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Review

Building materials alternative approaches: A bibliometric and review approach

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Abstract: In this paper, we develop a global vision of environmental impact with alternative building materials in architectural design. A bibliometric study is based on 1827 scientific research publications on alternative materials produced between 1998 and 2022. More than 90% of these documents have been published in the last ten years. This bibliometric study goal is to develop a systemic approach for the characterisation of alternative solutions in the context of scarce resource context and climate change. This study highlights three different approaches: 1) an 'integrative' approach that develops an implementation approach combining environmental concerns and design teams' own working methods in the selection of materials; 2) an 'additive' approach that selects some environmental criteria (carbon footprint and energy consumption) in addition to implementation issues; 3) a 'subtractive' approach that focuses solely on implementation issues.

Keywords: building material; alternative material; environmental impact; systemic; bibliometry

1. Introduction

Increasing awareness of resource scarcity [1–3] and carbon footprints [4–6] has strongly impacted the building material choice. Several ways have been explored on ecological and environmental consequences of raw material selection, manufacturing processes, and waste management. The life cycle assessment methods have made it possible to specifically look at ecological and environmental building material impacts. In this context, the idea of using alternative building materials has emerged. Disparate definitions appearing in multiple references:

This approach aims at finding complementary materials with low GHG emissions in order to manufacture such building products as cement or concrete [7]. The definition of what a "conventional" material is depends to a great extent on the parameters. The daily professional practice, nevertheless, demands no special explanation on the issue of defining "conventional materials", since it is taken for granted. In a systematic way, the construction of small-to-medium-sized buildings for residential use is developed with a reinforced concrete structure, vitrified ceramic wallings, polyurethane or polystyrene foam insulation, aluminum or PVC window and door frames, ceramic floor finishing and parquet floors, chemical paintings, and interior wood treatment in PVC. (…) Other possibilities in the structure or load-bearing walls, such as wood, or the use of other materials naturally found, e.g., wood, cork, etc., have almost disappeared from the conventional construction and can only be found in very special cases [8] or Alternative building materials are increasingly being employed to replace the conventional and traditional building materials. In some parts, though not widely common, earth-based materials are modified with plant residues or animal dung to improve the durability and the architectural aesthetics [9].

In the absence of a comprehensive study on alternative materials, countless isolated experiments have featured in scientific publications. Today, syntheses are beginning to compile and analyse research work focusing on a material type, such as cement to remedy the impact of clinker manufacturing [10–12], concrete to question the substitution of raw material by agricultural or industrial waste [13–15], brick to question the carbon impact of baking during the terracotta manufacturing process or to study the location of raw material for raw earth construction [16], wood to compare the impacts of CLT manufacturing [17,18], or phase change materials to analyse energy gains [19,20], etc. These studies concern all types of construction systems (wall, floor, roof) with bearing [21,22], insulating [23,24] and protective materials [25,26]. They look at the architectural scale [27,28] to improve the environmental evaluation of buildings, or even the urban scale [29,30] with the challenges of the urban climate. Some of this research is part of a strong local implementation to develop an approach towards circular construction (economy, local resources, etc.).

Each of these works reveals a fragmented vision of the concept of alternative materials, without ever contextualising it on a more comprehensive scale.

The purpose of this article is to compile a large number of research publications on alternative materials in an attempt to develop a systemic approach. Faced with the disparity of situations and experiences, it is necessary to take into account the various interactions existing between them and their complexities to be able to identify alternative material characteristics, including their links to environmental issues and areas of construction.

To this end, the working method is oriented towards creating a corpus from scientific publications on alternative building materials and analysing it with bibliometric tools. Bibliometry is defined as the application of mathematics and statistical methods to books, articles, and other means of communication [31]. Here it is used in the form of mapping to visualise and interpret the networks of metadata relationships taken from the publications studied.

A bibliometric network consists of nodes and edges. The nodes may be for instance publications, journals, researchers, or keywords. The edges indicate relations between pairs of nodes. (...) Bibliometric networks are usually weighted networks. Hence, edges indicate not only whether there is a relation between two nodes or not but also the strength of the relation [32].

This work is in keeping with the bibliometric reviews of sustainable construction research [33] or the Building Information Modelling (BIM) [34,35].

2. Working method

This section describes the procedures used to identify research related to alternative building materials as well as the methods used to analysis the corpus from the scientific literature.

2.1. Corpus creation

A corpus has been compiled from documents extracted from the Science Direct database. This is Elsevier's main platform, containing peer-reviewed scientific papers with journal articles, books, book chapters, and conference articles. No start date has been specified, so that the oldest articles in the literature can be identified.

The search string 'building material' and 'alternative' has been entered in the search engine. The Science Direct platform identified 1998 documents. After analysing the summaries, some were excluded as they were not relevant to the theme. Once sorted, the final corpus includes 1827 publications on alternative building materials.

The following diagram shows the annual distribution of the number of publications since 1998, the date of the first listed publications in scientific fields, even if this topic is not new (1923) [36]. Between 1998 and 2001, this topic was rarely dealt with in scientific literature, as demonstrated in **Figure 1**, and it was really in the last ten years that the subject was developed (90% of the documents in the selected corpus).

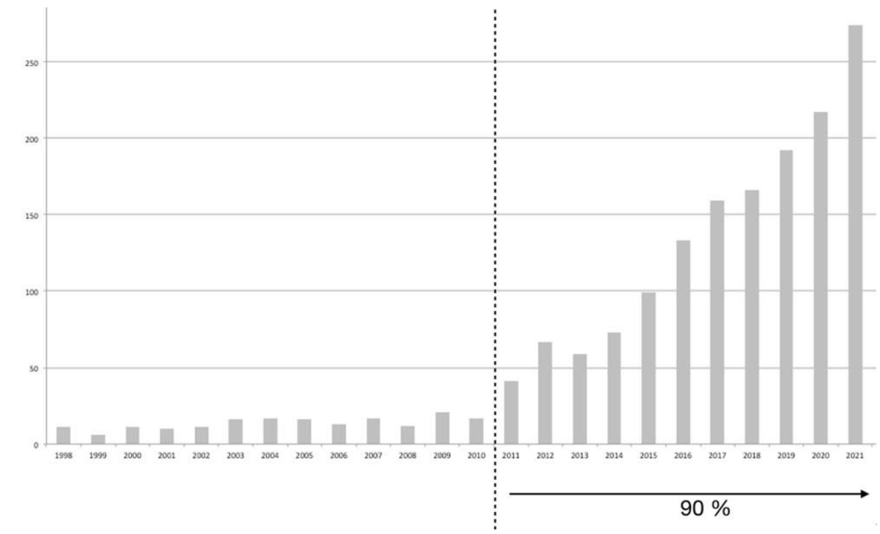


Figure 1. Annual distribution of the number of publications since 1998.

The corpus consists mainly of scientific articles (93%) and book chapters (7%), it counts 6677 authors of which less than 1% total a dozen different publications.

2.2. Corpus analysis

The corpus of 1827 documents contains bibliographic information, which is indexed by Science Direct. These 'metadata' include author names, titles, publication dates, as well as keywords and abstracts. To synthesise the knowledge production models in the corpus literature, bibliometric analyses were carried out using VOSviewer software [31].

VOSViewer software [32] enables the mapping and visualisation of this metadata in the form of maps from the bibliometric data of the corpus documents (authors, summaries, keywords, year of publication, etc.). If the size of the nodes represents the number of occurrences of the term studied, the distance between the different nodes is an indication of the proximity of the relationship between two terms [31]. The relationships between the keywords or by text analysis of the titles and abstracts of the articles of the corpus were then analysed.

A first study is based on the analysis of co-occurrences of keywords (co-word analysis) in VOSviewer. stated that ‘the number of co-occurrences of keywords indicates the number of publications in which the two keywords occur together in the title, summary, or list of keywords [of the documents of the examination database]’ [31].

Figure 2 represents the four clusters identified by analysing keywords of the documents in the corpus to visualise the similarities between the frequently co-occurring keywords.

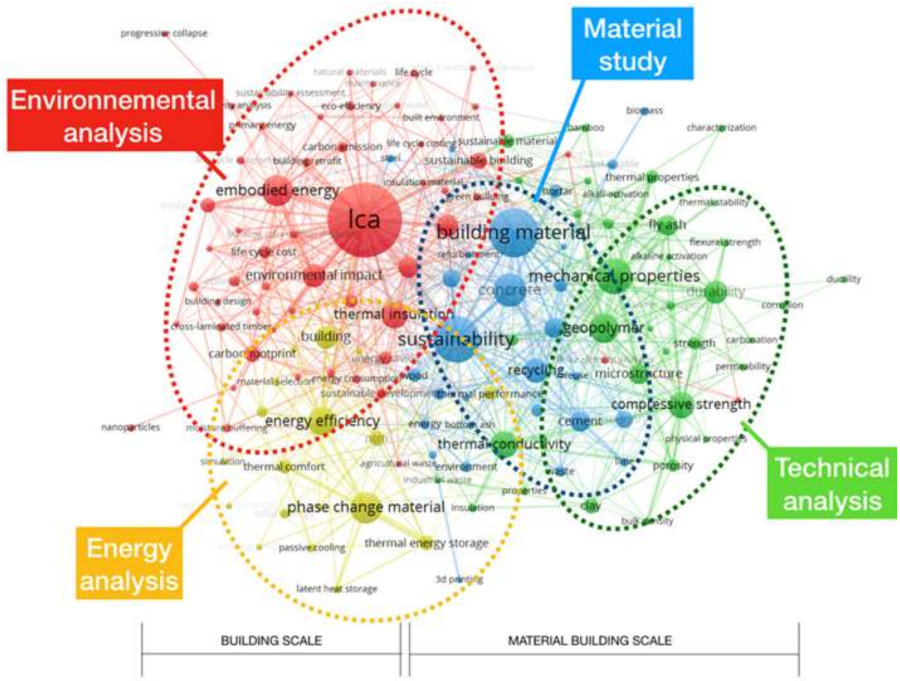


Figure 2. Four clusters identified by analysing keywords.

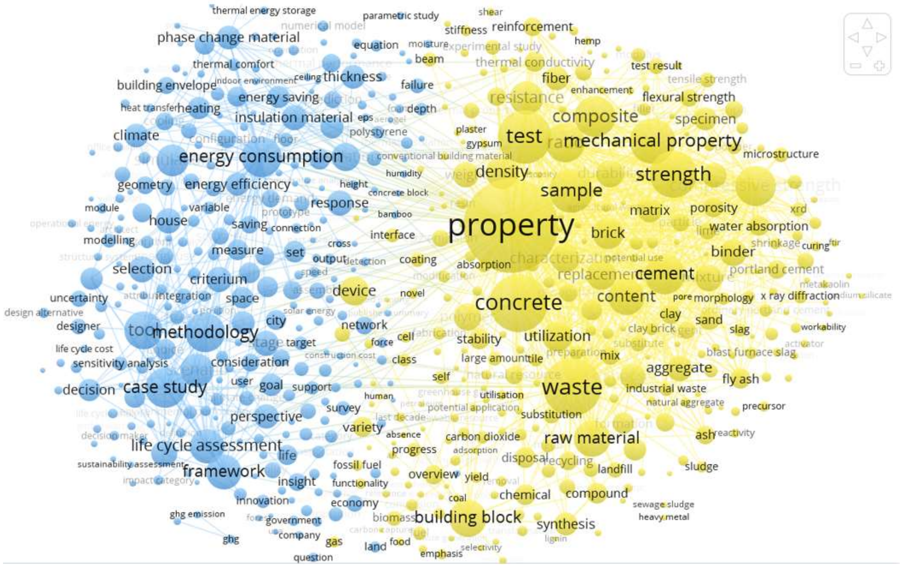


Figure 3. Textual analyses of the titles and summaries.

To complete the study, a textual analysis of the titles and summaries of the 1827 documents of the corpus was analysed using VOSviewer. This involved developing the mapping of recurring terms using the text analysis feature of VOSviewer, which is based on Apache's OpenNLP suite [31]. The following **Figure 3** highlights two clusters. This study makes it possible to be as close as possible to the work of the scientists by analysing their own terminologies.

The years of the weighted publications (average calculation) locate this research between 2014 and 2020. **Figure 4** highlights the homogeneity of the publication dates of this research and confirms the emergence of the recent proliferation of publications on alternative materials.

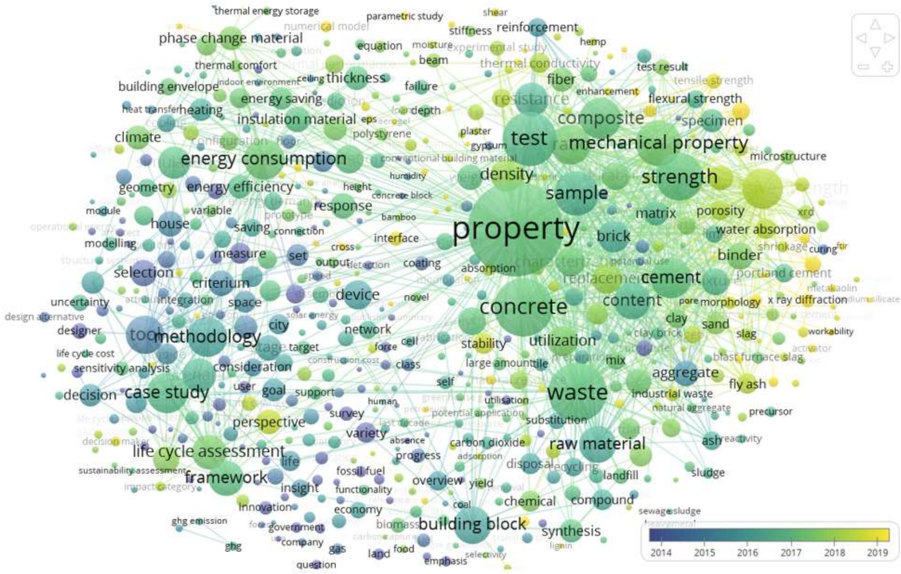


Figure 4. Homogeneity of the publication dates.

3. Results

This section describes the results of bibliometric analyses with thematic trends from keyword mappings supplemented by textual analysis of titles and abstracts.

3.1. Multi-criteria approach

Keyword mapping (**Figure 2**) suggests that literature on alternative building materials is primarily based on environmental, energy, and technical analyses.

The transversal term of this corpus is 'life cycle analysis'. It is positioned in the environmental analysis cluster. Many of the key words associated with environmental analysis are linked to evaluation criteria where computer simulation at the level of the shell and materials is used with economic issues. At a material level, reference is made to biobased materials [37,38], which represent the least processed materials and therefore have the least impact on environmental issues [39,40].

The cluster that refers to energy issues, and more specifically thermal approaches, is an identification of high-performance materials. The choice of materials and the use of computer software for building-scale simulations are also discussed. This research project step is characterised by the analysis of variants to consider the impact of each solution [41,42]. Generally, these studies are at the level of the building to interact with the choices of layout, morphology of the building, and also the choices of equipment (heating, ventilation, etc.).

As for the alternative materials studied (in blue), these are connected to the term 'sustainable'. This corresponds to the objective of the selection of this body of research, which is to demonstrate solutions and strategies for making environmentally friendly materials. This cluster is characterised by the combination of sustainable challenges (sustainability, environment, etc.) and the scale of construction materials according to their family (concrete, cement, brick, wood, steel, masonry, reuse, recycling, mortar, etc.) or raw material (composite, waste, bottom ash, rice husk ash, lime, etc.). The strategies employed vary between the use of agricultural waste recycling of aggregates [42,43] or the substitution of raw materials to manufacture new building materials, which can be biomimetic inspired to imagine new processes or the reuse of waste combination (recycling) [44]. These strategies aim to limit the extraction of resources such as sand [45] or aggregates and also to reduce the carbon footprint of materials. One of the most widely studied materials in this corpus is concrete. It is the subject of many variants with vegetable fibres [46,47], but in reality, it has above all an environmental impact from one of its components: cement. Its manufacturing process (clinker) [48,49] is particularly significant for greenhouse gas emissions.

Concrete studies are regularly associated with the use of more environmentally friendly geopolymers [50,51]. This association is on network mapping in connection with technical analyses (in green). This cluster mainly points towards the technical characteristics (mechanical properties, thermal conductivity, durability, compressive strength, microstructure, porosity, water absorption, permeability, strength, bulk density) intrinsic to building materials (clay, rammed earth, geopolymer concrete, bamboo, etc.) and their components (geopolymer, fly ash, portland cement, blast furnace slag, industrial waste, natural fiber, alkali-activation, etc.). It generally involves ensuring that substitutions of conventional raw materials by waste do not generate structural (solidity) disorders [52–54].

The mapping of key words in scientific documents highlights the need to cross environmental, energy, and technical criteria to develop knowledge of alternative materials. However, this mapping does not clearly establish the positioning of the links between alternative building materials and multidisciplinary approaches (environmental, energy, and technical).

3.2. Alternative materials approaches

Mapping based on textual data (titles and abstracts) of the 1827 documents in the corpus (**Figure 3**) highlights two clusters.

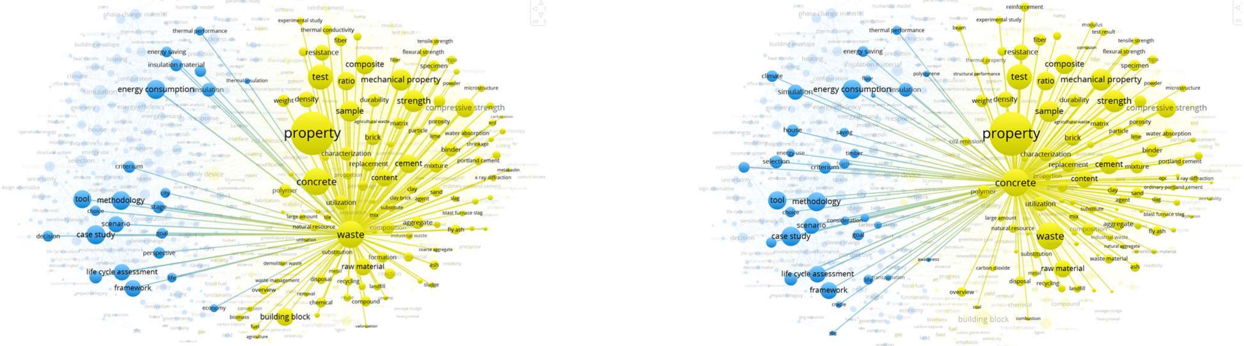
Environmental and climate issues are associated with methodological and analytical approaches (in blue). The aim is to identify the criteria (energy consumption, energy efficiency, thermal performance, indoor environment, life cycle assessment, climate change, etc.) and characteristics of working methods (methodology, scenario, selection, design alternative, etc.). Two approaches emerge: one from case studies (case study) and the other from sensitive analyses (sensitivity analysis) in the form of simulations to evaluate the performance of different constructive solutions. These studies are generally modelled using BIM-oriented software [55]. The mapping reveals questions involving the architectural context (geométry, orientation, variable, software, space, user, decision maker, company, etc.). This cluster represents the modalities of the design process, with its stakeholders (architects, users, designers, etc.), the uses of buildings (houses, residential buildings, office buildings, etc.), and the ideas of choice (selection, criteria, variable, etc.) of constructive systems (roof, floor, wall, envelope, etc.).

The second cluster focuses on the technical characteristics of building materials (brick, concrete, cement, lime, etc.) and raw materials (raw materials, fly ash, sludge, agriculture waste, etc.). It also contains the intrinsic characteristics of the materials (property, characterization, compressive, mechanical property, test, strength, water absorption, porosity, etc.).

From the mapping of the textual analysis (**Figure 3**), the following tables classify building materials and raw materials according to the number of links and their amplitudes (links between the two clusters or links internal to a cluster). These representations, classified by building materials and raw materials, represent trends from publications taken from the corpus studied. They do not make it possible to generalise, rather to identify a position of alternative materials in the face of environmental challenges and the operating methods of design teams when selecting building materials.

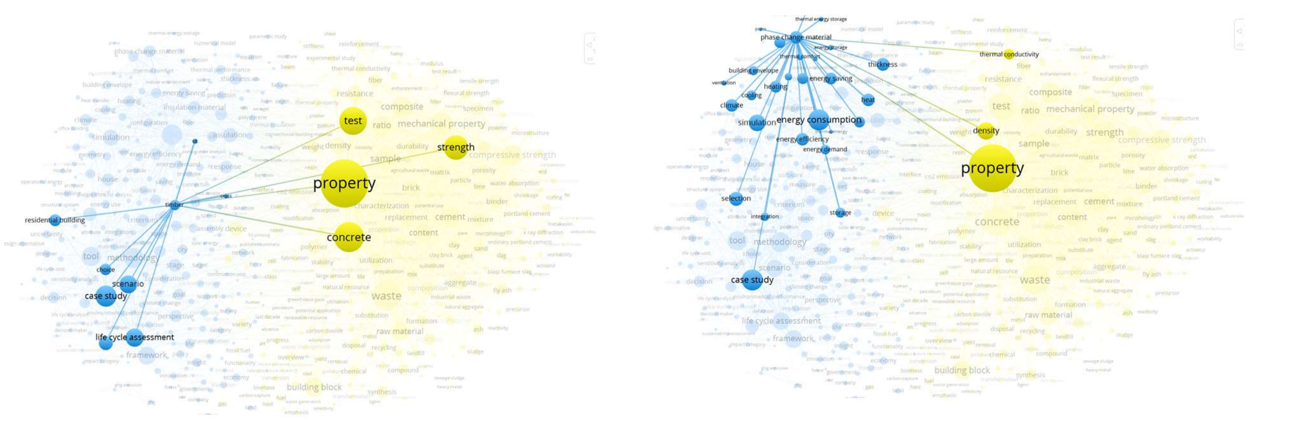
A first position is characterised by numerous links between the two clusters, this means the will to develop a comprehensive questioning that includes environmental issues and working methods specific to the project process. This approach can be called ‘integrative’ such as in **Figure 5**, as it develops the incorporation of a comprehensive vision of the issues relating to alternative materials. It is interesting to note that the most cited materials are concrete and waste. They are located in cluster 2 with the technical properties of the materials. While wood and phase change materials are positioned in cluster 1 with environmental issues.

A second approach presents links to the technical dimensions and some targeted links to the issues of Life Cycle Analysis within the choices of constructive solutions of shells for brick and of energy consumption and LCA for cement, unrelated to the working methods. This approach can be described as ‘additive’ such as in **Figure 6**, as these approaches superimpose environmental performance to improve a low carbon-impact score.



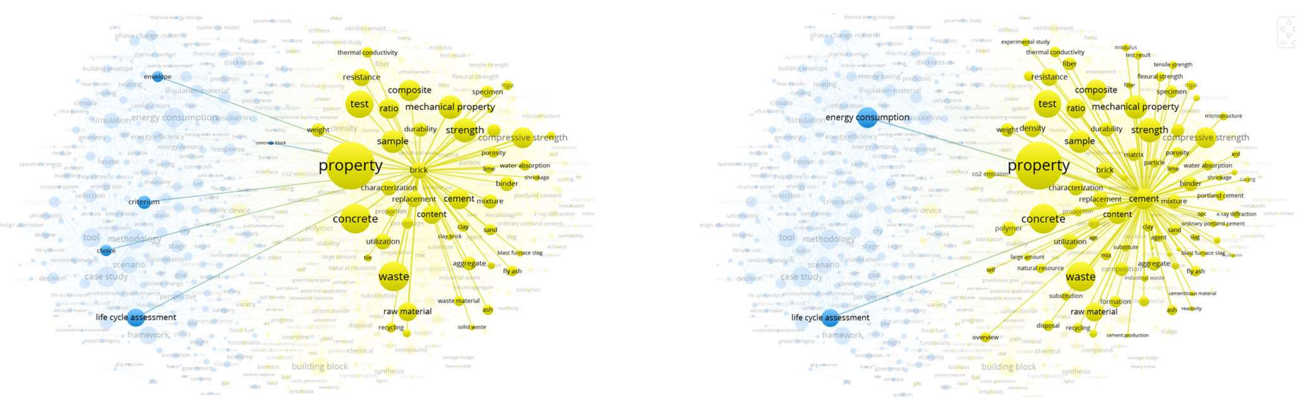
(a) **(b)**

Figure 5. (*Continued*).



(c) **(d)**

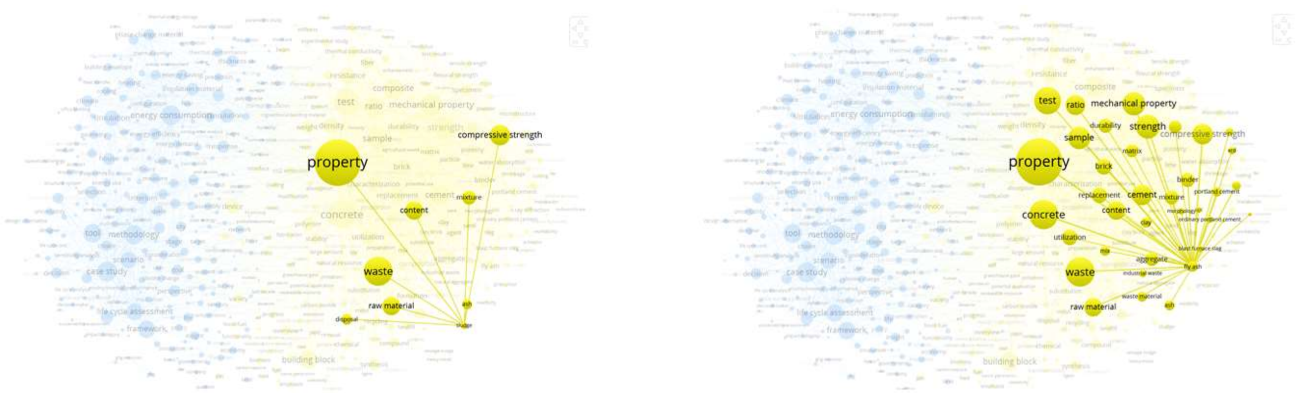
Figure 5. Integrative approach. **(a)** waste; **(b)** concrete; **(c)** wood; **(d)** phase change material.



(a) **(b)**

Figure 6. Additive approach. **(a)** brick; **(b)** cement.

Finally, a third approach shows analyses of materials or raw materials that focus solely on technical issues. This approach can be called ‘subtractive’ such as in **Figure 7**, as it obscures the environmental issues and the specificities of the architectural scale. This approach mainly involves raw materials that have a substitution role. This research is the most recent, which may explain the low number of redundancies.



(a) **(b)**

Figure 7. (*Continued*).

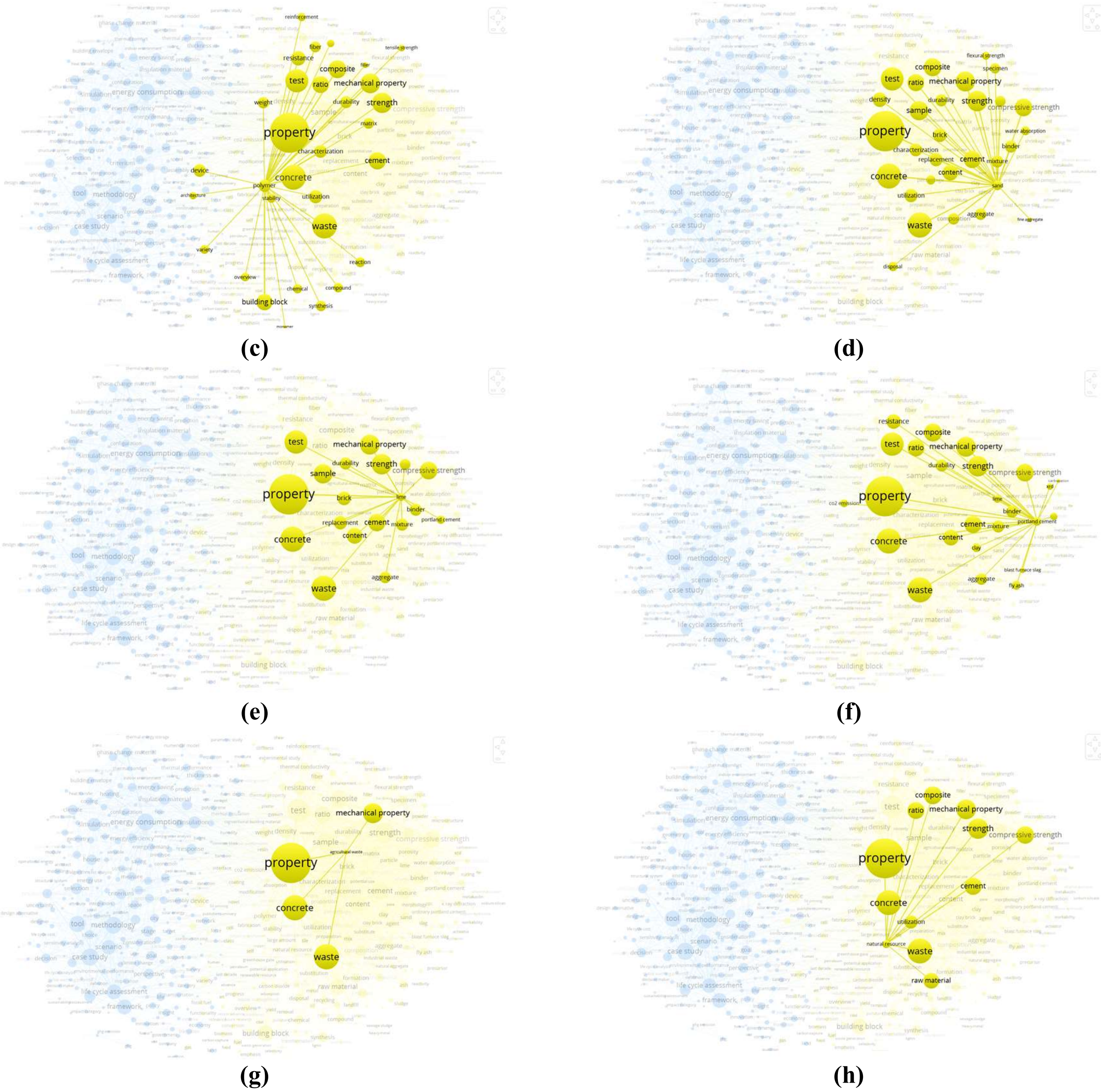


Figure 7. Subtractive approach. **(a)** mud; **(b)** fly ash; **(c)** polymer; **(d)** lime; **(e)** waste; **(f)** Portland cement; **(g)** agricultural waste; **(h)** natural resources.

4. Discussion

Using bibliometric analysis, this paper addressed the emergence of literature on alternative building materials. This section highlights the limitations and presents interpretations of the results.

4.1. Limitations of study

This study focused on the theme of 'alternative building materials'. The scope of this topic may have led to ambivalence in the selection of the documents that make up the corpus. A second limitation stems from our reliance on indexing Science Direct to source the documents, which impacted the availability of data. This study would have benefited from integrating documents from other platforms such as Google Scholar, Scopus, etc. In the absence of the exhaustiveness of the number of documents listed, the selection here focused on the quality of Science Direct publications with a peer selection.

4.2. Interpretation

This article generated a substantial foundation of knowledge and experiences on alternative building materials from 1827 documents indexed by Science Direct. The study showed that 90% of the documents in our corpus were published in the last ten years. An acceleration of publications emerged in 2010. This interest is linked to the climate context with the consideration of environmental issues [56] and their increasingly significant integration into building regulations. Also during this period, the development of databases on the LCA of building materials was strengthened [57], and computer tools integrating environmental simulations became widespread. The current context at the heart of the environmental, ecological, digital, etc. transitions suggests that an ever-growing number of publications on alternative materials will be developed in the coming years. Over the next decade, the number of publications could more than double in size. This reflects the rapid evolution of a new approach to improving building materials by reducing their environmental impacts within the architectural design process.

This study identified the positions on alternative materials in the face of environmental challenges and their integration into the architectural design process. This makes it possible to develop a comprehensive vision that identifies characteristics common to isolated experiments, generally classified by types of materials handled in a rather piecemeal fashion. The aim of the systemic approach proposal is to allow an understanding of current practices, to position the main issues and to anticipate their orientations. The definition of the three approaches (integrative, additive, and subtractive) shows that the aims of alternative materials are numerous. Each experiment defines its own scope of action. In this context, it is not appropriate to transcribe a generic definition of an alternative material but rather to identify the different positions and issues. The aim is to determine the environmental, social, and economic significance of the manufacture of alternative materials in a given territory. It is not because it is an alternative material but that it in fact participates in a greater ambition for sustainable development, introduced in 1987 by the Brundtland report (Our Common Future), which defines it as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [58].

Some approaches, such as integrative approaches, seek a territorial anchorage to develop a circular economy [59], working with local stakeholders, working for a building that respects the environment, both in the choice of layout (orientation, sunshine, etc.) of morphology (thermal efficiency, material economy, etc.) of materiality (performance levels of walls, LCA, etc.). These approaches are evolving towards a paradigm shift, with societal issues placing climate and environmental issues at the centre of design.

Additive approaches are firmly rooted in today's society. They involve changing existing materials to improve their environmental scores. Today, two criteria are particularly important: the carbon factor and energy consumption. The manufacture of these materials meets future regulatory requirements while maintaining the current operating modes. Finally, subtractive approaches are in keeping with additive approaches, as they focus on the ability to substitute energy-intensive raw materials and/or materials with a large carbon footprint with less impactful raw materials (waste, bio-based materials, etc.). These two positions raise the question of the close link between the choices of environmental performance expressed by future regulations and the orientation of the alternatives studied. For example, the inclusion of the 'carbon sink' phenomenon in the calculation of LCAs for construction materials has largely encouraged the addition of avengeable fibres or agricultural waste in the composition of bricks, concrete, etc. without, however, studying the real impact of supplying these raw materials, such as their transport.

5. Conclusion

This study has rigorously examined the potential and challenges of alternative building materials through a detailed bibliometric analysis of 1827 publications. We have uncovered that while these materials promise significant environmental benefits, integrating them into mainstream construction practices presents substantial hurdles. These challenges span technical feasibility, economic viability, and regulatory acceptance, each of which requires dedicated solutions to overcome.

Our findings reveal that the adoption of alternative materials is not merely a technical decision but a reflection of broader societal values and commitments toward sustainability. The integrative, additive, and subtractive approaches each map out different pathways for incorporating ecological considerations into building practices, influencing the industry's evolution toward sustainability. These approaches are indicative of the depth of systemic change needed—a shift that involves rethinking not only materials but also the frameworks within which they are used.

To navigate these complexities, we advocate for strengthened collaborations that bridge the gap between research and industry, underpinned by robust partnerships among scientists, industry experts, and policymakers. We emphasize the critical role of education and policy reform in fostering a culture that is receptive to innovative, sustainable materials. Incentives should be strategically designed to support the adoption of these materials, ensuring that they are not only technically and economically feasible but also aligned with regulatory frameworks.

Looking ahead, it is imperative that future research focus on creating adaptable frameworks for the practical application of these materials, considering economic, logistical, and scalability factors. Understanding their performance across different environmental and geographic conditions will also be crucial. Bibliometric studies are essential for providing the necessary perspective on ongoing developments, allowing us to position and reposition challenges within an informed context.

Ultimately, the integration of innovative building materials into the construction industry is essential for meeting global sustainability goals. It requires a concerted effort that spans multiple sectors and disciplines. By committing to this comprehensive approach, we can lay the groundwork for a construction industry that not only adapts to but also thrives in the face of ecological challenges, paving the way for a more sustainable future for generations to come.

Conflict of interest: The author declares no conflict of interest.

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