

Bibliometric analysis on the use of natural fibers in construction materials

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Abstract. Due to the increasing interest of the population in the sustainability theme, there was a consequent growth in publications related to the theme in the area of civil construction. Agro-industrial waste has become an environmental problem, and with that natural fibers have found space in the reuse of waste due to its characteristics and possibilities of improving the mechanical properties of its products. In order to achieve sustainable construction demand, along with the need to reuse waste, studies have begun to analyze the application of natural fibers in construction materials. The documents provided by the Web of Science (WOS) database through research carried out with the search for the terms ‘Natural Fibers’ and ‘Building materials’ restricted to the period 2010–2020 in the main WOS collection. The institutions involved with the publications, the countries of origin of the documents, the year of publication, the keywords used by the authors and the number of citations for each document were analyzed using bibliometrics in the VOSVIEWER (VOS) software. The result of the analysis shows an increase in documents related to the theme over the years, and that the countries with the most studies in the area are China (16), USA (14) and Brazil (11), respectively. The results presented after analysis of the keywords show that natural fiber (61 occurrences), mechanical properties (44 occurrences) and composites (31 occurrences) are the words with the highest occurrence among the analyzed

documents. The present study shows the growth of research related to the theme, in addition to discriminating countries, institutions and authors, which allows monitoring the scientific expansion of the theme and guiding future studies.

Key words: research, civil construction, building materials; sustainability, co-occurrence analysis.

INTRODUCTION

The growing interest in studies related to sustainability in the civil construction sector has mainly highlighted construction materials (da Silva et al., 2021). Thereby, the focus on the use of renewable sources of raw materials has been aimed at, for example, applications in composite materials of natural fibers in the construction sector, which has been presenting alternatives regarding the use of recycled fibers and reinforcements of natural fibers (organic and inorganic) in building materials (Fan, 2017; Asim et al., 2020; Erkmen et al., 2020).

The world production of natural fibers corresponds to around 32 million and 200 thousand tons, allowing us to state that most of the production of these fibers comes from cotton, which corresponds to approximately 80% of the total production weight, followed by jute, kenaf and allied fibers with about 10% of the total production weight. Wool and coconut fiber represent about 1 million tons each, and the sum of other natural fibers corresponds to 1 million and 530 thousand tons (Townsend & Sette, 2020). Bartolini et al. (2019) evidently show the growth in the number of articles published on the subject between the years 2014 and 2018 when compared to the stability presented in the period from 2006 to 2014.

Natural fibers are considered a renewable and easily obtainable resource, which can enhance the technological properties of composite materials, as well as the improvement of their mechanical and thermoacoustic characteristics, thus replacing synthetic fibers (Reddy et al., 2020). Sathish et al. (2021) also emphasize the need to reduce the use of petroleum-based synthetic fibers, allowing natural fiber to meet this need, in addition to reducing energy consumption and having high availability.

In this context, several studies have been developed for the application of natural fibers in construction materials such as Ferreira et al. (2020), who evaluated the influence of carboxylated styrene butadiene rubber coating on the mechanical performance of plant fibers and on their interface with the cementitious matrix. The authors highlighted that to reduce or mitigate interferences in the hydration of cementitious matrices, treatments for these fibers are necessary, such as reducing the fiber's dimensional variation, providing a greater interaction between the fiber surface and the hydration reactions, densifying the transition zone of the interface. The authors found that after addition of the polymer, all fibers showed an increase in tensile strength and better adhesion. The treatment reduced the water absorption capacity of all studied fibers (curauá, jute and sisal). From this perspective, it was possible to affirm that the fiber treatment provided a better interaction between the fibers and the cementitious matrix.

Azevedo et al. (2021a) evaluated the technological performance of natural açai fiber reinforced in cement-based mortars. Different fiber additions under natural conditions and after surface treatment with NaOH were studied. The authors concluded that the addition of açai fiber to mortar worked by filling part of the internal pores and as a reinforcing material for the cementitious matrix to absorb and redistribute internal

stresses. Furthermore, they emphasize that the açai fiber must be properly treated with a NaOH solution due to the loss of durable properties found in its untreated use. The authors also state that high proportions of natural fibers in cementitious composites can be harmful, thus confirming that the addition of 3.0% of natural fibers treated with NaOH in mortars is recommended to balance adequate technology and durability.

Wang & Chen (2017) studied the development of bamboo-based composites and showed that bamboo has more than ten cell layers in its cell structure, with each microfibril different and orientation with thick layers and thin layers in alternating arrangements on the cell wall. The results presented verified that bamboo-based composites are a combination of high strength, dimensional stability, durability, with reliable structural properties, having high modulus of elasticity and well dispersed through a matrix of low modulus of elasticity, thus presenting the modulus of composites greater than that of the matrix. Hamad et al. (2017) evaluated the microstructure properties and their bond with the tensile strength of different natural fibers (linen, jute, ramie and sisal fibers) and identified that jute and sisal fibers exhibit less variation in terms of fiber cross-sectional area, shape, inner lumen size and cell wall thickness compared to linen and ramie fibers, which ultimately reflects on the fibers' tensile properties. They also verified that the stress-strain behavior presented two distinct regimes. The authors found that this variation was linked to differences in fiber microstructure. When studying the development of mortar for laying and coating with natural pineapple fibers Azevedo et al. (2020) tested different percentages of fiber incorporation, as treatment (NaOH) and without fiber treatment. The authors observed that the treatment with NaOH solution and the percentage of natural pineapple fiber incorporated in up to 5% in relation to the cement mass form mortars with technological feasibility of application. Valášek & Habrová (2017) studied the hardness and abrasive wear resistance of epoxy resins filled with unordered short sisal fibers. They observed that the surface treatment of the fibers led to the removal of the surface layers of fiber, increasing surface segmentation. As for the hardness, there was a decrease in the same in the composites as the fiber addition increased.

In order to optimize the geopolymer matrix produced with Fired Clay Brick Powder Silva et al. (2020) studied the reinforcement of the material using the application of jute and sisal fibers. The authors observed that the increase in fiber content provides a linear increase in flexural strength, whereas in relation to the compression and tensile tests an optimal fiber content was presented, which varies according to the type of fiber used.

Wongsa et al. (2020) evaluated the performance of sisal fiber and coconut fiber as reinforcement of fly ash-based geopolymer mortar with high calcium content. The authors studied ten different mortar mixes, with sisal fibers, coconut fiber and glass fiber, in proportions of 0%, 0.50%, 0.75% and 1.00% of the volume of the mixture. The authors found a significant improvement in tensile and bending strength when compared to the control sample, and similar to the synthetic fiber sample. The authors observed a trend towards a decrease in compressive strength, workability, dry density and ultrasonic pulse velocity, in addition to no significant effect of the fiber on thermal conductivity and water absorption. Therefore, the authors conclude that geopolymer composites can use coir and sisal fibers as reinforcement material.

Study by Azevedo et al. (2021b) evaluated the physical and mechanical characteristics of geopolymer materials reinforced with natural fibers and geopolymer materials reinforced with synthetic fibers. They observed the need for a pre-treatment in natural fiber for better mechanical performance due to their sensitivity to alkaline environment and low adhesion to the matrix caused by substances present on its surface. When fiber pre-treatment is combined with improved traceability and ideal curing conditions, the application of natural fibers in geopolymer materials allows the replacement of synthetic fibers without harming their performance. However, the particular characteristic of each fiber must be analyzed, since the variation between different types of natural fibers can make the polymer matrix not ideally incorporated.

Tan et al. (2019) studied the application of 15 vegetable fibers from agricultural and forestry residues chosen due to their potential as a raw material for the manufacture of geopolymeric panels. The authors observed good compatibility of the studied vegetable fibers (without additives), with wood fibers being more compatible with the material than non-wood fibers in general. Zhang et al. (2021) studied the manufacture of geopolymer mortar with natural fiber as reinforcement. The authors observed good compatibility of the geopolymer matrix with the pre-treatment of natural fiber with CaCl_2 , in addition to an increase in flexural strength and tenacity according to the increase in the proportion of fiber. However, it was also observed a decrease in the compressive strength of the material due to the increase in voids caused by the fiber.

With this in mind, it is possible to affirm that the incorporation of natural fibers in construction materials has been constantly the focus for new researches aimed at the application of these fibers. Thus, using bibliometric analysis to enhance the incidence of these researches is very relevant (Hamdaoui et al., 2020). According to Aziz et al. (2020), bibliometrics is related to the quantitative study of the properties of scientific productions, incorporating new understandings about a given topic to the literature.

The purpose of bibliometric analysis is to measure production, impact and collaboration, using different information as indicators, with a broad coverage of information by the database being important (Mallig, 2010). As presented by Ye et al. (2020), the bibliometric analysis allows finding a knowledge map related to certain research metrics. Databases provide valuable bibliometric data for providing global academic information (Xie et al., 2020). The Web of Science (WOS) database is widely known as one of the main sources in the academic world, where research metrics are used taking into account publication and impact algorithms, which made it a reliable and recognized source for conducting research scientific (Powell & Peterson, 2017).

Thus, the aim of this study was to carry out a bibliometric analysis of works regarding the use of natural fibers in construction materials in the period from 2010 to 2020.

MATERIALS AND METHODS

Between the 21st and 22nd of January 2021, a bibliographic search was carried out in the WOS database. The search metrics used in the survey were the keywords 'Natural Fiber' and 'Building Materials', with the years 2010–2020 being adopted with a search criterion. The analysis was made through the main collection of the WOS database, adopting a broad scope of research, considering all the searchable fields available for

consultation. The documents resulting from the research were exported in a text file (TXT) in tab format (Windows), with the contents of the complete record and references cited.

The institutions involved with the publications found were analyzed with VOS through the co-authored analysis, with the metric ‘organizations’, considering all documents with at least one occurrence. From the results obtained, the three institutions with the highest occurrence were considered. The countries involved in the research were verified through VOS analysis, considering the co-authorship of the documents restricting to the countries. At least one quote per country was considered.

The information obtained through the database was placed in the Excel software, discriminating the documents by year of publication. To obtain information regarding co-occurrence parameters, countries and institutions linked to the documents, the VOS tool was used. Vosviewer (VOS) is open access software for creating and viewing bibliometric networks, which also allows analysis of text data.

To analyze the co-occurrence of keywords, initially, the metric of at least one occurrence of the keyword was used, which allowed obtaining all the keywords found in the analyzed documents. The search result was exported to a text file and opened in Excel, where equivalent and repeated words with different writing were unified through a model text file provided by VOS and later added to the program. The analysis was redone with the updated information, where the number of occurrences was defined as 5, and the keyword graph was subsequently generated.

The number of citations obtained by the publications was obtained through co-occurrence analysis of the VOS in the ‘citations’ type with the ‘documents’ analysis unit, where the 9 most cited documents were considered.

RESULTS AND DISCUSSION

Among the documents found in the WOS database, 107 were found for the period and research metrics analyzed, as shown in Fig. 1.

When analyzing the countries involved in the publications found in the WOS for the period from 2010 to 2020, a total of 43 countries were observed, the results can be seen in Fig. 2. The countries with the highest number of publications were: China (16 publications), United States (14 publications), Brazil (11 publications) and India (10 publications).

When analyzing the keywords resulting from the search in the VOS software, 34 keywords were found and presented in Fig. 3. Among them, natural fiber (61 key-words), mechanical properties (44 key-words) and composites (31 key-words).

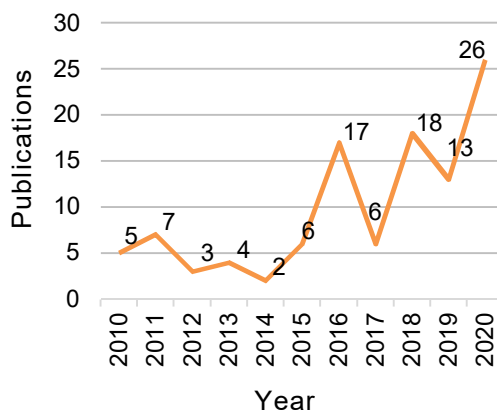


Figure 1. Number of publications per year.

natural fibers in construction materials such as Princeton University (New Jersey - USA) and University of São Paulo (São Paulo - Brazil), with 4 documents each.

Table 1. The 10 most cited documents

Author	Residue	Citations
Pacheco-Torgal & Jalali, 2011	Bagasse, Banana leaf, Banana trunk, Coconut coir, Coconut tissue, Eucalyptus e Sisal	213
Mahjoub et al., 2014	Kenaf	134
Yan et al., 2016	Coconut fiber	91
Karade, 2010	Wheat straw, Rice straw, Coir, Hazelnut shell, Oil palm residues, Cork granules, Bark, Bagasse, Arhar stalks, Construction demolition wastes, Waste timber, Waste MDF e Furniture industry waste	85
Elsaid et al., 2018	Kenaf	71
Senthilkumar et al., 2018	Sisal	70
Ferreira et al., 2015	Sisal	51
Hamza et al., 2013	Alfa leaves, rush stems, palm leaflets and date palm wood	40
Lertwattanaruk & Suntijitto, 2015	coconut coir and oil palm	39

The increase in interest in the use of natural fibers in civil construction by researchers is evident with the increase in research related to the theme over the years, as an example we can mention the study by Khasawneh & Alyaseen (2020) in which they analyzed the use of coconut fiber in bituminous mixtures for road materials, Alavez-Ramirez et al. (2012) analyzed the use of the same fiber, however in fiber cement sandwich panels. However, Freire et al. (2017) studied the application of agro-industrial waste in the manufacture of medium-density fiberboard (MDF) and high-density fiberboard (HDF) panels in order to add value to waste and reduce the demand for wood and by-products from the production of the panels.

Representing 47.66% of the publications found in the database used, in the studied period, are China, USA, Brazil and India. Pakistan (1 post), Vietnam (1 post), South Korea (1 post), Arab Emirates (1 post), Malaysia (5 post), Indonesia (2 post), Iran (1 post), Iraq (1 post), Jordan (1 publication), Taiwan (2 publications), Turkey (1 publication), Saudi Arabia (6 publication), India (10 publication) and Thailand (6 publication), countries belonging to the Asian continent, as observed in the analysis, also demonstrate great interest in research involving the topic, resulting in 46.70% of publications, which is justified by the fact that the continent is a major agricultural producer and most of the fibers from waste in the sector. In South America, research in the area is concentrated in Brazil, with 11 publications, followed by Colombia (2 publications), Argentina (1 publication), Chile (1 publication) and Peru (1 publication).

Asian countries are benchmarks for the strength of scientific research related to sustainability Det Udomsap & Hallinger (2020). The results are consistent with the studies by Li et al. (2018), which shows the growth of China in research related to the reuse of solid waste, where the country reaches the first place surpassing the USA in production in the area.

The residues obtained between the keywords were sisal, with 14 co-occurrences, followed by wood with 8 co-occurrences and coconut fiber with 7 occurrences. Also found during waste keyword analysis such as date palm (6), Fly Ash (5 occurrences),

Hemp (4 occurrences), Jute (4 occurrences), Kenaf (4 occurrences), Bagasse (4 occurrences), bamboo (3 occurrences) and rice straw (2 occurrences).

Hemp, jute, sisal, kenaf and coconut (coconut) residues are also recurrent keywords in WOS studies, such as Bartol & Mackiewicz-Talarczyk (2015), in relation to publications related to fiber studies. The potential of using Coffee husk, Coconut shell, and Banana pseudostem in scientific composites is presented in studies by Ferraz et al. (2020). Study by Kochova et al. (2020), demonstrates that coconut fiber has in its structure characteristics with adequate thermal and mechanical conditions, and can provide several applications in the construction industry. However, De Azevedo et al. (2021a) draws attention to the fact that some materials with cementitious matrix are not suitable for application of natural fibers due to the pH in the pore region of the matrix.

The use of agricultural by-products (natural fibers) in composite materials made with soil matrix and cement / lime has shown results of improved physical, mechanical and durability properties Danso & Manu (2020). The keywords also showed the occurrence of words related to material properties, such as mechanical properties (44) and thermal properties (7). The result showed the occurrence of behavior (26), strength (26), performance (18), tensile (6), physical properties (5), flexural strength (6), which analyze the properties of the material.

The mechanical performance of materials is the target of many studies, the term 'Mechanical Properties' was one of the ten most cited keywords in the study by Liu (2013), with 3,687 citations, with 'Building materials' being the second most cited with 6344 quotes.

The analyzes carried out by Alao et al. (2019) with marijuana fiber in polypropylene composites used tests of traction, compression, flexion, water absorption and expansion, air permeability and spectroscopy.

It is clear from the results presented by Karade (2010), the need for further research to better understand the durability property, a keyword with 18 occurrences in the publications from 2010 to 2020 analyzed in this article.

The literature review work by Pacheco-Torgal & Jalali (2011) reinforced the fact that mechanical properties, one of the keywords, are the focus of much of the available literature. The study by Slebi-Acevedo et al. (2019) draws attention to the lack of information regarding porous mixtures with addition of fibers, in addition to the need for studies on the mixture of two or more fibers to improve the mechanical properties of the composite.

There is a change in the need for studies over time, due to the emergence of new research in the area. The present work allows the monitoring of the scientific expansion of the theme through the bibliometric analysis carried out, allowing then to guide future studies.

CONCLUSIONS

Bibliometric analysis allowed an in-depth study of the number of documents referring to the use of natural fibers in construction materials, showing a considerable increase in the last eleven years, with a total of 26 publications in 2020. Among the countries identified in the documents are China, the United States, Brazil and India. The study found as keywords with the highest occurrence the words natural fiber, mechanical properties and composites.

The present study showed the growing interest in research related to the theme ‘Natural Fibers’ and ‘Building Materials’, in addition to presenting institutions and countries more closely linked to the theme and the relevance of the authors, in addition to allowing to follow the scientific expansion of the theme and guide future studies.

CHALLENGES AND FUTURE PERSPECTIVES

Based on this study, it is possible to affirm that the topic is very relevant, but it also needs to advance in certain issues, especially with regard to the emergence of new unconventional fibers. It was evidently possible to verify that materials produced with natural fibers contribute to improve the development of construction materials in terms of performance and sustainability. However, it is necessary to point out that the search for this theme should not be limited only to these parameters, but also to be sought considering that there is a large market behind it for these materials to be applied, not only to develop them.

Materials that incorporate natural fibers can offer a number of advantages over the traditional ones used in construction, however, the challenges continue to move towards the replacement of conventional materials by those that can exert a structure and function comparable to traditional ones, as well as presenting durability to long term, in addition to the cost and design of the material. Thus, it is possible to list some of these challenges that should be considered for future perspectives for the development of building materials using natural fibers: Mechanical property variability and stiffness; Standardization of these new materials; Long term durability; Cost reduction; Market acceptance.

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