Bibliometric analysis and research trends on earthen architecture and construction

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Abstract. Earthen construction is one topic that has received much interest lately due to its sustainability potential and upscalability in a circular production model. In recent years, the research projects and publications regarding this field have grown considerably, with a notable literature production that comes from many different disciplines and interdisciplinary approaches.

In this sense, a bibliometric analysis allows to study, process and represent data from the existing literature and large bibliographic databases. This tool makes it easier to manage this extensive information regarding parameters such as the occurrence of keywords, authors, number of publications and citations by year, publishers, journals, and production by countries or institutions, among others. Nevertheless, the main outcome of this technique is the identification of the trends and directions of a certain topic or research line.

A bibliometric analysis of the earthen construction and architecture literature production was performed in the Scopus database and processed with the software VOSViewer. The analysis of the keywords and their occurrence and emergence by year identifies the newest trends and research lines, more focused on the sustainable applications of these techniques and their inclusion into circular economy models. On the other hand, differentiated clusters of the literature production were found, showing the encounter between diverse disciplines and the different methodologies and approaches to the earthen architecture and construction phenomenon.

Keywords: bibliometric analysis, keyword analysis, earthen architecture, construction materials.

1 Introduction

Earth construction has been continuously used by humanity for more than ten thousand years, proven with the discovery of the hand-molded earth blocks found at Jericho and dated from 8000 BC [1], and even older fragments of earth mortars with traces of ramifications, from the first stages of sedentariness [2]. These and other techniques continued to be employed all over the world until the beginning of the 20th century. With the larger availability of industrialized materials, the use of earthen materials and systems suffered an immense decrease in many countries.

Due to concerns with the high environmental impact of the building industry, in the last decades, research on earth building materials and technologies has been recovered after many years of oblivion, resulting in a growing literature production. Several examples of systematic literature review regarding earthen construction can be found [3-18], focusing on diverse aspects and providing mainly useful qualitative information.

Bibliometric analysis techniques are still pioneering in many research topics, and its growth in the last years is exponential [19]. Regarding the earthen construction, some first approaches can be found with the Latapie *et al*. analysis [20], which explores the trends of the bio-based and earth-based building materials; the bibliometric review of Rong and Bahauddin with a focus on the vernacular architecture [21], which includes intrinsically the traditional earthen technologies; or the recent article by Djombou, Gorra and Malet-Damour (2024) that analyzes the literature production regarding the properties of excavated soils and some earth-based techniques [22]. The main objective of this research is to perform a bibliometric analysis on the literature production regarding earthen architecture and construction.

2 Methodology

Bibliometry, or bibliometric analysis specifically, is a literature review technique that treats bibliographic data by means of statistical and quantitative methods [23], allowing to identify the historical development and current trends in the global literature, the main gaps and challenges and the relationship between research constituents or actors. The methodology of five steps proposed by Mselle *et al*. [24] is followed in this paper: (1) query formation, (2) data extraction, (3) data curation, (4) analysis methods, (5) interpretations and conclusions.

The first step is the definition of the query, one of the essential factors to perform a correct bibliometric analysis [25]; it is important to identify the proper keywords to conduct an efficient search with the possible fewer errors. The search was performed with the Scopus database for all type of documents, looking for the matches within the title, abstract and keywords in the time period between 1973 (when the first references indexed in the database were found) and 2023, generating the following query:

TITLE-ABS-KEY ("earth construction*" OR "earth archit*" OR "earth building*" OR "earthen construction*" OR "earthen archit*" OR "earthen building*" OR "earthen material*" OR "earth-based material*" OR "earth-based building*" OR "earth-based construction*") AND PUBYEAR > 1972 AND PUBYEAR < 2024

The formulation of the query was an important task, and the authors consulted several experts to define the most common concepts in the literature and the possible misleading words, for instance earthquake. Other synonyms like soils have been traditionally related to geotechnical, geological or even nature documents sources, and for this reason the keywords selected were earth, earthen and earth-based, the latter becoming more and more common in recent literature.

The results obtained with this query were downloaded from the Scopus database in .csv format, including all the bibliometric data collected, to be curated and manually sampled before being processed with the software VOSviewer. Finally, the analysis methods included performance and science mapping, which are essential tools to interpretate all the information available and extract conclusions.

The data curation step is essential for the correct analysis of the data. For instance, during the design and generation of the co-occurrence maps, it is common to identify some critical issues, like the repetition or overlapping of some keywords. For this research, the generic words like article, conference proceedings or country names were eliminated since they add nothing to the co-occurrence analysis, as well as the duplicates or the same keywords included in the query.

Finally, the utilization of VOSviewer allowed to generate the visual maps exploring different relations within this literature production, for this specific study case the keyword co-occurrence and the countries co-occurrence and collaboration. The science mapping allows to identify the trends and opportunities in the field studied, while identifying the relationships between authors, institutions and countries.

3 Results

The results of the bibliometric analysis can be classified into two categories: the performance analysis and the science mapping. The first allows assessing and quantifying the general productivity, while the second consists in a relational technique that is able to display graphically the relationships between research constituents and disclose classifying clusters [19, 23].

3.1 Performance analysis

Figure 1 presents the yearly literature production on earthen architecture and construction until now. The first mentions in scientific literature databases appear in the 70's, with some isolated articles that address some relevant topics, the first one being from 1973 and focusing on the earthen buildings in the tropics [26]. It is important to note that earlier references can be tracked from the bibliography list of these same documents; however they are not indexed in the modern databases due to their antiquity.

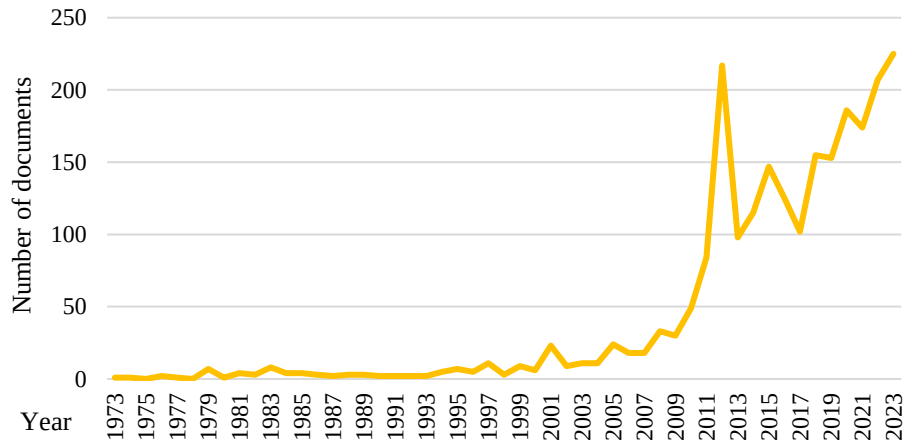

Fig. 1. Earthen related yearly literature production from 1973 to 2023.

It can be seen how the yearly literature production has been continuously increasing, with a notable peak in 2012, which has not been matched and surpassed till 2023. This impressive production associated to 2012 can be explained by the publication of some specialized books with several chapters, including Earth Building: Methods and Materials, Repair and Conservation (reissue) [28] and Modern Earth Buildings: Materials, Engineering, Constructions and Applications [27]; and also the conduction of conferences related to the topic and the publication of their proceedings, like the 1st International Conference on Rammed Earth Conservation, RESTAPIA [29].

Figure 2 contains the 10 most productive authors within the search, according to the total number of publications, starting from the 21 documents of E. Hamard to the 45 of A. Fabbri. It is significant that only European researchers appear in this list, working in three countries: France, Spain and Portugal.

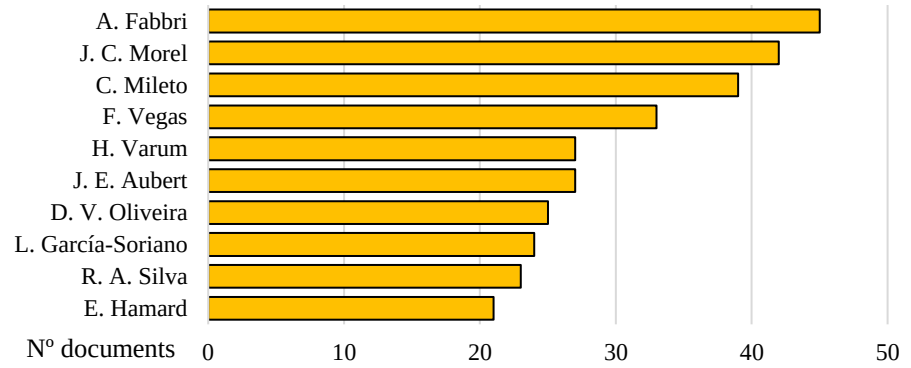

Fig. 2. Main authors by total published documents.

These principal authors can be also related to the main institutions and the countries with the highest production shown in Figure 3. It is interesting to note the presence and relevance of European countries, competing with research powerhouses like the United States, China or India.

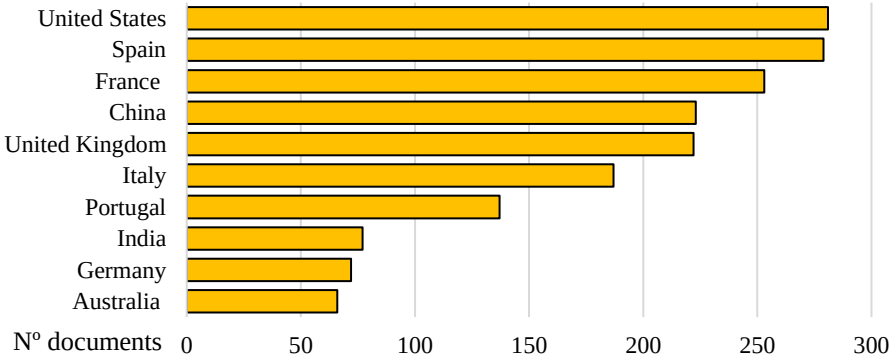

Fig. 3. Countries with more research literature production.

3.2 Science mapping

Figure 4 displays the keyword co-occurrence map generated with VOSviewer for the total of 2315 documents. The map shows those keywords with a minimum occurrence of 40 times and a maximum of 1000 bonding lines between keywords, to have a relevant and well-readable graphic. The most utilized keywords are emphasized by the label size, while the number of links exhibit the connection between them and their co-occurrence in the document overview.

From the keyword co-occurrence analysis three main clusters can be found. First, the green cluster can be related to the environmental and sustainability aspects of earth as a building material, as well as the modern building industry and the thermal and hygrothermal properties of earthen building products and elements. Secondly, the yellow cluster comprises the heritage features of earthen architecture combined with the vulnerability and structural analysis of historical earthen constructions. Thirdly, the red cluster contains the keywords related to the materials properties and characterization methods, with terms that are inherent to the experimental research carried out in the laboratory.

It is interesting to verify how some general keywords, like rammed earth, construction materials or concrete appear in the center (being common to various cluster), while the words contained in the periphery are associated with more specific concepts or techniques like finite element method, thermal conductivity or fly ash. Conversely, the specific earthen techniques are also closer or in intermediate position between clusters, which can be very useful to explain how they have been approached historically from the scientific studies. For instance, adobe and rammed earth are included in the heritage cluster, while cob and compressed earth block remain in the environmental cluster.

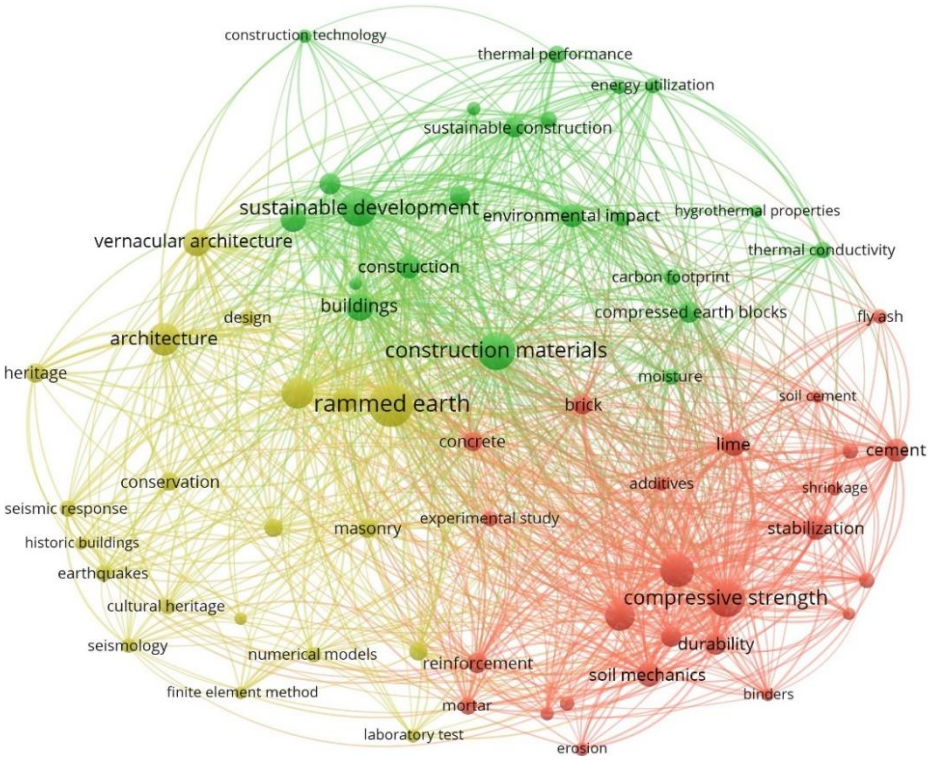

Fig. 4. Earthen related keyword co-occurrence map by association strength.

Figure 5 displays the country co-occurrence map by association strength, for the countries that present a minimum of 10 total documents. Similarly to the keyword analysis the total production for each is emphasized in the labels and fonts, as well as the lines width representing the collaboration between countries. This map can be analyzed in combination with the performance analysis from Figures 2 and 3. The scientific co-occurrence between different countries can be analyzed from two factors: the total number of lines, representing the existing collaborations with other countries; and the size of the lines which expresses the bonding strength between two different nations. In this sense, it is noteworthy the cooperation between the United Kingdom and France, being much wider than any other.

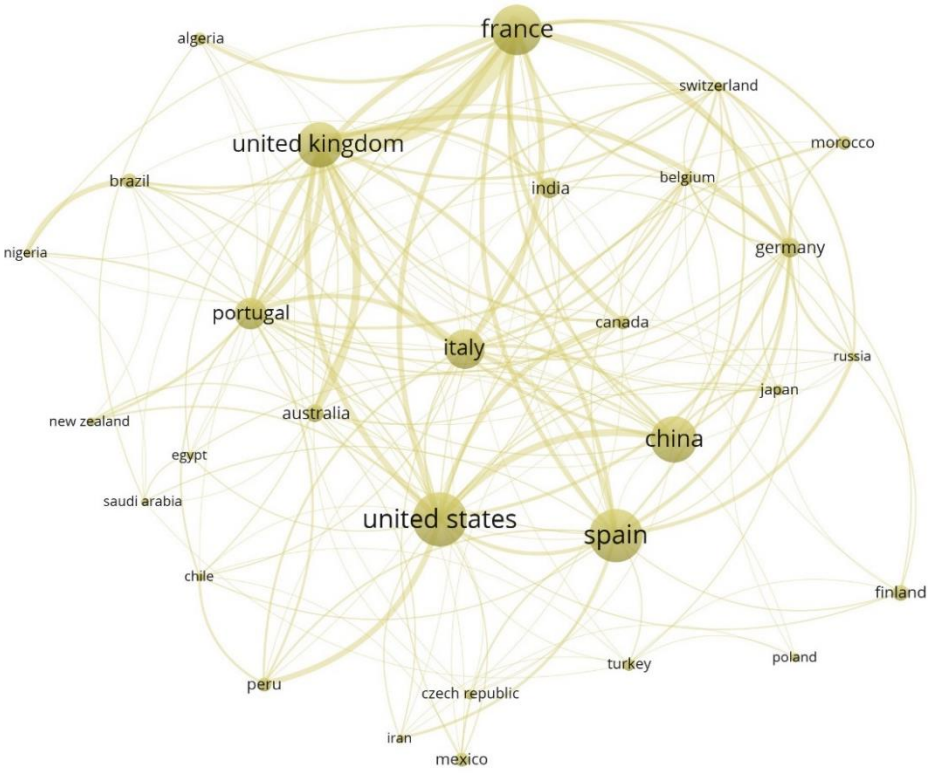

Fig. 5. Countries co-occurrence map by association strength.

4 Conclusions

A bibliometric analysis on literature production has been done in the research field of earthen architecture and construction. Results showed an increasing trend in the number of publications of the last decades, which indicates the growing interest in this research topic. From the performance analysis, it can be observed that European researchers are within the ten top most productive authors; regarding the national production, the United States, Spain, and France are the three top countries with more published documents.

On the other hand, the science mapping generated by the keyword analysis allowed identifying the main research trending topics in earthen construction field, which can be clustered in (1) environment and sustainability, (2) heritage and vulnerability, (3) materials properties and characterization methods. As expected, the general keywords and the main techniques, like adobe and rammed earth, have intermediate positions between the three clusters.

In perspective, further research could include a specific analysis for the main earthen techniques, including science mappings for earthen plasters, adobe, rammed earth or

compressed earth blocks among others. Furthermore, it is expected to analyze historically the trends and main keywords, tracking their evolution over the last decades, and predicting the challenges and opportunities of earthen building in the next years.

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