



Contents lists available at ScienceDirect

# Construction and Building Materials

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Review

## Bibliometric analysis of research on thermal, acoustic, and/or fire behaviour characteristics in bio-based building materials

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### ARTICLE INFO

#### Keywords:

Bio-based materials  
Building materials  
Bibliometric  
Thermal insulation  
Thermal conductivity  
Acoustic absorption  
Acoustic properties  
Fire Behaviour  
Construction materials

### ABSTRACT

The use of bio-based building materials is a sustainable opportunity to reduce the environmental footprint associated with the construction sector. The achievement of this objective is primarily achieved through the valorisation of vegetable waste, resulting in a reduction in the use of primary source material and waste generation. Within the scope of this study, the focus is directed towards research concerning the thermal, acoustic, and fire behaviour properties of bio-based building materials. This study conducts a comprehensive bibliometric analysis encompassing all documents meeting these criteria within the Scopus database, spanning two decades, from 2003 to 2023. The comprehensive analysis covered a total of 1081 documents, which were analysed. This analysis furnishes insight into various facets, including the temporal evolution of publications, journals boasting the highest publication counts and impact, influential research areas, countries with substantial contributions and their collaborative patterns, noteworthy affiliations, prolific authors, and seminal documents, alongside recurrent keywords. The objective of this comprehensive study is to provide a detailed analysis of the documents published up to the present day, in order to identify research gaps and potential opportunities in this field, to assist new researchers interested in the subject. The analysis reveals that bio-based building materials have gained substantial attention over the past decade. With each passing year, the published documents have increased their impact and become more specific, underscoring the growing importance of this subject. This evolution has also fostered a broader network of researchers engaged in this field. However, it is noteworthy that the characterization of these materials focuses predominantly on their thermal properties, while research avenues related to acoustic and fire properties remain less explored and present opportunities for future investigation.

### 1. Introduction

The construction sector stands out as one of the primary contributors to environmental pollution worldwide, alongside being a significant consumer of non-renewable resources and a substantial generator of waste. In 2019, greenhouse gas (GHG) emissions from this sector accounted for 21% of the annual global total, with 19% attributed to the production of construction materials such as cement and steel [1]. Furthermore, the environmental footprint of the construction sector accounts for 40% of the world's total energy consumption, with 30% of this energy expended on raw material usage [2].

For example, in the case of insulating materials, they can be categorized into three primary product categories: mineral-derived inorganic materials, constituting approximately 50–60% of current

insulation, fossil-based organic materials, accounting for around 30–40%, and lastly, organic sourced from biological origin, which would make up approximately 10% [3–5].

At least 90% of the Insulation materials are from non-renewal sources. In inorganic insulation materials the greatest impact in the life cycle assessment (LCA) occurs in the production process, while in the petroleum-derived insulations the highest LCA impact is related with the raw material obtention. In fact, both kind of non-renewable insulation materials present a high impact in most of the categories considered in LCA [6,7]. For this reason, the option of bio-based materials as an alternative to conventional materials is a great opportunity to reduce the impact produced by the construction sector.

Currently, there are a significant number of studies conducted using various bio-based materials that have demonstrated their capacity to

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<https://doi.org/10.1016/j.conbuildmat.2024.136569>

Received 14 March 2024; Received in revised form 30 April 2024; Accepted 6 May 2024

Available online 17 May 2024

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compete in terms of thermal properties with the traditional non-renewable materials [7], however every bio-based material requires a specific study to analyse their properties. Bio-based materials, even though being a relatively recent topic, have generated a multitude of articles covering a wide range of raw materials, with their properties and applications studied [8–12].

Therefore, before embarking on new studies, it is recommended to be fully aware of the state of the art achieved so far, as well as the existing market gaps. For this reason, a large number of review articles can be found, which compile the research conducted to provide a comprehensive overview of the materials used and the studies performed, along with their results.

The bibliometric analysis is a research method employed to examine and summarize the knowledge structure of a specific field, discover emerging trends within that field, assess research impact, identify influential research and publications, track evolving research trends, and facilitate informed decision-making regarding research funding and collaborations [13,14]. This approach relies on quantitative and evidence-based techniques to assess the scholarly contributions and impact of individuals, journals, institutions, and research fields. Consequently, bibliometric analysis serves as a valuable tool for researchers and scholars, enabling them to gain insights into the current state of their area of interest and offering guidance for future research endeavours.

Bibliometric articles can be found across a wide range of fields, including those related to construction and construction materials, such as those based on cement [15], bituminous materials [16], or the reuse of municipal waste [17–19]. Regarding bibliometric studies related to the field of bio-based construction materials, only one article was found [20], which compares bio-based materials with earth-based materials, serving as the main objective of the study.

## 2. Methodology

The established methodology consists in different steps [21]. First of all, it is essential to establish precise keywords definitions for effective literature searches. In this case the research field is in bio-based materials used in construction, with specific focus on their thermal, acoustical and fire-related properties. For this reason, one of the initial search query possibilities included "Bio-based AND construction AND material AND thermal OR acoustic OR fire". However, the outcomes yielded fewer results, and the findings were more scattered across the literature. Consequently, the refined search query, "Bio-based AND (building OR construction) AND material AND thermal OR acoustic OR fire", ultimately generated a more comprehensive and focused set of results for the study. However, when narrowing the search specifically to the term "bio-based", it was observed that some articles related to the topic were not appearing in the search results. For instance, terms like bio-composites, bio-fibre, or bio-waste, among others, were not captured. For this reason, to encompass other words related to biological materials used in construction, it was decided to remove the "bio-based" specification and use only "bio" as the search term. Therefore, the search conducted and subsequently analysed in this study is "Bio AND (building OR construction) AND material AND thermal OR acoustic OR fire" and it was made on the 2nd of January of the 2024.

Once the keywords were defined, various database sources, including Web of Science, Google Scholar, and Scopus were utilized for the search. These sources provided access to a wide range of scientific journals, conference proceedings, books, among other types of publications. The results of the search varied significantly across different databases. Initially, Google Scholar was dismissed due to its limited analytical data compared to Web of Science (WoS) and Scopus. When the search was conducted in both WoS and Scopus, notable differences emerged, primarily in the number of publications and, secondarily, in the research areas to which they were affiliated. In WoS, which encompasses a broader range of subjects, the research areas and keywords

included publications that were dispersed across unrelated fields such as optics, medicine, and pharmacy. These unrelated publications introduced noise into the search results and necessitated the use of over 100 filters to refine and limit the research. This complexity added more variables to the search process, making data collection challenging. On the other hand, in the case of the Scopus database, the research areas and keywords were more specific. By excluding just 12 keywords, the results became more focused and reasonable. The keywords excluded in this study were "Phase change materials", all keywords related to polymers, and terms such as "concrete" and "glass transition". This exclusion was made because the primary focus of this study is on raw waste bio-based materials and their primary use in construction materials. Consequently, the final choice for the database in this study was Scopus due to its ability to provide a more targeted and relevant dataset for the research and the advantage of providing updated bibliometric data and superior compatibility with VOS Viewer [22,23].

The next step in this methodology involves the analysis of several key metrics. These metrics include the evolution of publications, journals, contributing institutions, contributing countries, changes in research areas, author analysis, keyword analysis, and the examination of different networks such as co-occurring subjects, journals, citation patterns, and collaboration trends. To obtain these metrics, various software tools are employed in this study. Specifically, two software applications are used: VOS Viewer (version 1.6.19) developed by the Centre for Science and Technology Studies (CWTS) and Biblioshiny of Bibliometrix 3 with RStudio (version 4.3.1) [24]. These tools facilitate the extraction and analysis of pertinent bibliometric data, enabling a comprehensive evaluation of the research landscape in the field of bio-based building materials. Another interesting avenue for comparison lies in exploring the distinctions between studies conducted with thermal, acoustic, or fire-related objectives. To investigate this further, three additional searches are performed using the following queries: "Bio AND (building OR construction) AND material AND thermal", "Bio AND (building OR construction) AND material AND acoustic" and "Bio AND (building OR construction) AND material AND fire".

Subsequently, the final step of the study entails an analysis of the performance and outcomes of these distinct searches, culminating in the formulation of results and conclusions that shed light on the unique aspects and trends within each of these research subdomains related to bio-based building materials.

## 3. Results

### 3.1. Publications evolution

The initial article under consideration dates back to 2003 and this bibliometric analysis encompasses all publications up to 2023. However, the earliest discovered publication in this search can be traced back to 1994, and by 2024, additional articles have emerged. It is important to note that for the purpose of this analysis, only complete years are included in the count.

The search conducted as described above yielded a total of 1081 documents from 492 distinct sources. Fig. 1 also illustrates that up until 2010, the annual publication count remained consistently low, typically fewer than 10 articles, without showing a discernible upward trend. However, starting from that year, there was a notable exponential increase in published articles, eventually culminating in the current annual growth rate of 25.2%. However, in 2020, a notable deviation is observed as it marks the first year with stagnation or even a slight decline in production. This trend shift could potentially be attributed to the disruptive impact of the Covid-19 pandemic. The widespread lockdown measures and sector-wide disruptions imposed by the pandemic likely hindered research activities, including access to laboratories and other essential resources, thereby affecting academic output. It could reflect the exceptional circumstances faced worldwide.

Despite experiencing an annual growth rate, the generation of

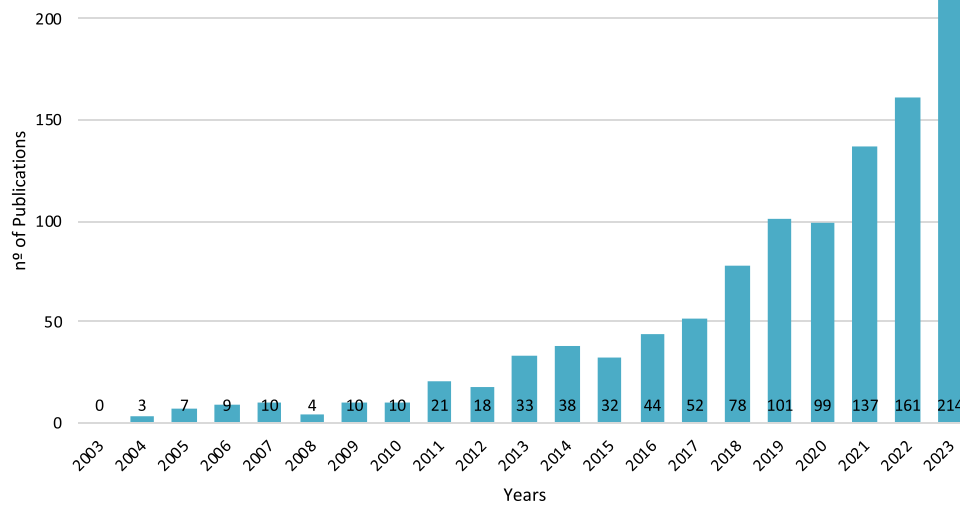


Fig. 1. Evolution of the number of publications per year published of bio building materials with thermal, acoustic or fire properties according to Scopus data.

publications per year in this field seems quite modest when compared to other scientific topics like indoor air quality [25] or biomimetic membranes [26], which may have over 500 publications annually. However, it is noteworthy that interest in this area has been steadily increasing, suggesting its growing importance in the construction sector with each passing day.

Fig. 2 displays the types of documents that have been published, with the majority being journal articles. Nevertheless, it is noteworthy that 33 of the documents are categorized as reviews, which is particularly significant given the relatively limited existing literature on the subject.

### 3.2. Journals analysis

In this section, an analysis of the top ten journals in the field of bio-based material research is conducted, despite the existence of 492 different journals with publications in this research area. Various parameters have been taken into consideration, including the number of published articles, their percentage in relation to the total, and several citation metrics for the year 2023.

These metrics encompass the h-index, which evaluates a journal's influence based on its publication volume and citation frequency, D for the documents in this research and J for the journal in general; CiteScore, provides a recent perspective on a journal's impact, indicating the

average citations per document within a specified period; SNIP (Source Normalized Impact per Paper), which accounts for a journal's citation impact within its subject domain, adjusting for field-specific citation norms; SJR (Scimago Journal & Country Rank), measuring scientific influence by factoring in citations and the prestige of citing journals; and the quartile score, categorizing journals into quartiles (Q1-Q4) based on their performance within specific subjects to aid researchers in identifying journal quality within their respective fields. A detailed presentation of these metrics is available in Table 1.

In the field of publications on bio-based materials, the top ten journals collectively account for a modest 2.0% of the total number of journals that have contributed to this subject. Interestingly, these top journals have hosted 14.1% of the publications in this domain, highlighting a remarkable diversity of journal options for disseminating research articles in this field. However, it is noteworthy that one journal, "Construction and Building Materials", stands out prominently. This journal, classified as Q1 by SJR, boasts a substantial total of 73 publications and has garnered over 1600 citations. This notable performance sets it apart significantly from other journals in the list, including the second-ranked "Journal of cleaner production". Despite the availability of numerous journals for publishing research on bio-based materials, the leading journal in the list serves as a prominent reference in the field. The third-ranked journal, "Energy and Buildings", with 21 publications,

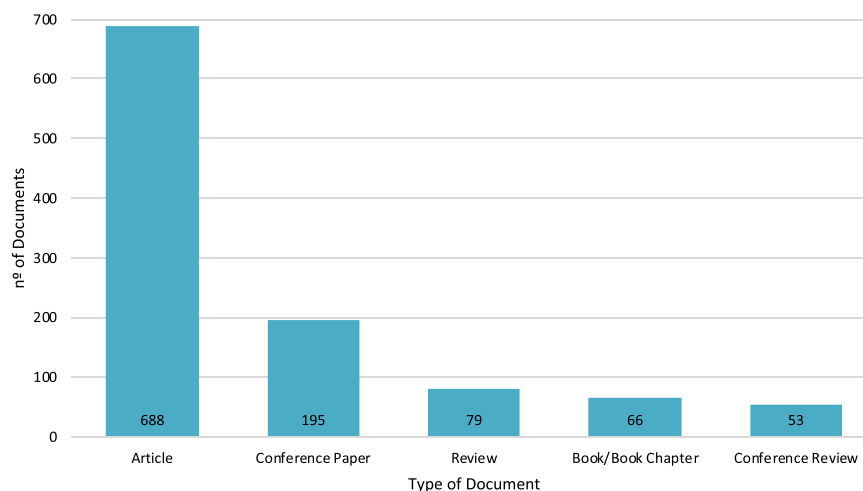


Fig. 2. Total number of publications according to the type of document of the search carried out for bio building materials with thermal, acoustic or fire properties according to Scopus data. Between 2003 and 2023.

**Table 1**

Top ten of the journals that publish bio-based building materials research indicating the number of total documents, the percentage related with the total, the number of citations and the indexes according to Scopus data.

| JOURNAL   | DOCUMENTS | %   | CITATIONS | h_Index<br>D. | h_Index<br>J. | CiteScore<br>2022 | SNIP<br>2022 | SJR<br>2022 | QUARTILE<br>SCORE |
|---|-----------|-----|-----------|---------------|---------------|-------------------|--------------|-------------|-------------------|
| Construction and building materials                     | 73        | 4.1 | 1645      | 25            | 230           | 12.4              | 2.214        | 1.888       | 1Q                |
| Journal of cleaner production                           | 24        | 1.3 | 607       | 15            | 268           | 18.5              | 2.379        | 1.981       | 1Q                |
| Energy and buildings                                    | 21        | 1.2 | 999       | 15            | 214           | 11.8              | 1.992        | 1.608       | 1Q                |
| Polymers  | 19        | 1.1 | 611       | 9             | 113           | 6.6               | 1.167        | 0.720       | 1Q                |
| Advanced materials research*                            | 19        | 1.1 | 9         | 2             | 47            | -                 | 0.182        | 0.121       | 4Q                |
| Journal of building engineering                         | 18        | 1.0 | 149       | 7             | 72            | 8.3               | 1.914        | 1.232       | 1Q                |
| Sustainability (switzerland)                            | 17        | 0.9 | 120       | 6             | 136           | 5.8               | 1.198        | 0.664       | 2Q                |
| Industrial Crops and Products                           | 16        | 0.9 | 1034      | 11            | 158           | 9.7               | 1.567        | 0.897       | 1Q                |
| IOP Conference Series: Earth and Environmental Science* | 16        | 0.9 | 97        | 4             | 41            | 0.8               | 0.197        | 0.255       | -                 |
| Materials   | 15        | 0.8 | 134       | 7             | 148           | 5.2               | 1.067        | 0.563       | 2Q                |

\* The majority of publications in these journals consist of Conference review, meaning that they are documents where only a summary of the conference topic is provided.

has garnered close citations with the leading journal on the list, amassing almost 1000 citations. This information suggests that while the number of articles may be relatively limited, their impact within the field has been significant.

In the fourth and fifth positions of this ranking, despite having the same number of articles, 19 in each case, the difference in terms of citations is considerable. Specifically, there are 611 for "Polymers" and only 9 citations for "Advanced Materials Research". Another case of low citations below 100, it is "IOP Conference Series: Earth and Environmental Science". This is because, in both cases, primarily comprise articles presented at conferences or seminars. It is important to note that conference articles and those published in scientific journals serve distinct purposes and undergo varying review processes. Conference papers often possess shorter lengths and tend to focus on specific facets of research, with varying levels of review scrutiny conducted by conference committees. Conversely, journal articles are characterized by their greater length, rigorous peer review, and adherence to a standardized format. Although both types of publications are citable, journal articles are generally regarded as more authoritative, enjoy higher visibility and accessibility, and contribute significantly to the cumulative body of knowledge within a particular field.

Concerning citations, it is also noteworthy that the second journal with the highest number of citations "Industrial Crops and Products" is ranked eighth in terms of published articles, with 1034 citations across only 16 articles. Upon closer examination, the citations for each article are quite homogeneous, except for one case that stands out above all, with 490 citations. This exceptional article is titled "Bioprocess preparation of wheat straw fibres and their characterization" [27]. This indicates that, although the journal has good scores and a relatively high average citation per article, the difference compared to other journals is attributed to the significant impact generated by the previously mentioned article.

The pattern of citations among these journals presents an intriguing observation. Specifically, the fifth journal, "Advanced Materials Research", has not been cited in any publication of the other journals on the list. The fact that this journal had been discontinued by Scopus as of 2014 could contribute to its lack of citations in subsequent years. Scopus implements rigorous quality control procedures, and journals failing to uphold high-quality standards risk being removed. Indicators of low-quality publications may include substandard writing, inadequate data analysis, flawed research methodology, or a lack of originality. In contrast, the remaining journals exhibit a citation network, albeit divided into two distinct clusters. One cluster revolves around the "Construction and Building Materials" journal, forming strong connections among those journals. The second cluster includes "Polymers", "Materials", and "Sustainability", which are linked together, with additional ties to the journal "IOP Conference Series". The presence of a second cluster in the citation network suggests that the journals

"Polymers," "Materials," and "Sustainability" may have a broader scope that encompasses topics beyond the specific theme or focus of bio-based materials. This broader scope could lead these journals to publish papers that may not have a strong thematic connection to the subject matter studied in this case. It highlights the multidisciplinary nature of research and publication, where journals covering a wide range of topics may include articles that extend beyond their primary focus. Researchers and authors in these fields might find opportunities to explore diverse subjects and collaborate across disciplines, contributing to the cross-pollination of ideas and knowledge exchange. This clustering pattern is evident in Fig. 3 and reflects the interconnections and citation trends among these journals.

Furthermore, in this case it is very interesting that almost all the current top ten journals nowadays started publishing documents about this topic after 2013. Only a few of these journals published an article between 2006 and 2013. This indicates a relatively recent and growing interest in this area of research.

The data presented in Fig. 4 supports the hypothesis that, due to the novelty of the subject, the research area was not well-defined in its early years. However, it has gradually evolved and become more specialized in recent times. This specialization has led to the publication of higher-quality documents in journals with a higher impact factor. In the upcoming section, additional evidence will be provided to further substantiate this hypothesis, shedding more light on the evolving nature of research in this field.

### 3.3. Bibliometric evolution in research areas

The study of bio-based materials has multiple areas to investigate from different perspectives such as environmental issues, chemical composition, materials science or physical characterization among others. Due to the newness popularity of the theme and the wide collection of different points of view it is possible to choose diverse subjects of the research areas, therefore there are 22 different subjects in this research. Fig. 5 provides a visual representation of the top ten research areas and their evolution since the earliest selected year. In the initial years, when the number of documents published was relatively low, these publications covered a wide range of diverse topics. This included fields such as Engineering, Chemistry, Agricultural and Biological Sciences, among others. This early diversity reflects the exploratory nature of research in the nascent stages of the field of bio-based materials, where scholars were investigating various aspects of the subject across multiple domains. As the field has matured over time, it is likely that research has become more specialized and focused within specific research areas, as indicated by the changing trends in Fig. 5. Nowadays the most dominant research area is Engineering, accounting for a significant 24.1% of the research output, following closely is Materials Science, which has experienced substantial growth and

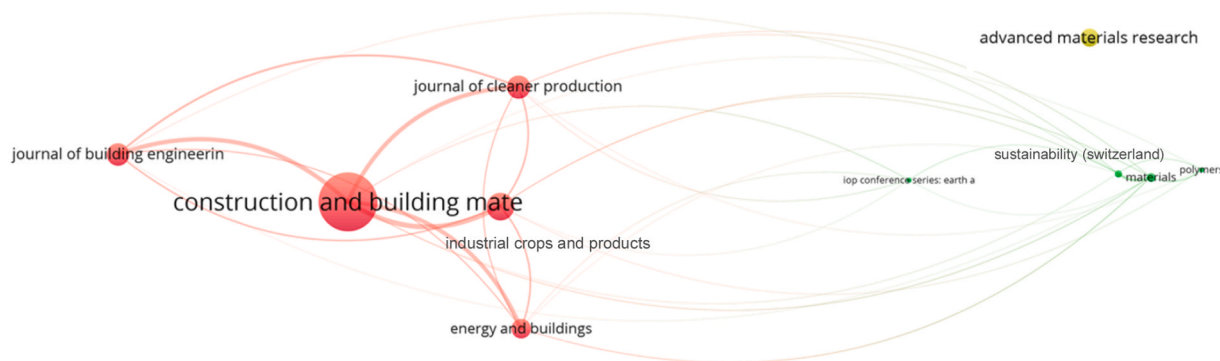


Fig. 3. Clustering and linking pattern of the connections between the top ten journals according to co-citations carried out with the VOSviewer software.

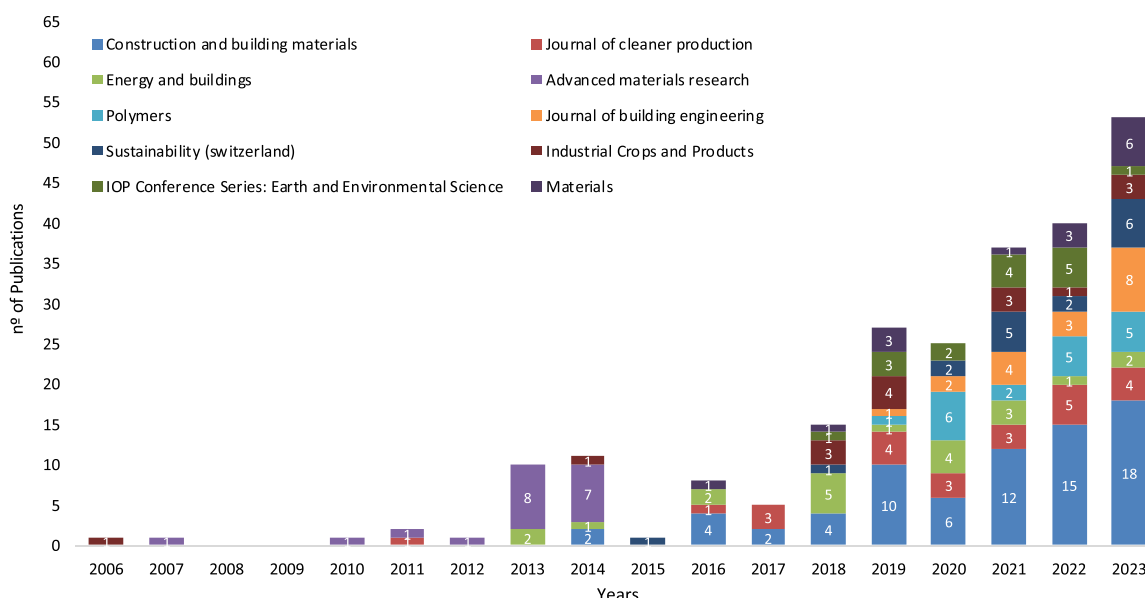


Fig. 4. Evolution of the number of publications per year of each of the journals located in the top 10 publications. From the first publication of these journals until 2023.

represents the 20.7%. Environmental Science is the third-largest research area, comprising 9.8% of the publications, with Energy and Chemistry rounding out the top five at 7.8% and 7.6% respectively. Together, these five research areas collectively encompass approximately three-quarters of the total research output in the field, highlighting their paramount importance and influence in the current research landscape of bio-based materials.

Despite the growth observed in all of the top five research areas, it is noteworthy that the research area of Energy has exhibited a slower rate of growth trend over time. In recent years, Energy has experienced a plateau in terms of research output, and in the most recent years, it has been surpassed by other research areas like Chemistry and Chemical Engineering. This shift in the ranking of research areas underscores the dynamic nature of the field, where the focus and emphasis of research can evolve over time in response to emerging trends and priorities within the broader scientific community. As said in the previous section, in the graphic displayed in Fig. 5 it can be observed a similar trend between the journals and the research areas inasmuch as the subject area is directly related with the journals, for example, the Construction and Building Material journal have the half of articles in Engineering and the other half in Materials Science, in fact in the first five articles in the top ten there are just these two areas. Therefore, the hypothesis on the specialization of matter in recent years becomes more forceful. The collected data facilitates the identification of research areas within the

bio-based materials field that have garnered the greatest interest among the scientific community.

### 3.4. Geographical analysis

The bio-based materials' scientific production is worldwide as it is shown in Fig. 6. In the heat map it can be observed that all continents (except Antarctica) have representation to a greater or lesser extent. There are also some of the articles, 60, that have not defined the location, all of them without author name available and in the majority as a conference review document. In the field of this research topic, a noteworthy observation emerges: a total of 81 countries have made contributions with at least one publication. However, the distribution of research output is highly skewed, as only a select few, precisely 37 countries, have surpassed the threshold of 10 articles in this domain.

Remarkably, two countries stand out prominently among them all, those are France and China, with a total of 172 and 159 articles respectively to its credit. These numbers exhibit a notable contrast with the third and fourth-ranking countries on the list. Italy, having published 101 articles, closely trails behind, while the USA closely follows with 99 articles in this field. India secures the fifth position with 79 publications on this subject. Fig. 6 also provides insights into the top 20 countries that have made the most substantial contributions in this field.

The evolution of publications in the top ten countries follows a

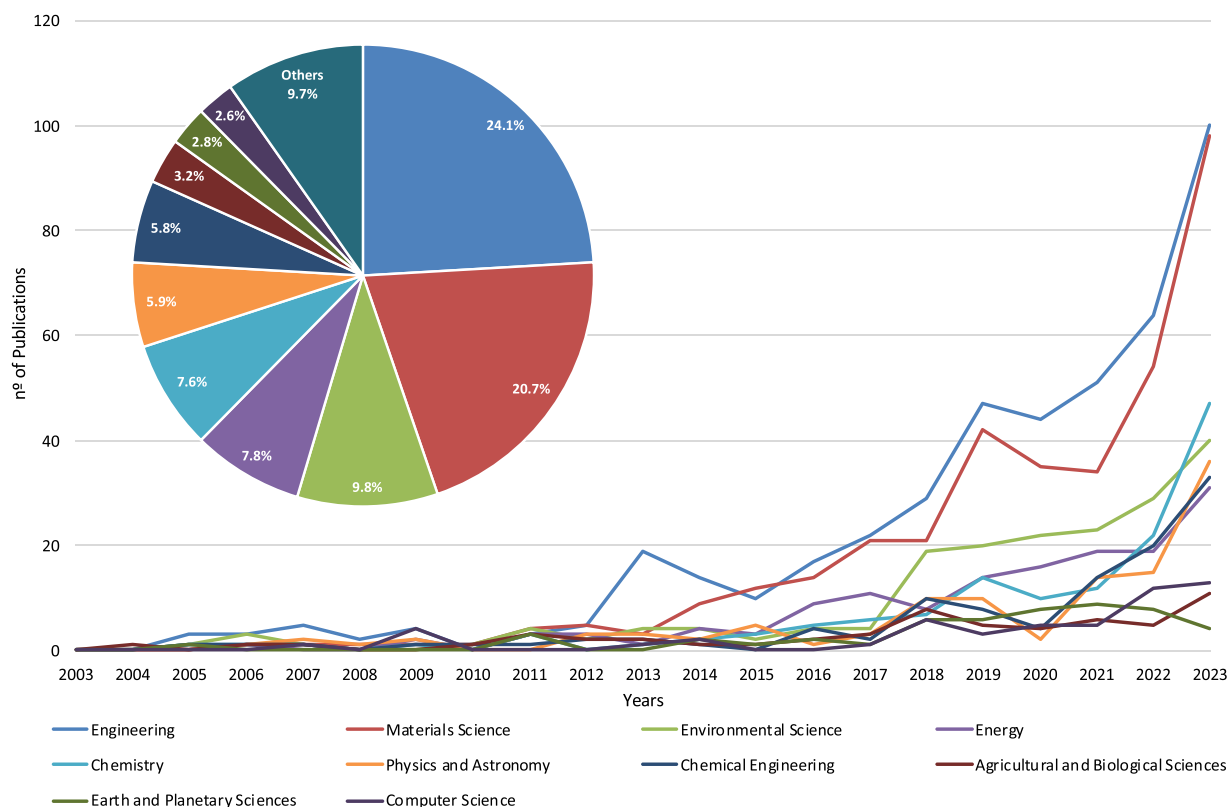


Fig. 5. Evolution of publication per year of the ten research areas with the most documents and the current percentage of each of these, between 2003 and 2023 represented in the linear graph. Distribution of research areas in the last years, 2023, shown in the pie chart.

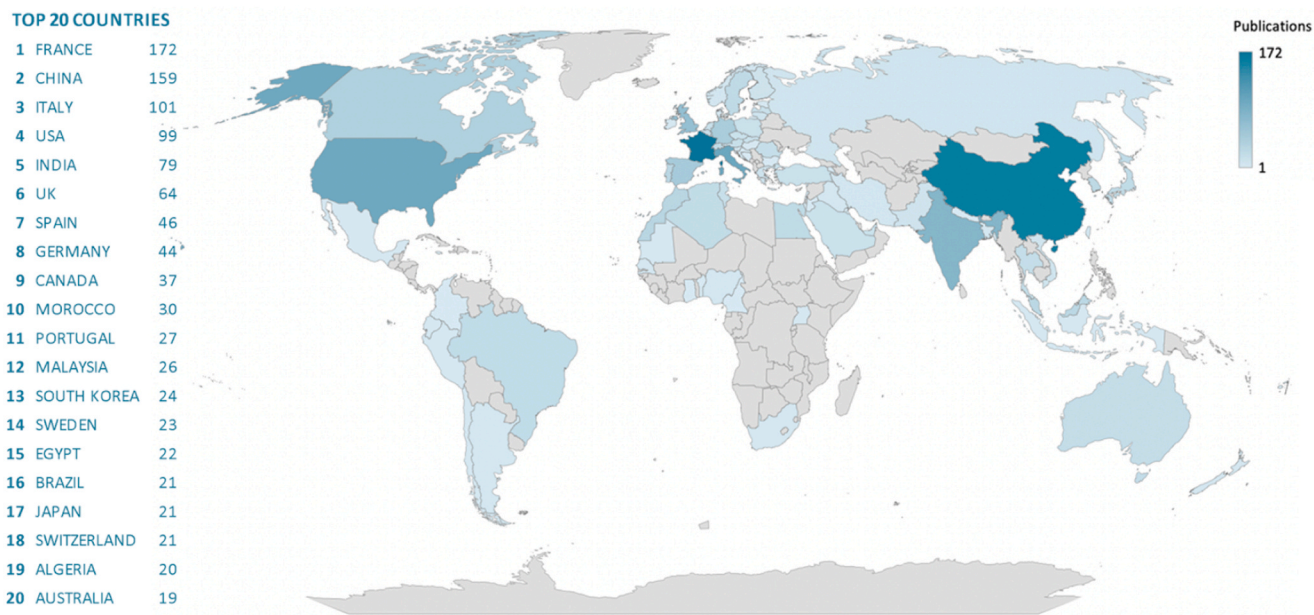


Fig. 6. Heat map of the countries with the greatest number of global publications, with the darkest countries being those with the most publications. Along with the list of the top 20 countries with the greatest contributions to the subject.

similar trend to the overall number of publications per year shown in Fig. 5, initially, only a few countries contributed articles before 2014. However, after 2014, all the top ten countries significantly increased their research output, with a particularly notable upsurge in recent years. It is worth noting that there was a temporary exception for some countries in 2020 due to the impact of the pandemic, which may have

affected research and publication activities. In Fig. 7, it is evident that there has been a substantial growth in recent years among certain countries in the top 10, notably the top 4 countries, France, China, Italy, and the USA. The publications of France output in the field of bio-based building materials was relatively modest before 2016, even trailing behind countries like Italy and the UK. However, starting from 2016,

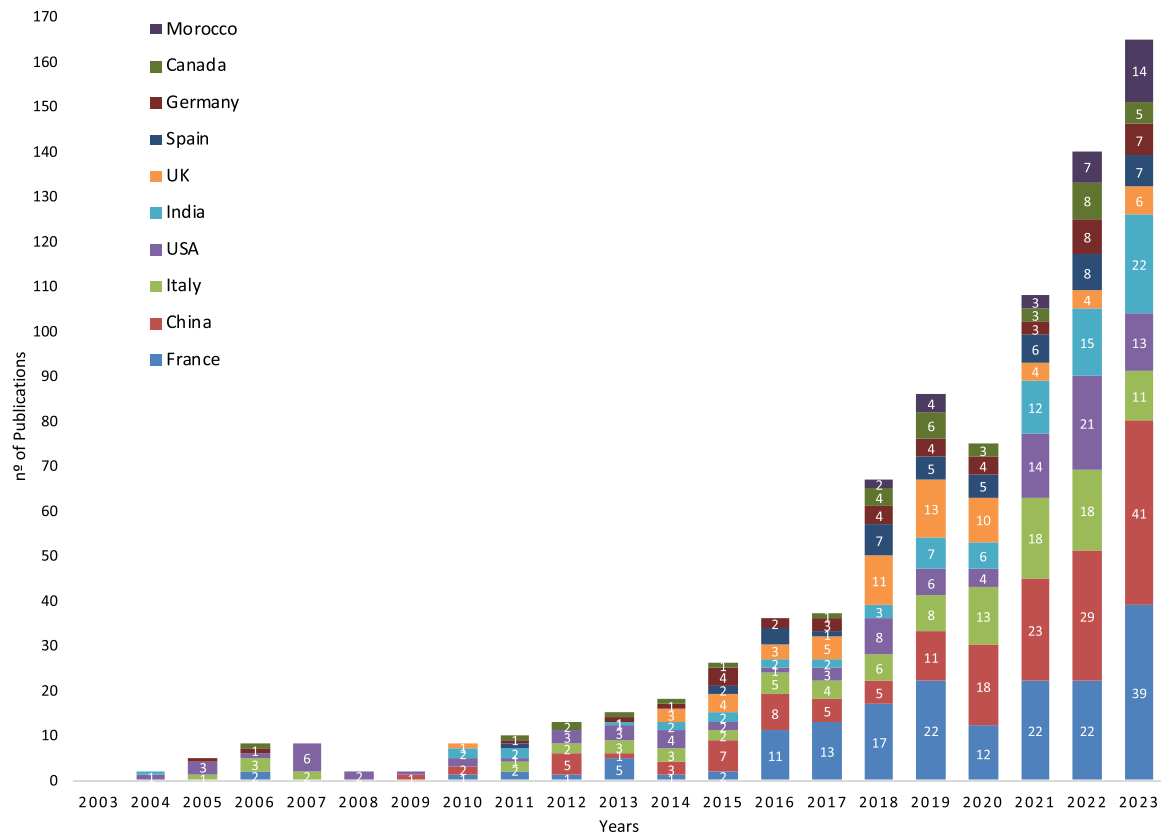


Fig. 7. Evolution of publications per year of the 10 countries with the most publications in this research area.

France experienced exponential and consistent growth in contributions to articles in this domain.

This remarkable trend has catapulted France to the forefront, making it the most prominent country in this research theme today. Although

China has demonstrated remarkable productivity in this field, particularly in the last three years. During this period, China has generated more articles than ever before, surpassing until the third country in the top 20 list. This surge in research output underscores China's growing

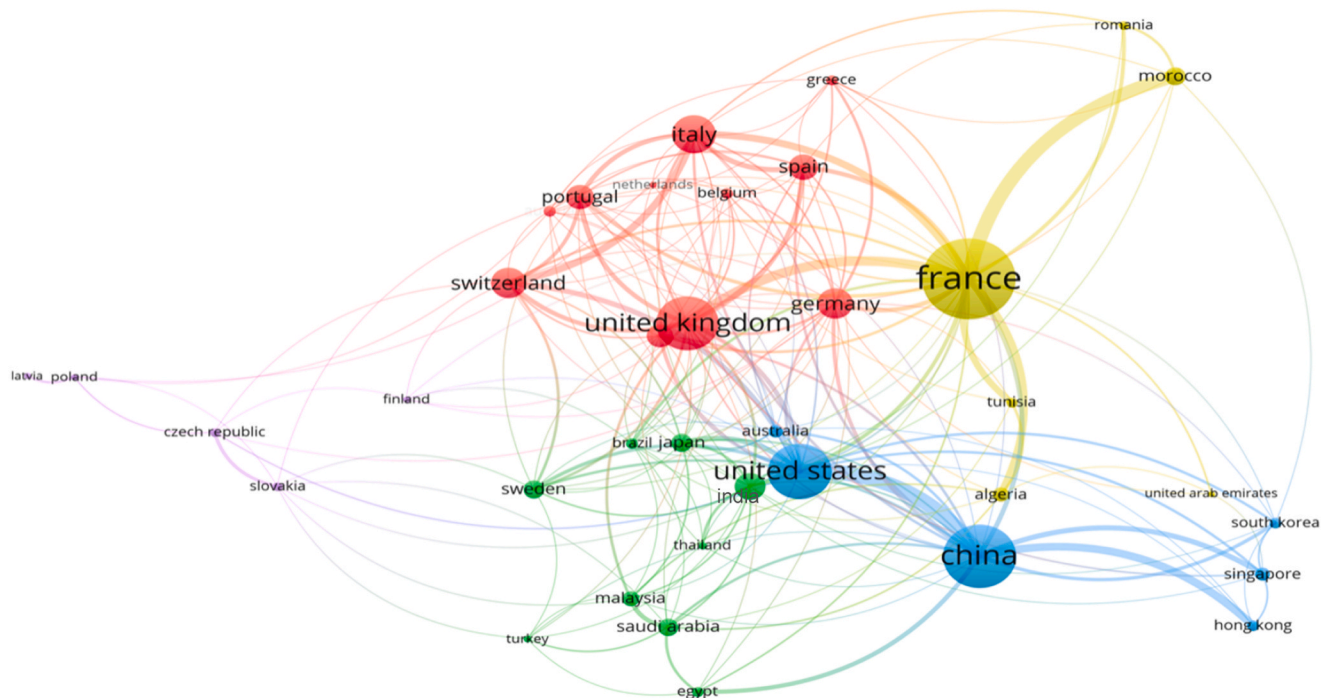


Fig. 8. Diagram of co-authorship relationships of publications according to the country of affiliations, divided into clusters according to colour, and the bulk of the connections between them. Carried out with VOSviewer software.

influence and active engagement in the subject area. As for Italy, up until 2018, their contribution to publications stood at 27 articles, but in the past four years, they have significantly increased their involvement, participating in 74 articles. Concerning the USA, despite a consistent but modest stream of article publications from 2004 to 2017, the total number of articles published during that period remained relatively low at 33. However, from 2018 to 2023, there has been an exponential surge in article production, resulting in a total of 66 publications within that timeframe, with a notable concentration of output in the last two years. The fifth-ranked country, like the majority, has been more productive in recent years. If this trend persists, it may surpass the fourth and third countries in the ranking in the coming years.

The total number of contributions in this field amounts to 1490, considering articles with multiple-country authorship and the undefined. Among these contributions, France stands out with 172 publications, making up 11.5% of the total. China follows with 159 contributions, Italy with 101, and the USA with 99, representing the leading countries in this domain. Fig. 8 illustrates the collaborations between countries, specifically highlighting those with more than 10 contributions involving other nations. France, which has co-authored with 37 countries, exhibits significant collaboration with Morocco, with 15 collaborations, as well as with the UK with 11 collaborations, and Algeria and Italy with 8, among others, including Tunisia, Vietnam, and China. Securing the second position in collaborative endeavours is China, having established partnerships with 28 distinct countries. The USA closely trails with 27 collaborations, while both India and the UK share the same standing, each boasting 26 collaborations. These findings reveal that a significant portion of the publications from the United Kingdom, approximately 65%, involve collaborations with other countries. In contrast, France has a higher percentage of publications without co-authorship or with primarily local co-authorship, representing around 25% of multiple-country publications. The overall international co-authorship rate in this field is 26.4%, with an average of 4.4 authors per document.

Geographical data in this analysis are determined based on the authors' university affiliations declared in their articles. The institution contributing the most to this field is the CNRS (Centre National de la Recherche Scientifique) in Paris, France, with a total of 36 publications. In affiliations with more than 10 articles, totalling 12 in all, it is noteworthy that 6 of them originate from France. Only six other countries are represented, each with one institution: China, the UK, Switzerland, Latvia, Morocco, and finally, Italy, as shown in Table 2. In the top five, the only non-French institutions to make the list is the Ministry of Education of the People's Republic of China, securing the second position with 33 publications and the University of Bath tied with two other French universities with 16 publications. However, it is important to note that the number of citations received by publications from these universities varies widely.

To gauge the impact of these documents, it is valuable to consider the average number of citations per publication, as this metric is directly related to the influence that the publications have. In this regard, two universities stand out with exceptional averages: ETH Zürich leads the list with an average of 64 citations per document. Furthermore, the University of Bath follows with an average of almost 40 citations per document. Additionally, the 11th-ranked university, Politecnico di Milano, holds the 3rd best average with 32 citations per document. These averages reflect the high impact and influence of publications from these institutions in the field of bio-based building materials. In contrast, the CNRS, which boasts the highest number of publications, averages only 13.9 citations per document, placing it in eighth place in the top ten affiliations based on average citations per publication.

To gain a deeper understanding of the variations in average citations among these four universities, we conducted a specific analysis of citations by articles and the journals in which they were published. For the top-ranking affiliation, CNRS, which contributed 36 documents (including 25 articles, 4 reviews, 4 conference paper and 1 book

**Table 2**

Affiliations with more than 10 publications ordered by number of documents, and indicating the percentage of the total, the country of origin, the total citations received and the average number of citations per publication.

| AFFILIATIONS  | N° PUBLICATION | %   | COUNTRY     | TOTAL CITATIONS | AVG. CIT./ PUBL. |
|---|----------------|-----|-------------|-----------------|------------------|
| CNRS Centre National de la Recherche Scientifique       | 36             | 3.3 | France      | 500             | 13.89            |
| Ministry of Education of the People's Republic of China | 33             | 3.1 | China       | 710             | 21.52            |
| Université de Toulouse                                  | 24             | 2.2 | France      | 560             | 23.33            |
| University of Bath                                      | 16             | 1.5 | UK          | 638             | 39.88            |
| Université de Rennes                                    | 16             | 1.5 | France      | 359             | 22.44            |
| Université Paris-Est Créteil Val de Marne               | 16             | 1.5 | France      | 301             | 18.81            |
| Université de Lorraine                                  | 15             | 1.4 | France      | 126             | 8.40             |
| ETH Zürich  | 14             | 1.3 | Switzerland | 897             | 64.07            |
| Riga Technical University                               | 14             | 1.3 | Latvia      | 73              | 5.21             |
| Université Mohammed Premier Oujda                       | 12             | 1.1 | Morocco     | 92              | 7.67             |
| Politecnico di Milano                                   | 11             | 1.0 | Italy       | 354             | 32.18            |
| Université de Reims Champagne-Ardenne                   | 11             | 1.0 | France      | 90              | 8.18             |

chapter), 14 of the articles garnered more than 10 citations each. However, one outlier, the paper titled "Recommendation of the RILEM TC 236-BBM: characterisation testing of hemp shiv to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity" [28], collaboratively conducted with the Université Rennes, Toulouse and Bretagne Sud and the University of Bath and Belfast, received the highest number of citations with just 75.

In the case of ETH Zürich, which contributed 14 documents (including 8 articles, 4 conference papers, 1 review, and 1 book chapter), there was a diverse distribution of citations. Only 8 articles received more than 10 citations each, with two of them surpassing 100 citations: "Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls" [29] conducted in collaboration with the "Politecnico di Milano", fifteenth in the list, with 135 citations and "Structure-property-function relationships of natural and engineered wood" [30] co-authoring with the University of Maryland, USA among other institutions, with a total of 563 citations, most of which were acquired in the last year. Notably, these two articles have a direct connection to the theme of this study and were published in two different journals, both of which have a quartile score of Q1: "Construction Building Materials" and "Nature Reviews Materials", respectively.

On the other hand, the University of Bath, with 16 documents (comprising 13 articles and 3 book chapters), exhibited a notably even distribution of citations, with just 2 documents having fewer than 10 citations. Nevertheless, three articles stood out with the highest number of citations: "Wood waste as an alternative thermal insulation for buildings" [31] co-authored with Istanbul Technical University, garnered 123 citations and displayed an increasing trend in citations each year. The second one, "Porosity, pore size distribution,

micro-structure" [32] received 89 citations but showed a decreasing trend. The last one, "Determination of hygrothermal parameters of experimental and commercial bio-based insulation materials" [33] was collaboratively conducted with the "Universitat Politècnica de Catalunya", maintaining a homogeneous number of citations per year since its publication.

Four of these documents were published in top-ranked journals in this research area, particularly in "Construction Building Materials", and all the other documents were in Q1 journals, with the exception of 2 papers that appeared in Q2 and Q3 quartile score journals. Lastly, the "Politecnico di Milano", with 11 documents (including 7 articles, 4 conference paper), had only 5 documents with fewer than 10 citations, 4 of them are the conference papers. Conversely, the remaining 6 documents, unless one, had a significant impact, each receiving 28 or more citations per document. The highest-cited document from this affiliation, "Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls" [20], the one that has been conducted with the ETH Zürich institution. Interestingly, these documents were published in nearly distinct journals, all of which had a substantial impact and were categorized within the Q1 quartile score. In addition to the number of published documents, a journal's quartile rank serves as a valuable indicator of the quality and impact of a publication within the scientific community.

### 3.5. Author evolution and documents

The total number of authors in the research area amounts to 3622, with the vast majority, nearly 85%, having only one document published. Only 23 authors have contributed to 5 or more documents. The author with the highest number of documents is F. Collet, having a total of 14 articles, followed closely by M. Charai with 13. Subsequent authors in terms of document count are illustrated in Fig. 9, with the third and

fourth authors closely trailing with 12 publications each. The following four authors each have 10 documents, and finally, the last three authors contribute 9 documents each. This figure also illustrates the production of articles by these prolific authors in the research area, revealing that their contributions began during the peak of publications in this sector, starting around 2011 and becoming more significant from 2017 onward.

Nevertheless, the productivity of the authors is not always directly related with the impact of their publications, to know the real impact of them it is usual to use the h-index. The h index of the authors is a metric that measures the productivity and the citation impact of the publications, and drives from the collection of a scientist's most frequently referenced papers and the quantity of citations they have garnered in other published works. In this instance, the overall author h-index will be indicated, considering all the articles published by the author. Additionally, specific emphasis will be given to articles exclusively appearing in the sample, further identifying those with the greatest influence in each case.

The author with the highest number of publications in the sample, F. Collet, possesses a global h-index of 18, specifically attaining a score of 9 in this context. Their articles in the sample accumulate a total of 357 citations, with only 5 articles surpassing the 20-citation mark. Their most cited publication in this research is "Hygric and thermal properties of hemp-lime plasters", [34] published in 2016, with 98 citations. Notably, this publication experienced a peak in citations in 2020 with 25 citations, but the trend has been decreasing since then. Another author with a local h-index of 9 is M. Lawrence, but in this case, the global h-index surpasses that of the previous author, standing at 23. The 10 published articles have a total of 375 citations, matching the case mentioned earlier. Out of these, 7 have garnered more than 20 citations, with the article from 2017, "Porosity, pore size distribution, micro-structure" [32] standing out above the rest with 89 citations.

The next author with a higher h-index is C. Magniont, possessing a

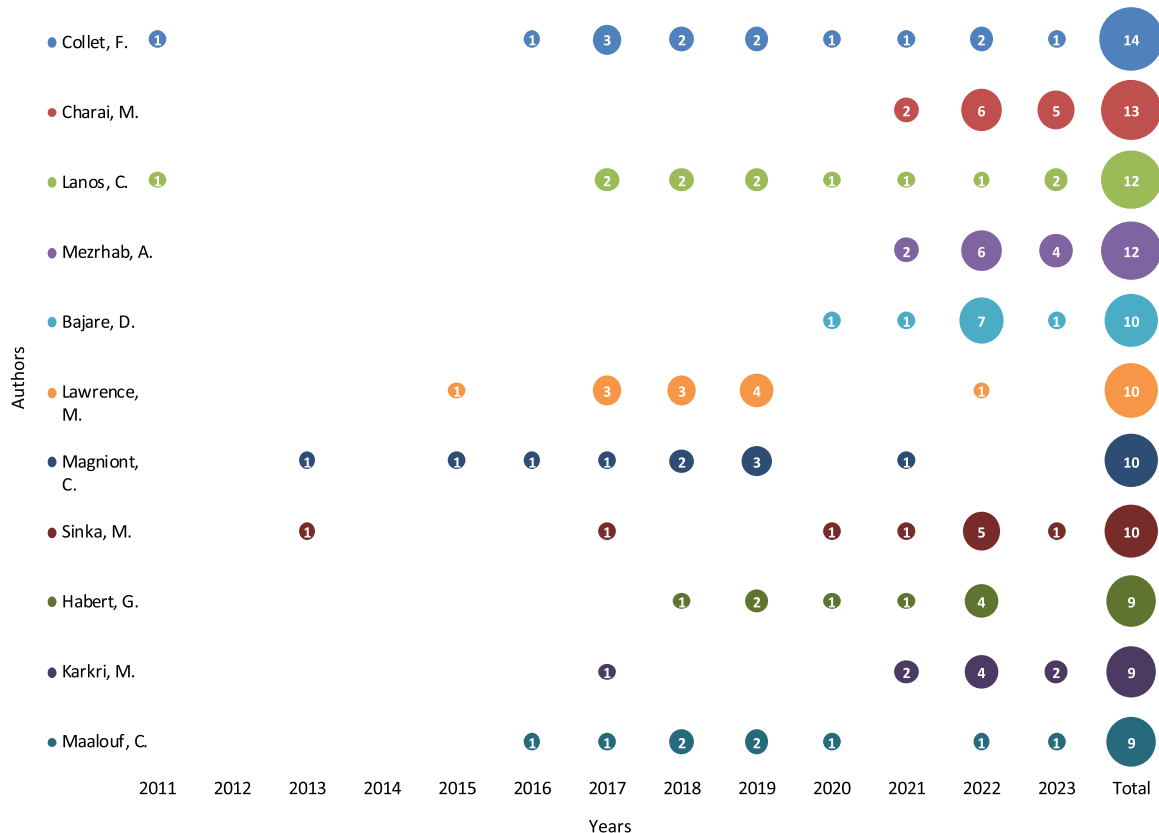


Fig. 9. Evolution diagram over the time of the authors' production with more than 9 productions in total and the year of publication of each of the documents from 2011 to 2023.

local h-index of 8 and a global h-index of 18. Despite having 10 articles, the total citations are slightly fewer, totalling 369. Six of these articles have over 20 citations, with four exceeding 50 citations. Two other authors, C. Lanos and G. Habert, share a local h-index of 8, but there is a notable difference in the number of articles contributed to this research, with 12 and 9, respectively. However, their global h-index shows a substantial gap, with C. Lanos at 27 and G. Habert at 50. Concerning citations, G. Habert has more citations with fewer documents, accumulating a total of 284 citations. Almost all of these citations are attributed to a single article, the first one titled "Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls" [34], which has 136 citations. On the other hand, C. Lanos exhibits a more evenly distributed citation pattern, totalling 175 citations. While six of these citations fall within the range of 10–64, five have less than 2 or none at all. It is worth highlighting that two of them are from 2023. The highest citation count, reaching 65, is associated with the article "Chemical and multi-physical characterization of agro-resources' by-product as a possible raw building material" [35] published in 2018.

Among the other authors listed in Fig. 9, including M. Charai, A. Mezrhab, D. Bajare, M. Sinka, M. Karki, and C. Maalouf, all have a local h-index of 5, except for D. Bajare with 4. However, outside of this specific context, their global h-indices range between 19 and 28, with the exception of M. Charai and M. Sinka, who have h-indices of 5 and 11, respectively.

Additionally, aside from author citations, another parameter to gauge an author's contribution in this field is the number of published documents and the impact those documents have had.

The number of citations is not the sole determinant of a document's impact, as there are instances where a document may have numerous citations but is not directly relevant to the topic. Therefore, examining the cited references provides a valuable indicator of a document's impact within the same research area. Cited references represent the documents that have been cited as references within the compilation of documents analysed in the research, which, in this case, includes the 1081 documents subjected to bibliometric analysis. Another noteworthy aspect of this indicator is that it can reveal documents that might not have appeared in the search results due to specific parameters or keyword selection issues but are nevertheless significant within the research area.

In this context, the number of citations can be assessed through two distinct parameters: global citations and local citations. Global citations encompass the total number of citations a document has received, irrespective of the research area or the source of the document. Conversely, the Biblioshiny software introduces an intriguing alternative known as local citations, which specifically counts the number of

citations within the subset of examined documents pertaining to the subject at hand – in this case, the 1081 documents analysed in this article. This new perspective provides a clearer view of the true impact of documents within the same research area. It allows for the identification of documents with the greatest influence on the subject matter and the discovery of impactful papers in this analysis.

Table 3 provides an overview of the top 10 most cited references within the documents analysed in this research. Leading the list is "A review of unconventional sustainable building insulation materials" authored by Asdrubali et al. [10]. This paper has exerted a profound influence on researchers engaged in this research area, as indicated by its frequent citation in subsequent studies.

Following closely is "Thermal conductivity of hemp concretes: Variation with formulation, density, and water content" by Collet and Pretot [36], a highly cited reference with 18 citations, underlining its significant impact on the subject matter. In this context, the article discusses the use of hemp as an aggregate in concrete, which is not directly aligned with the precise focus of this research study, as it pertains to the utilization of bio-materials as aggregates rather than as primary raw materials. Nonetheless, certain aspects of this article may offer valuable insights when juxtaposed with research that directly explores the use of such materials.

The third most cited reference is "Experimental study of parameters influencing mechanical properties of hemp concretes" [37] written by Arnaud and Gourlay, with a total of 14, far of the first ones with a total of 14 citations, notably fewer than the top-ranked references. Following closely, with just a one-citation difference, is "Determination of hygrothermal parameters of experimental and commercial bio-based insulation materials" [33] by Palumbo et al. Slightly below, with a total of 12 citations, is, "Life cycle assessment of a hemp concrete wall: impact of thickness and coating" [38] by Pretot et al. The subsequent references share the same number of citations, totaling 10, these include "Assessment of distilled lavender stalks as bioaggregate for building materials: Hygrothermal properties, mechanical performance and chemical interactions with mineral pozzolanic binder" [39] by Ratiarisoa et al., "Comparison of the hygric behaviour of three hemp concretes" [40] by Collet et al., and the last one "Moisture Buffer Value of Building material: A Review" [41] By Rode et al.

Regarding the article by Palumbo, it provides substantial information regarding the performance of certain bio-materials used as insulation materials, aligning closely with the central theme of this research. However, in the case of the subsequent two articles, the same situation applies to the previous article authored by F. Collet, their primarily focus on bio-materials used as aggregates rather than as primary building materials. Nevertheless, these articles could offer valuable insights in

**Table 3**

Top 10 publications with the most local citations, indicating the name of the document, the DOI, the author, as well as the year of publication and the total number of citations.

| DOCUMENT   | DOI                               | AUTHOR                     | YEAR | CITED REF. |
|--|-----------------------------------|----------------------------|------|------------|
| A review of unconventional sustainable building insulation materials   | 10.1016/j.susmat.2015.05.002      | F. ASDRUBALI et al.        | 2015 | 25         |
| Thermal conductivity of hemp concretes: Variation with formulation, density and water content  | 10.1016/j.conbuildmat.2014.05.039 | F. COLLET and S. PRETOT    | 2014 | 21         |
| Experimental study of parameters influencing mechanical properties of hemp concretes   | 10.1016/j.conbuildmat.2011.07.052 | L. ARNAUD and E. GOURLAY   | 2012 | 14         |
| Determination of hygrothermal parameters of experimental and commercial bio-based insulation materials   | 10.1016/j.conbuildmat.2016.07.106 | M. PALUMBO et al.          | 2016 | 13         |
| Life cycle assessment of a hemp concrete wall: impact of thickness and coating   | 10.1016/j.buildenv.2013.11.010    | S. PRETOT et al.           | 2014 | 12         |
| Assessment of distilled lavender stalks as bioaggregate for building materials: Hygrothermal properties, mechanical performance and chemical interactions with mineral pozzolanic binder | 10.1016/j.conbuildmat.2016.08.011 | R.V. RATIARISOA et al.     | 2018 | 11         |
| Comparison of the hygric behaviour of three hemp concretes   | 10.1016/j.enbuild.2013.03.010     | F. COLLET et al.           | 2013 | 11         |
| Moisture Buffer Value of Building Materials  | 10.1520/JAI100369                 | C. RODE et al.             | 2005 | 11         |
| Plant aggregates and fibers in earth construction materials: A review  | 10.1016/j.conbuildmat.2016.02.119 | A. LABOREL-PRÉNERON et al. | 2016 | 10         |
| The development history and prospects of biomass-based insulation materials for buildings  | 10.1016/j.rser.2016.11.140        | L. LIU et al.              | 2017 | 10         |

terms of measurement techniques or the characteristics of the bio-materials employed, which may still be pertinent to the research area.

In light of this rationale, the consideration of the source or origin of citations emerges as a critical factor in the research process. It plays a pivotal role in facilitating the acquisition of information that is not only relevant but also tailored to the specific nuances of the research area being investigated. Recognizing the provenance of citations becomes instrumental in discerning the most impactful and contextually appropriate literature, ensuring that the gathered knowledge aligns seamlessly with the intricacies of the subject matter.

Despite the efficacy of local citations as a valuable filter for identifying more pertinent documents within this thematic framework, it remains evident that, in certain instances, the primary objectives of the referenced articles extend beyond the exploration of biomaterials specifically for insulation. Some articles may prioritize investigations into the mechanical properties of materials or delve into comprehensive assessments of the life cycle dynamics, indicating the multidimensional nature of the research landscape. This observation underscores the need for a nuanced understanding of the motivations and focal points of individual research contributions within the broader context of the study's subject matter.

### 3.6. Keyword analysis

Keywords play a pivotal role in information retrieval, significantly influencing the quality of search results within a specific research area. Hence, it is imperative to master the skill of identifying the most appropriate keywords for each case. These keywords can be derived through various methods, either directly from the keywords selected by authors themselves, referred to as Author Keywords, or by employing automated algorithms in bibliographic software to identify frequently used words and phrases found in the titles of cited references. This automated process is known as Keywords Plus, which disregards their presence in the article's title or as Author Keywords.

In the context of this study, there were notable similarities between Author Keywords and Keywords Plus, as demonstrated in Fig. 10. However, distinctions also existed. Firstly, Keywords Plus encompassed a larger number of words compared to Author Keywords. Nevertheless, the top three keywords were nearly identical in both sets: "thermal conductivity" (constituting 9% of the keywords), "thermal insulation" (7–8%), and "mechanical properties" for Author Keywords, while "sustainable development" emerged as the leading term for Keywords Plus. Notably, "mechanical properties" did not appear until the 17th rank in Keywords Plus, showcasing a significant difference.

Another contrast was the repetition of similar words within Author Keywords, with minimal variation, such as "bio-based material" or "bio-based materials", "biocomposites" or "bio-composite", among others. In contrast, Keywords Plus exhibited a greater diversity of terms, with most words being distinct from one another. This diversity enabled a more

precise definition in each document.

An additional analysis of interest is the evolution of keywords, as depicted in Fig. 11. This analysis covers the years from 2014 to 2023, with this timeframe selected because of the limited number of articles published before 2014, which could make it more challenging to discern the evolution of keywords.

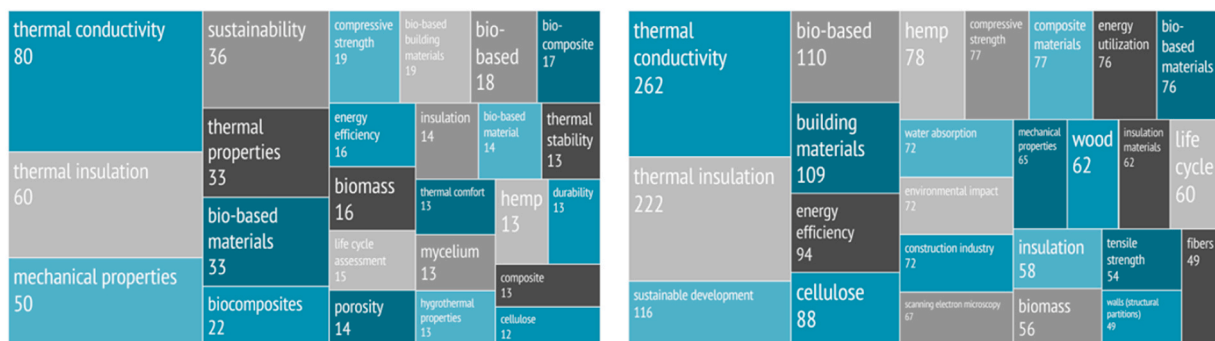
The image provides a visual representation of how the usage of keywords has evolved over time, reflecting the increasing specificity of the research focus within this field. In the initial years depicted in light blue, general terms like "bio-composites", "biomass", "chemistry", or "article" were prevalent. Gradually, as shown in the greenish-coloured circles, keywords became more refined, with terms like "mechanical properties" and "building materials" taking centre stage during this period. Around 2018, the keywords evolved further to include more precise terms such as "sustainable development", "thermal performance", and "hemp".

Moving closer to the present, the most frequently used keywords, highlighted in yellow, are directly related to material properties, notably "thermal conductivity" and "thermal insulation". Additionally, terms like "energy efficiency" and "energy utilization" are gaining importance. In the reddish-coloured section, which represents the most recent year included in this analysis (2023), standout keywords include "bio-based" and "building materials".

The evolution of keywords underscores the increasing specialization within this research area, with investigations branching into various subfields. However, it is worth noting that thermal properties continue to dominate the research landscape, even as the subject matter expands to cover a wider range of topics and areas of interest.

The properties that have been extensively studied, as revealed in the keyword analysis, primarily revolve around thermal properties. These include parameters such as conductivity, insulation, heat storage, heat transfer, specific heat, and more. Additionally, some articles have delved into the examination of mechanical properties, specifically focusing on attributes like compressive strength. Indeed, when examining the keyword frequencies in the documents, it becomes evident that acoustic properties and fire behaviour are relatively scarce topics in these publications.

The keyword related to acoustic properties, "acoustic wave absorption", is only found in the 42nd position with 37 occurrences. Similarly, "fire resistance" is the top keyword related to fire behaviour, but it ranks in the 38th position with just 21 occurrences. These observations underscore the limited attention given to acoustic and fire properties in the existing research on bio-based building materials. To gain further insights into this aspect, several modified searches were conducted within the selected database, Scopus. Instead of the original search query, "Bio AND (building or construction) AND material AND thermal OR acoustic OR fire", three distinct searches were executed, with each search focusing on only one specific property. These searches were as follows: 1. "Bio AND (building or construction) AND material AND thermal"; 2.



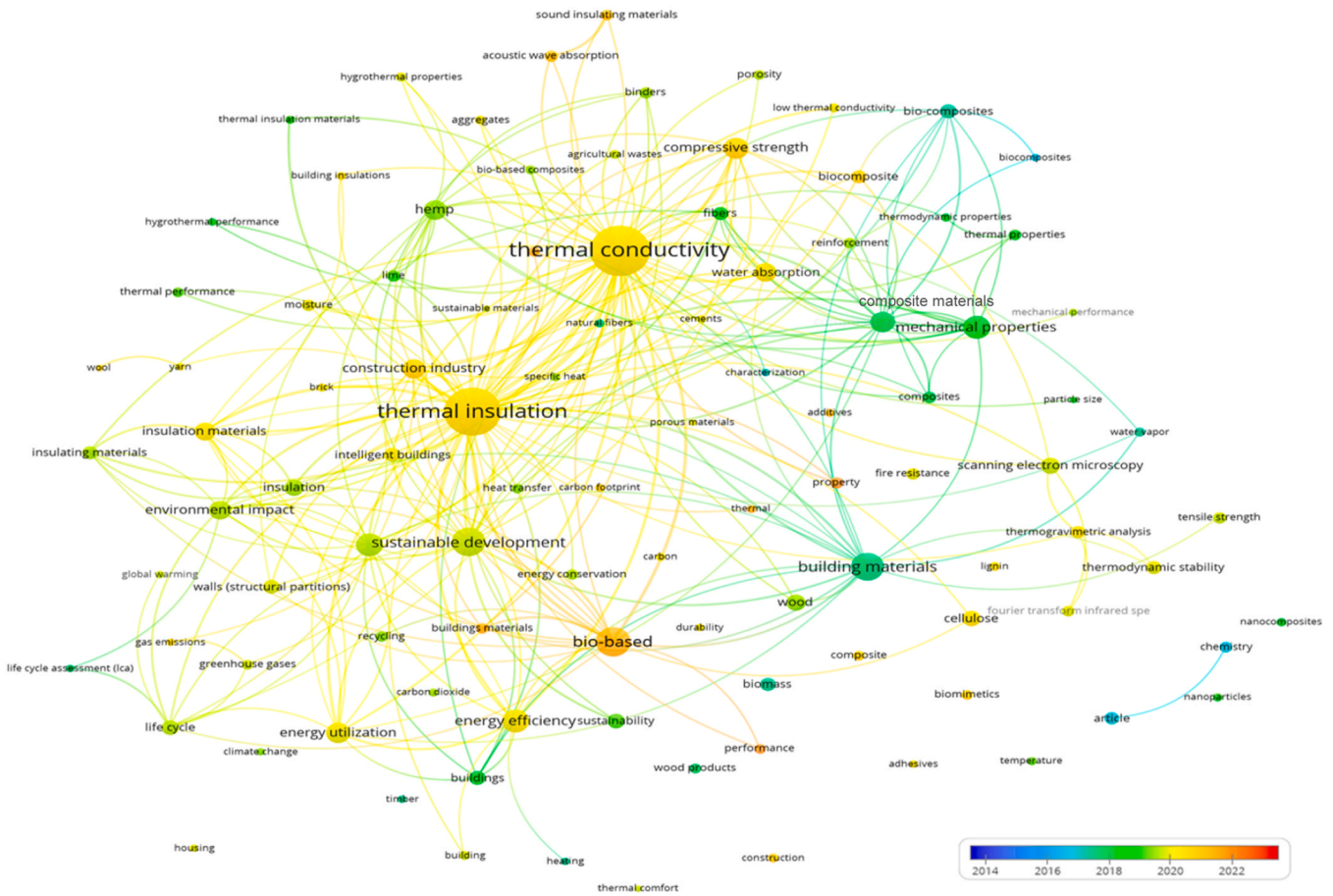


Fig. 11. Evolution of Carried out by VOSviewer software Keywords in the topic of bio building materials from 2014 to 2023, grouped into clusters and related to each other through the links shown.

“Bio AND (building or construction) AND material AND acoustic” and “Bio AND (building or construction) AND material AND fire”. The results of the searches are the next ones shown in Fig. 12.

The results of the search focusing solely on thermal properties, 965, comprise nearly the entirety of the results, accounting almost the 90% of the total publications. In contrast, documents related to acoustic and fire properties 157 represent a significantly smaller portion, with acoustic properties contributing 10.5% and fire properties accounting for 14.5% of the total publications. This indicates a considerable emphasis on research related to thermal properties in the field of bio-based building

materials, with relatively fewer studies dedicated to acoustic and fire properties.

4. Conclusions

The analysis presented in this study is crucial for comprehending the significance and global research progress in the field of bio-based materials specifically with thermal, acoustic and/or fire properties. The last two decades under examination have been marked by significant growth and an explosion of research activity, particularly since 2014, with an impressive annual growth rate of 25.2%. This current juncture presents an ideal opportunity to closely observe the research conducted and emerging trends within the field of bio-based building materials.

In the field of scientific journals, the research area of bio-based building materials has seen a proliferation of publications in various journals. However, one journal stands out, boasting nearly triple the number of publications compared to its closest competitor, and that is "Construction and Building Materials", which ranks in Q1 according to SJR, and has exhibited substantial growth in recent years. This journal's prominence is indicative of the increasing importance of research in this field. Additionally, the research areas associated with these publications have evolved and become more focused over time. Currently, the most prominent research areas are Engineering and Materials Science, reflecting a trend towards increasingly specialized and impactful articles.

Furthermore, it is worth noting that the subject of study in this paper has a global reach, with contributions from many countries around the world, underscoring its international significance and collaboration across borders. Nevertheless, France and China stand out prominently as

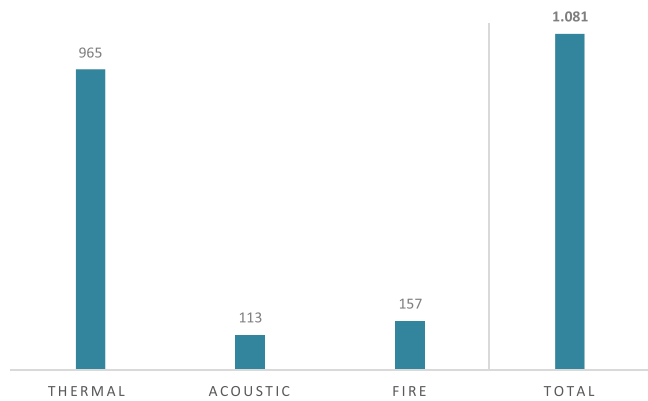


Fig. 12. Comparison of the results obtained from three different searches of “Bio AND (building or construction) AND material” and indicating in each case, thermal, acoustic or fire as the last filter.

the leading contributors, with 172 articles and 159 respectively, exhibit a notable contrast with the third one, Italy. This remarkable growth in contributions from France since 2016, and China in the last four years, has catapulted them to the forefront of bio-based building materials research. Significant international collaboration is observed, with France, the United Kingdom, and China being key collaborators with numerous countries. The overall international co-authorship rate is approximately 26.4%, indicating a global network of researchers in this field.

In the field of scientific affiliations contributing to the highest number of documents, France unsurprisingly takes the lead, with the CNRS (Centre National de la Recherche Scientifique) in Paris emerging as the most prolific institution. Interestingly, when assessing impact based on the average number of citations per publication, a nuanced perspective emerges. Although initially the CNRS seems to lead in terms of publication of documents, it is essential to note that in terms of relevance of the referenced articles in terms of citations obtained on average per publication, this falls strongly below the tenth position. In contrast, ETH Zürich and the University of Bath achieve average citation scores of 64.1% and 39.9%, respectively, which carry more relevance to the study's central theme. Notably, the University of Bath's citation distribution exhibits a remarkable degree of homogeneity, distinguishing it in terms of theme-related impact.

A significant number of authors, totalling 3622, have made contributions, with the majority having only a single publication. However, a distinct group of 23 authors stands out, having produced five or more documents, led by F. Collet with 14 articles and M. Charai with 13. It is important to note that an author's impact is assessed not only by their publication count but also by their h-index, which considers both productivity and citation influence. F. Collet holds the highest h-index at 9, backed by 357 citations across their work. Nevertheless, the significance of an article goes beyond its citation count, emphasizing its relevance to the research theme. Examining cited references reveals influential papers, with F. Asdrubali's "A review of unconventional sustainable building insulation materials" being the most impactful. These insights into authorship and citations offer a comprehensive view of the bio-based building materials research landscape, highlighting key contributors and influential works, thus guiding future research directions in this field.

Finally, the choice of keywords holds paramount importance in information retrieval within a specific research domain. This study highlights the critical role of keywords, which can be derived from Author Keywords or automated algorithms like Keywords Plus. While both sets exhibited notable similarities, Keywords Plus encompassed a larger vocabulary. Nevertheless, "thermal conductivity" and "thermal insulation" emerged as key terms in both sets. A temporal analysis revealed an evolution of keywords from general terms to more refined descriptors, reflecting the growing specialization in this research area. Thermal properties, including conductivity and insulation, dominate the keyword landscape, while topics like acoustic properties and fire behaviour receive comparatively less attention. This analysis informs researchers of the evolving landscape and highlights the research priorities within bio-based building materials, shedding light on areas where further exploration is warranted.

## Funding

This work was supported by the Spanish MCIN/AEI/10.13039/501100011033 through the research project BioSAFE (PID2020-117530RB-I00). Also, they want to thank the Generalitat de Catalunya for the quality accreditation given to the research group GICITED (2021 SGR 01405) and the European Union Erasmus+ Programme for the project Bio-Fibre (2022-1-DK01-KA220-HED-00086641). B. A-C, gratefully acknowledges receipt the financial support of the Spanish Minister scholarship: "Subprograma Estatal de Formación del Programa Estatal para Desarrollar, Atraer y Retener Talento,

en el marco del Plan Estatal de Investigación Científica, Técnica y de Innovación 2021–2023".

## CRediT authorship contribution statement

**Ana Maria Lacasta:** Writing – review & editing, Validation, Supervision, Funding acquisition. **Laia Haurie:** Writing – review & editing, Validation, Supervision, Funding acquisition, Conceptualization. **Brenda Arias-Cárdenas:** Writing – original draft, Software, Methodology, Investigation, Formal analysis.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data Availability

Data will be made available on request.

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