. Build. Mater.* 250, 118890. https://doi.org/10.1016/j.conbuildmat.2020.118890.
16. Naganathan, S.; Silvadanan, S.; Chung, T.Y.; Nicolasselvam, M.F.; Thiruchelvam, S. (2014) Use of wastes in developing mortar – a review. in: green technologies and sustainable development in construction. trans tech publications. *Adv. Mat. Res*. 9352014, 146–150.
17. Cuenca-Moyano, G.M.; Martín-Morales, M.; Valverde-Palacios, I.; Valverde-Espinosa, I.; Zamorano, M. (2014) Influence of pre-soaked recycled fine aggregate on the properties of masonry mortar. *Constr. Build. Mater.* 70, 71–79. http://doi.org/10.1016/j.conbuildmat.2014.07.098.
18. Ferreira, R.L.S.; Anjos, M.A.S.; Ledesma, E.F.; Pereira, J.E.S.; Nóbrega, A.K.C. (2020) Evaluation of the physical-mechanical properties of cement-lime based masonry mortars produced with mixed recycled aggregates. *Mater. Construcc.* 70 [337], e210. https://doi.org/10.3989/mc.2020.02819.
19. Vieira, C.S.; Pereira, P.M. (2015) Use of recycled construction and demolition materials in geotechnical applications: A review. *Resour. Conserv. Recycl*. 103, 192–204. https://doi.org/10.1016/j.resconrec.2015.07.023.
20. Cardoso, R.; Silva, R.V.; Brito, J. de; Dhir, R.K. (2016) Use of recycled aggregates from construction and demolition waste in geotechnical applications: A literature review. *Waste Manag*. 49, 131–145. https://doi.org/10.1016/j.wasman.2015.12.021.
21. Marín-Uribe, C.R.; Navarro-Gaete, R. (2021) Empirical relationships between compressive and flexural strength of concrete containing recycled asphalt material for pavement applications using different specimen configurations. *Mater. Construcc.* 71 [342], e249. https://doi.org/10.3989/mc.2021.11520.
22. Chen, H.; Yang, Y.; Yang, Y.; Jiang, W.; Zhou, J. (2014) A bibliometric investigation of life cycle assessment research in the web of science databases. *Int. J. Life Cycle Assess*. 19 [10], 1674–1685. https://doi.org/10.1007/s11367-014-0777-3.
23. Rodríguez-Bolívar, M.P.; Alcaide-Muñoz, L.; Cobo, M.J. (2018) Analyzing the scientific evolution and impact of e-Participation research in JCR journals using science mapping. *Int. J. Inf. Manage*. 40, 111–119. https://doi.org/10.1016/j.ijinfomgt.2017.12.011.
24. Callon, M.; Courtial, J.-P.; Laville, F. (1991) Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemsitry. *Scientometrics*. 22, 155–205. Retrieved from https://www.academia.edu/28341042/Co_word_analysis_as_a_tool_for_describing_the_network_of_interactions_between_basic_and_technological_research_The_case_of_polymer_chemsitry.
25. Noyons, E.C.M.; Moed, H.F.; Luwel, M. (1999) Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. *J. Am. Soc. Inf. Sci*. 50 [2], 115–131.
26. Morris, S.A.; Van der Veer Martens, B. (2009) Mapping research specialties. *Annu Rev Inf Sci Technol*. 42 [1], 213–295. http://doi.wiley.com/10.1002/aris.2008.1440420113.
27. Cobo Martín, M.J.; Martínez, M.A.; Gutiérrez-Salcedo, M.; Fujita, H.; Herrera-Viedma, E. (2015) 25 years at knowledge-based systems: a bibliometric analysis. *Knowledge-Based Syst*. 80, 3–13. http://doi.org/10.1016/j.knosys.2014.12.035.
28. Cobo Martín, M.J.; López-Herrera, E.; Herrera-Viedma, E.; Herrara, F. (2011) Science mapping software tools: review, analysis, and cooperative study among tools. *J. Am. Soc. Inf. Sci. Technol*. 62 [7], 1382–1402. https://doi.org/10.1002/asi.21525.
29. Cobo Martín, M.J.; Lõpez-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. (2012) SciMAT: A new science mapping analysis software tool. *J. Am. Soc. Inf. Sci. Technol*. 63 [8], 1609–1630. https://doi.org/10.1002/asi.22688.
30. Persson, O.; Danell, R.; Schneider, J. (2009) How to use Bibexcel for various types of bibliometric analysis. *Celebr. Sch. Commun. Stud. A Festschrift Olle Persson His 60th Birthd*. 5, 9–24.
31. Chen, C. (2006) CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Am. Soc. Inf. Sci. Technol*. 57 [3], 359–377. https://doi.org/10.1002/asi.20317.
32. Wise, J.A. (1999) The Ecological Approach to Visualization. *J. Am. Soc. Inf. Sci.* 50, 1224–1233. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.93.8319&rep=rep1&type=pdf.
33. Sci2 Team. (2009) Sci2 A tool for science of science research & practice. Retrieved from http://sci2.cns.iu.edu.
34. Cobo-Martín, M.J. (2011) SciMAT: Herramienta software para el análisis de la evolución del conocimiento científico. propuesta de una metodología de evaluación. Universidad de Granada. 2011. Retrieved from http://hdl.handle.net/10481/20201.
35. van Eck, N.J.; Waltman, L. (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*. 84 [2], 523–538. https://doi.org/10.1007/s11192-009-0146-3.
36. Martí-Vargas, J.R.; García-Taengua, E.; Hale, W.M.; ElBatanouny, M.K.; Ziehl, P.H. (2015) Bibliometric analysis of Web of Science-indexed papers on concrete segmental bridges. *PCI J*. 60 [1], 118–133. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84938089242&partnerID=40&md5=28e8d93003a2238ab212d9806a2e24ea.
37. Mymoon, M.; Mahendran, S.; Lakshmi-Poorna, R.; Suryakala, S. (2016) Directions in self consolidating concrete research : A bibliometric study. *J Struct Eng*. 43 [4], 329–340. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-85016088593&partnerID=40&md5=e631247174590589df97657ce1839ed5.
38. Liang, H.; Zhang, S.; Su, Y. (2020) The structure and emerging trends of construction safety management research: a bibliometric review. *Int. J. Occup. Saf. Ergon*. 26 [3], 1–20. https://doi.org/10.1080/10803548.2018.1444565.
39. Geng, S.; Wang, Y.; Zuo, J.; Zhou, Z.; Du, H.; Mao, G. (2017) Building life cycle assessment research: A review by bibliometric analysis. *Renew. Sustain. Energy Rev*. 76, 176–184. http://doi.org/10.1016/j.rser.2017.03.068.
40. Nwodo, M.N.; Anumba, C.J. (2019) A review of life cycle assessment of buildings using a systematic approach. *Build. Environ*. 162, 106290. https://doi.org/10.1016/j.buildenv.2019.106290.
41. Rojas-Sola, J.I.; de San-Antonio-Gómez, C. (2010) Análisis bibliométrico de las publicaciones científicas españolas en la categoría construction & building technology de la base de datos web of science (1997-2008). *Mater. Construcc.* 60 [300], 143–149. https://doi.org/10.3989/mc.2010.59810.
42. Cañas-Guerrero, I.; Mazarrón, F.R.; Calleja-Perucho, C.; Pou-Merina, A. (2014) Bibliometric analysis in the international context of the “Construction & Building Technology” category from the Web of Science database. *Constr. Build. Mater.* 53, 13–25. http://dx.doi.org/10.1016/j.conbuildmat.2013.10.098.
43. Sorli-Rojo, A.; Mochón-Bezares, G. (2013) ‘Materiales de Construcción’ Journal, 2003-2012: a bibliometric analysis. *Mater. Construcc.* 63 [312], 613–621. https://doi.org/10.3989/mc.2013.07513.

44. Blank, L.; Vasl, A.; Levy, S.; Grant, G.; Kadas, G.; Dafni, A.; et al. (2013) Directions in green roof research: A bibliometric study. *Build Environ*. 66, 23–28. https://doi.org/10.1016/j.buildenv.2013.04.017.
45. Farzaneh, A.; Monfet, D.; Forgues, D. (2019) Review of using Building Information Modeling for building energy modeling during the design process. *J. Build. Eng*. 23, 127–135. https://doi.org/10.1016/j.jobe.2019.01.029.
46. Matarneh, S.T.; Danso-Amoako, M.; Al-Bizri, S.; Gaterell, M.; Matarneh, R. (2019) Building information modeling for facilities management: A literature review and future research directions. *J. Build. Eng.* 24, 100755. https://doi.org/10.1016/j.jobe.2019.100755.
47. Norouzi, M.; Chàfer, M.; Cabeza, L.F.; Jiménez, L.; Boer, D. (2021) Circular economy in the building and construction sector: A scientific evolution analysis. *J. Build. Eng.* 44, 102705. https://doi.org/10.1016/j.jobe.2021.102704.
48. Mhatre, P.; Panchal, R.; Singh, A.; Bibyan, S. (2021) A systematic literature review on the circular economy initiatives in the European Union. *Sustain. Prod. Consum*. 26, 187–202. https://doi.org/10.1016/j.spc.2020.09.008.
49. Jin, R.; Yuan, H.; Chen, Q. (2019) Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018. *Resour. Conserv. Recycl*. 140, 175–188. https://doi.org/10.1016/j.resconrec.2018.09.029.
50. Wu, H.; Zuo, J.; Zillante, G.; Wang, J.; Yuan, H. (2019) Construction and demolition waste research: a bibliometric analysis. *Archit. Sci. Rev*. 62 [4], 354–365. https://doi.org/10.1080/00038628.2018.1564646.
51. Liu, Y.; Sun, T.; Yang, L. (2017) Evaluating the performance and intellectual structure of construction and demolition waste research during 2000–2016. *Environ. Sci. Pollut. Res*. 24 [23], 19259–19266. https://doi.org/10.1007/s11356-017-9598-9.
52. Ji, L.; Liu, C.; Huang, L.; Huang, G. (2018) The evolution of resources conservation and recycling over the past 30 years: a bibliometric overview. *Resour. Conserv. Recycl*. 134, 34–43. https://doi.org/10.1016/j.resconrec.2018.03.005.
53. Wong, S.; Mah, A.X.Y.; Nordin, A.H.; Nyakuma, B.B.; Ngadi, N.; Mat, R.; et al. (2020) Emerging trends in municipal solid waste incineration ashes research: a bibliometric analysis from 1994 to 2018. *Environ. Sci. Pollut. Res*. 27 [8], 7757–7784.
54. Det Amornrut, U.; Hallinger, P. (2020) A bibliometric review of research on sustainable construction, 1994–2018. *J. Clean. Prod*. 254, 120073. https://doi.org/10.1016/j.jclepro.2020.120073.
55. Gutiérrez-Salcedo, M.; Martínez, M.A.; Moral-Munoz, J.A.; Herrera-Viedma, E.; Cobo Martín, M.J. (2018) Some bibliometric procedures for analyzing and evaluating research fields. *Appl. Intell*. 48 [5], 1275–1287. https://doi.org/10.1007/s10489-017-1105-y.
56. Castillo-Vergara, M.; Alvarez-Marin, A.; Placencio-Hidalgo, D. (2018) A bibliometric analysis of creativity in the field of business economics. *J. Bus. Res*. 85, 1–9. https://doi.org/10.1016/j.jbusres.2017.12.011.
57. Hosseini, M.R.; Martek, I.; Zavadskas, E.K.; Aibinu, A.A.; Arashpour, M.; Chileshe, N. (2018) Critical evaluation of off-site construction research: A Scientometric analysis. *Autom. Constr*. 87, 235–247. https://doi.org/10.1016/j.autcon.2017.12.002.
58. Kazmi, S.M.S.; Munir, M.J.; Wu, Y.F.; Patnaikuni, I.; Zhou, Y.; Xing, F. (2019) Axial stress-strain behavior of macro-synthetic fiber reinforced recycled aggregate concrete. *Cem. Concr. Compos.* 97, 341–356. https://doi.org/10.1016/j.cemconcomp.2019.01.005.
59. Fernández-González, J.M.; Díaz-López, C.; Martín-Pascual, J.; Zamorano, M. (2020) Recycling organic fraction of municipal solid waste: Systematic literature review and bibliometric analysis of research trends. *Sustain*. 12 [11], 4798. https://doi.org/10.3390/su12114798.
60. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; et al. (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J. Clin. Epidemiol*. 62 [10], e1-34. https://doi.org/10.1016/j.jclinepi.2009.06.006.
61. Mongeon, P.; Paul-Hus, A. (2016) The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics*. 106 [1], 213–228. https://doi.org/10.1007/s11192-015-1765-5.
62. Bordons, M.; Zulueta, M.A. (1999) Evaluación de la actividad científica a través de indicadores bibliométricos. *Rev. Española Cardiol*. 52 [10], 790–800. Retrieved from https://www.revespcardiol.org/es-evaluacion-actividad-cientifica-traves-indicadores-articulo-X0300893299001904.
63. Torres-salinas, D. (2007) Diseño de un sistema de información y evaluación científica. Análisis ciencimétrico de la actividad investigadora de la Universidad de Navarra en el área de ciencias de la salud. 1999-2005. Tesis Doctoral. 396. Retrieved from http://eprints.rclis.org/10545/1/Tesis_Daniel_Torres.pdf.
64. Hirsch, J.E. (2005) An index to quantify an individual´s scientific research output. *Proc Natl. Acad. Sci*. 102 [46], 16569–16572. https://doi.org/10.1073/pnas.0507655102.
65. Martínez Sánchez, M.A.; Herrera Díaz, M.; Lima Fernández, A.I.; Herrera Gómez, M.; Herrera-Viedma, E. (2014) Un análisis bibliométrico de la producción académica española en la categoría de Trabajo Social del "Journal Citation Report". *Cuader. Trab. Soc.* 27 [2], 429–438. https://doi.org/10.5209/rev_CUTS.2014.v27.n2.44662.
66. Eggue, L. (2006) Theory and practise of the g-index. *Scientometrics*. 69, [1] 131–152. Retireved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.395.9064&rep=rep1&type=pdf.
67. Alonso, S.; Cabrerizo, F.J.; Herrera-Viedma, E.; Herrera, F. (2010) hg-index: A new index to characterize the scientific output of researchers based on the h- and g-indices. *Scientometrics*. 82 [2], 391–400. https://doi.org/10.1007/s11192-009-0047-5.
68. Cabrerizo, F.J.; Alonso, S.; Herrera-Viedma, E.; Herrera, F. (2010) q2-Index: Quantitative and qualitative evaluation based on the number and impact of papers in the Hirsch core. *J. Informetr*. 4 [1], 23–28. Retrieved from http://hdl.handle.net/10481/5679.
69. Cobo Martín, M.J.; Herrera, F. (2013) SciMAT User guide. 1–17. Retrieved from http://sci2s.ugr.es/scimat.
70. Thomé, A.M.T.; Ceryno, P.S.; Scavarda, A.; Remmen, A. (2016) Sustainable infrastructure: A review and a research agenda. *J. Environ. Manage*. 184 [Pt 2], 143–156. https://doi.org/10.1016/j.jenvman.2016.09.080.
71. Rip, A.; Courtial, J.P. (1984) Co-word maps of biotechnology: An example of cognitive scientometrics. *Scientometrics*. 6 [6], 381–400. https://doi.org/10.1007/BF02025827.
72. Buck, A.D. (1973) Recycle concrete. *Highw Res Rec*. [430], 1–8. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-0015560896&partnerID=40&md5=1dad6016cb43cf976ff6a5af3574da05.
73. Comisión Europea. (2016) Protocolo de gestión de residuos de construcción y demolición en la UE. *Com Eur y ECORYS Ref Ares (2016) 6914779 - 12/12/2016*. [septiembre] 61.
74. Oliveira Neto, R.; Gastineau, P.; Cazacliu, B.G.; Le Guen, L.; Paranhos, R.S.; Petter, C.O. (2017) An economic analysis of the processing technologies in CDW recycling platforms. *Waste Manag*. 60, 277–289. http://doi.org/10.1016/j.wasman.2016.08.011.
75. Parlamento Europeo; Consejo de la Unión Europea. (2018) Directiva (UE) 2018/851 del Parlamento europeo y del Consejo de 30 de mayo de 2018 por la que se modifica la Directiva 2008/98/CE sobre los residuos. *DOUE*. L 150, [14 de junio] 109–140.
76. Evangelista, L.; De Brito, J. (2007) Mechanical behaviour of concrete made with fine recycled concrete aggregates. *Cem. Concr. Compos.* 29 [5], 397–401.
77. Gomes, M.; de Brito, J. (2009) Structural concrete with incorporation of coarse recycled concrete and ceramic aggregates: Durability performance. *Mater. Struct.* 42 [5], 663–675. https://doi.org/10.1617/s11527-008-9411-9.
78. Evangelista, L.; de Brito, J. (2010) Durability performance of concrete made with fine recycled concrete aggregates. *Cem. Concr. Compos.* 32 [1], 9–14. http://doi.org/10.1016/j.cemconcomp.2009.09.005.
79. de Brito, J.; Pereira, A.S.; Correia, J.R. (2005) Mechanical behaviour of non-structural concrete made with recycled ceramic aggregates. *Cem. Concr. Compos.* 27 [4], 429–433. https://doi.org/10.1016/j.cemconcomp.2004.07.005.

80. López-Uceda, A.; Ayuso, J.; Jiménez, J.R.; Agrela, F.; Barbudo, A.; De Brito, J. (2016) Upscaling the use of mixed recycled aggregates in non-structural low cement concrete. *Materials*. 9 [2], 91. https://doi.org/10.3390/ma9020091.
81. Carro-López, D.; González-Fonteboa, B.; Martínez-Abella, F.; González-Taboada, I.; de Brito, J.; Varela-Puga, F. (2017) Proportioning, microstructure and fresh properties of self-compacting concrete with recycled sand. *Procedia Eng*. 171, 645–657. https://doi.org/10.1016/j.proeng.2017.01.401.
82. Esquinas, A.R.; Álvarez, J.I.; Jiménez, J.R.; Fernández, J.M.; de Brito, J. (2018) Durability of self-compacting concrete made with recovery filler from hot-mix asphalt plants. *Constr. Build. Mater.* 161, 407–419. https://doi.org/10.1016/j.conbuildmat.2017.11.142.
83. Barroqueiro, T.; da Silva, P.R.; de Brito, J. (2019) Fresh-state and mechanical properties of high-performance self-compacting concrete with recycled aggregates from the precast industry. *Materials*. 12 [21], 3565. https://doi.org/10.3390/ma12213565.
84. Pedro, D.; de Brito, J.; Evangelista, L. (2018) Durability performance of high-performance concrete made with recycled aggregates, fly ash and densified silica fume. *Cem. Concr. Compos*. 93, 63–74. https://doi.org/10.1016/j.cemconcomp.2018.07.002.
85. Silva, J.; de Brito, J.; Veiga, R. (2009) Incorporation of fine ceramics in mortars. *Constr. Build. Mater.* 23 [1], 556–564. https://doi.org/10.1016/j.conbuildmat.2007.10.014.
86. Jiménez, J.R.; Ayuso, J.; López, M.; Fernández, J.M.; de Brito, J. (2013) Use of fine recycled aggregates from ceramic waste in masonry mortar manufacturing. *Constr. Build. Mater.* 40, 679–690. https://doi.org/10.1016/j.conbuildmat.2012.11.036.
87. Silva, J.; de Brito, J.; Veiga, R. (2010) Recycled red-clay ceramic construction and demolition waste for mortars production. *J. Mater. Civ. Eng*. 22 [3], 236–244. https://doi.org/10.1061/(ASCE)0899-1561(2010)22:3(236).
88. Pereira, P.M.; Evangelista, L.; de Brito, J. (2012) The effect of superplasticisers on the workability and compressive strength of concrete made with fine recycled concrete aggregates. *Constr. Build. Mater.* 28 [1], 722–729. http://doi.org/10.1016/j.conbuildmat.2011.10.050.
89. Barbudo, M.A.; de Brito, J.; Evangelista, L.; Bravo, M.; Agrela, F. (2013) Influence of water-reducing admixtures on the mechanical performance of recycled concrete. *J. Clean. Prod*. 59, 93–98. http://doi.org/10.1016/j.jclepro.2013.06.022.
90. Cartuxo, F.; de Brito, J.; Evangelista, L.; Jiménez, J.R.; Ledesma, E.F. (2015) Rheological behaviour of concrete made with fine recycled concrete aggregates - Influence of the superplasticizer. *Constr. Build. Mater.* 89, 36–47. http://doi.org/10.1016/j.conbuildmat.2015.03.119.
91. Kurda, R.; de Brito, J.; Silvestre, J.D. (2017) Influence of recycled aggregates and high contents of fly ash on concrete fresh properties. *Cem. Concr. Compos*. 84, 198–213. https://doi.org/10.1016/j.cemconcomp.2017.09.009.
92. Kurda, R.; de Brito, J.; Silvestre, J.D. (2018) Indirect evaluation of the compressive strength of recycled aggregate concrete with high fly ash ratios. *Mag. Concr. Res*. 70 [4], 204–16. https://doi.org/10.1680/jmacr.17.00216.
93. Kurda, R.; de Brito, J.; Silvestre, J.D. (2019) Water absorption and electrical resistivity of concrete with recycled concrete aggregates and fly ash. *Cem. Concr. Compos*. 95, 169–182. https://doi.org/10.1016/j.cemconcomp.2018.10.004.
94. Evangelista, L.; de Brito, J. (2004) Criteria for the use of fine recycled concrete aggregates in concrete production. *Int. RILEM Conf. Use Recycl. Mater. Build. Struct*. [November] 503–510.
95. Evangelista, L.; Guedes, M.; de Brito, J.; Ferro, A.C.; Pereira, M.F. (2015) Physical, chemical and mineralogical properties of fine recycled aggregates made from concrete waste. *Constr. Build. Mater.* 86, 178–188. http://doi.org/10.1016/j.conbuildmat.2015.03.112.
96. Neno, C.; de Brito, J.; Veiga, R. (2014) Using fine recycled concrete aggregate for mortar production. *Mater. Res*. 17 [1], 168–77. https://doi.org/10.1590/S1516-14392013005000164.
97. Li, W.; Xiao, J.; Shi, C.; Poon, C.S. (2015) Structural behaviour of composite members with recycled aggregate concrete - An overview. *Adv. Struct. Eng*. 18 [6], 919–938. https://doi.org/10.1260/1369-4332.18.6.919.
98. Zhang, J.; Shi, C.; Li, Y.; Pan, X.; Poon, C-S.; Xie, Z. (2015) Influence of carbonated recycled concrete aggregate on properties of cement mortar. *Constr. Build. Mater.* 98 [Supplement C], 1–7. https://doi.org/10.1016/j.conbuildmat.2015.08.087.
99. Kou, S-C.; Poon, C-S. (2009) Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates. *Cem. Concr. Compos*. 31 [9], 622–627. http://doi.org/10.1016/j.cemconcomp.2009.06.005.
100. González-Corominas, A.; Etxeberria, M.; Poon, C-S. (2017) Influence of the quality of recycled aggregates on the mechanical and durability properties of high performance concrete. *Waste Biomass Valor*. 8 [5], 1421–1432.
101. Lu, J.X.; Yan, X.; He, P.; Poon, C.S. (2019) Sustainable design of pervious concrete using waste glass and recycled concrete aggregate. *J. Clean. Prod.* 234, 1102–12. https://doi.org/10.1016/j.jclepro.2019.06.260.
102. Poon, C.S.; Kou, S.C.; Lam, L. (2002) Use of recycled aggregates in molded concrete bricks and blocks. *Constr. Build. Mater.* 16 [5], 281–9. https://doi.org/10.1016/S0950-0618(02)00019-3.
103. Poon, C.S.; Chan, D. (2006) Paving blocks made with recycled concrete aggregate and crushed clay brick. *Constr. Build. Mater.* 20 [8], 569–577. https://doi.org/10.1016/j.conbuildmat.2005.01.044.
104. Poon, C-S.; Chan, D. (2007) Effects of contaminants on the properties of concrete paving blocks prepared with recycled concrete aggregates. *Constr. Build. Mater.* 21 [1], 164–75. https://doi.org/10.1016/j.conbuildmat.2005.06.031.
105. Poon, C-S.; Lam, C.S. (2008) The effect of aggregate-to-cement ratio and types of aggregates on the properties of pre-cast concrete blocks. *Cem. Concr. Compos*. 30 [4], 283–289. https://doi.org/10.1016/j.cemconcomp.2007.10.005.
106. Poon, C-S.; Kou, S-C.; Wan, H. wen; Etxeberria, M. (2009) Properties of concrete blocks prepared with low grade recycled aggregates. *Waste Manag*. 29 [8], 2369–77. http://doi.org/10.1016/j.wasman.2009.02.018.
107. Kou, S-C.; Poon, C-S.; Chan, D. (2004) Properties of steam cured recycled aggregate fly ash concrete. *Int. RILEM Conf. use Recycl. Mater. Build. Struct. Barcelona*. [1], 590–9.
108. Poon, C.S.; Shui, Z.; Lam, L.; Fok, H.; Kou, S.C. (2004) Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete. *Cem. Concr. Res*. 34 [1], 31–6. https://doi.org/10.1016/S0008-8846(03)00186-8.
109. Zhan, B.J.; Xuan, D.X.; Zeng, W.; Poon, C.S. (2019) Carbonation treatment of recycled concrete aggregate: Effect on transport properties and steel corrosion of recycled aggregate concrete. *Cem. Concr. Compos*. 104, 103360. https://doi.org/10.1016/j.cemconcomp.2019.103360.
110. Hossain, U.; Poon, C-S.; Lo, I.M.C.; Cheng, J.C.P. (2016) Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA. *Resour. Conserv. Recycl.* 109, 67–77. http://doi.org/10.1016/j.resconrec.2016.02.009.
111. Fonseca, N.; de Brito, J.; Evangelista, L. (2011) The influence of curing conditions on the mechanical performance of concrete made with recycled concrete waste. *Cem. Concr. Compos*. 33 [6], 637–643. https://doi.org/10.1016/j.cemconcomp.2011.04.002.
112. Silva, R.V.; de Brito, J.; Dhir, R.K. (2014) Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Constr. Build. Mater.* 65, 201–217. http://doi.org/10.1016/j.conbuildmat.2014.04.117.
113. Silva, R.V.; de Brito, J.; Dhir, R.K. (2016) Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete. *J. Clean. Prod.* 112 [4], 2171–2186. http://doi.org/10.1016/j.jclepro.2015.10.064.
114. Barroqueiro, T.; da Silva, P.R.; de Brito, J. (2019) Fresh-state and mechanical properties of high-performance self-compacting concrete with recycled aggregates from the precast industry. *Materials*. 12 [21], 3565. http://doi.org/10.3390/ma12213565.

115. Fernández-Ledesma, E.; Jiménez, J.R.; Ayuso, J.; Fernández, J.M.; de Brito, J. (2015) Maximum feasible use of recycled sand from construction and demolition waste for eco-mortar production – Part-I: ceramic masonry waste. *J. Clean. Prod.* 87, 692–706. https://doi.org/10.1016/j.jclepro.2014.10.084.
116. Poon, C-S.; Kou, S-C.; Lam, L. (2007) Influence of recycled aggregate on slump and bleeding of fresh concrete. *Mater. Struc*. 40 [9], 981–988.
117. Xiao, Z.; Ling, T-C.; Kou, S-C.; Wang, Q.Y.; Poon, C-S. (2011) Use of wastes derived from earthquakes for the production of concrete masonry partition wall blocks. *Waste Manag*. 31 [8], 1859–1866. https://doi.org/10.1016/j.wasman.2011.04.010.
118. Kou, S-C.; Poon, C-S.; Etxeberria, M. (2014) Residue strength, water absorption and pore size distributions of recycled aggregate concrete after exposure to elevated temperatures. *Cem. Concr. Compos*. 53, 73–82. http://doi.org/10.1016/j.cemconcomp.2014.06.001.
119. Barbudo, M.A.; Agrela, F.; Ayuso, J.; Jiménez, J.R.; Poon, C-S. (2012) Statistical analysis of recycled aggregates derived from different sources for sub-base applications. *Constr. Build. Mater.* 28 [1], 129–38. http://doi.org/10.1016/j.conbuildmat.2011.07.035.
120. Sánchez de Juan, M.; Gutiérrez Alaejos, P. (2009) Study on the influence of attached mortar content on the properties of recycled concrete aggregate. *Constr. Build. Mater.* 23, [2] 872–7. http://doi.org/10.1016/j.conbuildmat.2008.04.012.
121. Poon, C-S.; Shui, Z.; Lam, L. (2004) Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. *Constr. Build. Mater.* 18, [6] 461–468. https://doi.org/10.1016/j.conbuildmat.2004.03.005.
122. Xiao, J.; Li, J.; Zhang, C. (2005) Mechanical properties of recycled aggregate concrete under uniaxial loading. *Cem. Concr. Res*. 35 [6], 1187–1194. https://doi.org/10.1016/j.cemconres.2004.09.020.
123. Etxeberria, M.; Vázquez-Ramonich, E.; Marí, A.R.; Barra de Oliveira, M. (2007) Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. *Cem. Concr. Res*. 37 [5], 735–742. https://doi.org/10.1016/j.cemconres.2007.02.002.
124. Katz, A. (2003) Properties of concrete made with recycled aggregate from partially hydrated old concrete. *Cem. Concr. Res.* 33 [5], 703–711. https://doi.org/10.1016/S0008-8846(02)01033-5.
125. Hansen, T.C. (1986) Recycled aggregates and recycled aggregate concrete second state-of-the-art report developments 1945-198. *Mater. Struct*. 19 [111], 201–46.
126. Buck, A.D. (1977) Recycled concrete as a source of aggregate. *J. Am. Concr. Inst*. 74, [5] 212–219.
127. Barra de Oliveira, M.; Vázquez-Ramonich, E. (1996) The influence of retained moisture in aggregates from recycling on the properties of new hardened concrete. *Waste Manag*. 16 [1–3], 113–117. https://doi.org/10.1016/S0956-053X(96)00033-5.
128. Hansen, T.C.; Narud, H. (1983) Strength of recycled concrete made from crushed concrete coarse aggregate. *Concr. Int*. 5 [01], 79–83. Retrieved form https://www.concrete.org/publications/internationalconcreteabstractsportal.aspx?m=details&ID=9140.
129. Parlamento Europeo; Consejo de la Unión Europea. (2008) Directiva 2008/98/CE del Parlamento Europeo y del Consejo de 19 de noviembre de 2008 sobre los residuos y por la que se derogan determinadas Directivas. *DOUE*. L 312 [22 de noviembre], 28.
130. Ministerio de la Presidencia. (2008) Real Decreto 105/2008, de 1 de febrero, por el que se regula la producción y gestión de los residuos de construcción y demolición. *BOE*. 38, [13 de febrero] 11. Retrieved form http://www.boe.es/boe/dias/2008/02/13/pdfs/A07724-07730.pdf.
131. Jefatura del Estado. (2011) Ley 22/2011, de 28 de julio, de residuos y suelos contaminados. *BOE*. 181 [29 de julio], 56. Retrieved form http://www.minetur.gob.es/.
132. Solís-Guzmán, J.; Marrero, M.; Montes-Delgado, M.V.; Ramírez-de-Arellano, A. (2009) A Spanish model for quantification and management of construction waste. *Waste Manag*. 29 [9], 2542–2548. https://doi.org/10.1016/j.wasman.2009.05.009.
133. Corinaldesi, V.; Moriconi, G. (2009) Influence of mineral additions on the performance of 100% recycled aggregate concrete. *Constr. Build. Mater.* 23 [8], 2869–2876. http://doi.org/10.1016/j.conbuildmat.2009.02.004.
134. Comisión Europea. (2013) Decisión Nº 1386/2013/UE del parlamento europeo y del consejo de 20 de noviembre de 2013 relativa al Programa general de acción de la Unión en materia de medio ambiente hasta 2020 "Vivir bien, respetando los límites de nuestro planeta" (VII PMA). *DOUE*. [28 diciembre], 30.
135. Comisión Europea. (2012) COM 433. Comunicación de la comisión al parlamento europeo y al consejo. Estrategia para una competitividad sostenible del sector de la construcción y de sus empresas. *Bruselas*. [31 de julio], 1–16.
136. Martín-Morales, M.; Zamorano, M.; Valverde-Palacios, I.; Cuenca-Moyano, G.M.; Sánchez-Roldán, Z. (2013) Quality control of recycled aggregates (RAs) from construction and demolition waste (CDW). In: Handbook of Recycled Concrete and Demolition Waste Woodhead Publishing Limited. 2013. 270–303.
137. Tam, V.W.Y.; Soomro, M.; Evangelista, A.C.J. (2018) A review of recycled aggregate in concrete applications (2000–2017) *Constr. Build. Mater.* 172, 272–292. https://doi.org/10.1016/j.conbuildmat.2018.03.240.
138. Marinković, S.B.; Radonjanin, V.; Malešev, M.; Ignjatović, I.S. (2010) Comparative environmental assessment of natural and recycled aggregate concrete. *Waste Manag*. 30 [11], 2255–2264. https://doi.org/10.1016/j.wasman.2010.04.012.
139. Pedro, D.; de Brito, J.; Evangelista, L. (2015) Performance of concrete made with aggregates recycled from precasting industry waste: influence of the crushing process. *Mater Struct*. 48, 3965-3978. http://doi.org/10.1617/s11527-014-0456-7.
140. Topcu, I.B.; Güncan, N.F. (1995) Using waste concrete as aggregate. *Cem. Concr. Res*. 25 [7], 1385–1390.
141. Bairagi, N.K.; Vidyadhara, H.S.; Ravande, K. (1990) Mix design procedure for recycled aggregate concrete. *Constr. Build. Mater.* 4 [4], 188–193. https://doi.org/10.1016/0950-0618(90)90039-4.
142. Bairagi, N.K.; Ravande, K.; Pareek, V.K. (1993) Behaviour of concrete with different proportions of natural and recycled aggregates. *Resour. Conserv. Recycl.* 9 [1–2], 109–126.