A Systematic Analysis on the Applications of Local Materials in Civil Engineering

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Abstract. This article presents a comprehensive bibliometric analysis of the utilization of local materials in civil engineering projects, examining their role in fostering sustainable construction practices. Through a systematic review spanning from 2004 to 2024, the study delves into various dimensions of sustainability within civil engineering, emphasizing the critical importance of employing local materials. It underscores the environmental, economic, and socio-cultural benefits of integrating local resources into construction, while also highlighting the challenges associated with their variability, limited availability, and the need for standardized testing. The methodology involves a detailed bibliometric analysis, including data collection from prominent databases, and employs bibliometric software for data analysis, focusing on identifying key trends, research gaps, and emerging themes in the domain. The results reveal a stable annual growth rate in publications, with a significant emphasis on conference papers, indicating an active discourse within academic and professional forums. The study identifies China as a leading contributor to research in this area, showcasing a global interest with varying degrees of focus. Additionally, the analysis of keyword co-occurrences maps out the central research themes, reflecting a strong integration of traditional civil engineering concerns with modern sustainability challenges. The conclusion advocates for a continued emphasis on sustainable building practices, integrating local materials as a fundamental component of civil engineering projects to enhance environmental outcomes and societal value.

1. Introduction

In the evolving landscape of civil engineering, the pursuit of sustainability has become a paramount objective, steering the industry toward innovative practices and materials. Amidst this paradigm shift, the utilization of local materials emerges as a cornerstone strategy that promises to reconcile the dual imperatives of environmental stewardship and economic viability [1-8]. This article embarks on a systematic exploration of the applications of local materials within civil engineering, underpinned by the broader context of sustainable development goals (SDGs) and the imperative for reduced carbon footprints in construction projects.

The significance of local materials in civil engineering transcends mere cost-efficiency; it encompasses a multifaceted spectrum of benefits, including the reduction of transportation emissions, support for local economies, and the enhancement of the socio-cultural relevance of constructed spaces [9-17]. Moreover, the adoption of local materials aligns with global sustainability objectives, offering a pathway to more resilient and environmentally harmonious infrastructure [18-24]. However, despite their apparent benefits, the integration of local materials into mainstream construction practices encounters a myriad of challenges. These include variability in material properties, limited availability, and a dearth of standardized testing protocols, which collectively hinder their widespread adoption [25-29].

This article aims to dissect these complexities through a comprehensive analysis that bridges theoretical perspectives with empirical insights. By weaving together a rich tapestry of case studies, literature reviews, and comparative analyses, we endeavor to illuminate the multifarious dimensions of local materials' applications in civil engineering. Our objectives are twofold: to catalog the current state of knowledge surrounding the use of local materials and to unearth innovative practices that could foster their broader integration into civil engineering projects.

In charting this inquiry, we not only contribute to the academic discourse but also offer pragmatic insights for practitioners, policymakers, and stakeholders vested in the sustainable evolution of civil engineering. The scope of our analysis encompasses a broad spectrum of local materials, from traditional resources like stone and timber to innovative composites and recycled products. Through this exploration, we seek to underscore the potential of local materials as catalysts for sustainable development, advocating for a reimagined approach to construction that prioritizes environmental integrity, economic sustainability, and social equity.

2. Theoretical Framework

2.1 Sustainability in Civil Engineering

Sustainability in civil engineering is a multifaceted concept that encompasses environmental, economic, and social dimensions [30-37]. The Brundtland Commission's definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" serves as a guiding principle for sustainable civil engineering practices [38, 39].

Within this context, sustainable civil engineering aims to minimize environmental impacts, optimize resource use, and maximize social welfare through the lifecycle of infrastructure projects [1, 40, 41]. This section will delve into the key principles of sustainability in civil engineering, including the reduction of greenhouse gas emissions, conservation of natural resources, and the enhancement of community resilience and adaptability.

2.2 Overview of Local Materials

Local materials refer to construction materials that are sourced and processed within close proximity to the construction site [42]. These materials can range from natural substances like stone, wood, and clay, to be recycled and upcycled materials such as reclaimed timber and crushed concrete.

The utilization of local materials is not a novel concept; however, its resurgence in contemporary civil engineering is propelled by the sustainability movement [43-45]. This subsection will provide a comprehensive classification of local materials commonly employed in civil engineering, highlighting their inherent properties, sources, and processing methods [46-48].

2.3 Advantages and Challenges

The use of local materials in civil engineering presents a constellation of advantages and challenges that influence their adoption in construction projects.

- **Advantages:**
  - Environmental Benefits: Reduced transportation distances lead to lower carbon emissions and a smaller environmental footprint.
  - Economic Benefits: Supporting local economies by creating demand for locally sourced materials and labor.
  - Socio-cultural Benefits: Materials that are indigenous to a region can enhance the cultural significance and aesthetic integration of structures within their local context.

- **Challenges:**
  - Material Variability: Local materials can exhibit significant variability in quality and properties, necessitating comprehensive testing and standardization.
  - Availability: The availability of specific local materials can be limited by geographic and seasonal factors, potentially impacting project timelines.
  - Technical Limitations: There may be constraints regarding the structural capabilities and durability of certain local materials, requiring innovative engineering solutions or hybrid material approaches.

3. Methodology

3.1 Bibliometric Analysis Overview

Bibliometric analysis is a statistical method used to quantitatively assess academic literature, allowing researchers to explore the development, structure, and dynamics of scientific fields over time [49, 50]. By applying bibliometric techniques, this study aims to systematically review and analyze existing research on the applications of local materials in civil engineering. This approach will enable the identification of influential studies, emerging trends, and research gaps within the domain [51, 52].

3.2 Data Collection

The analysis will commence with the identification of relevant databases for sourcing academic publications. Key databases will include Web of Science, Scopus, and Google Scholar, known for their comprehensive coverage of engineering and sustainability literature [51].

A structured search strategy will be developed, employing a combination of keywords and Boolean operators to capture publications related to local materials in civil engineering. Keywords will include "local materials," "sustainable construction," "civil engineering," and specific types of local materials.

Criteria for including and excluding studies will be established to ensure relevance and quality. Inclusion criteria will encompass peer-reviewed articles published in English, with a focus on the application of local materials in civil engineering projects. Exclusion criteria will exclude non-peer-reviewed sources, articles not focusing on local materials, and studies outside the field of civil engineering.

3.3 Data Analysis

Bibliometric analysis will be conducted using specialized software such as VOSviewer or CiteSpace. These tools facilitate the visualization of bibliometric networks, including co-citation, co-authorship, and keyword co-occurrence analyses [53].

Network analysis will be employed to identify clusters of research, key authors, institutions, and countries contributing to the field. This will highlight the most influential studies and reveal the structure of academic collaboration.

Trend analysis will focus on identifying emerging topics and trends over time. By analyzing patterns in keyword usage and citation rates, we will pinpoint areas of growing interest and potential directions for future research.

3.4 Ethical Considerations

The study will adhere to ethical guidelines for bibliometric research, ensuring the responsible use of academic publications and data. The analysis will respect copyright laws and intellectual property rights, citing all sources appropriately.

4. Results

The bibliometric data obtained encapsulates two decades of scholarly output from 2004 to 2024, revealing a collection of 233 documents published across 137 sources, such as journals and books (Table 1). Despite the breadth of literature, the analysis indicates an annual growth rate of 0%, suggesting a steady state in the volume of published works over the years. The documents exhibit a moderate citation impact with an average of approximately 26.61 citations per document, although the total number of references is not specified. The scholarly discourse is reflected through 2513 Keywords Plus (ID) and 755 Author's Keywords (DE), indicating a diverse range of themes and focal points. The authorship pattern includes 678 authors with a small portion (14) contributing single-authored documents, denoting a collaborative field with multiple contributors.

For highest types of published documents are Conference Papers, accounting for 47.2% of the total, suggesting that this field is actively discussed in conference settings, which often serve as venues for presenting cutting-edge research (Fig. 1). Articles make up the second largest category with 39.5%, indicating a substantial contribution to peer-reviewed journals. The remaining types of documents—Conference Reviews (8.6%), Reviews (2.6%), Books (0.9%), and Book Chapters (0.9%)—comprise a smaller fraction of the corpus, while Editorials are the least represented at 0.4%. This distribution underscores a dynamic field where new research is frequently shared in academic and professional gatherings, while also being solidified through peer-reviewed articles and to a lesser extent, through more in-depth reviews and books.

Table 1. Main informations.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2004 : 2024
Sources (Journals, Books, etc)	137
Documents	233
Annual Growth Rate %	0
Document Average Age	9,17
Average citations per doc	26,61
DOCUMENT CONTENTS	
Keywords Plus (ID)	2513
Author's Keywords (DE)	755
AUTHORS	
Authors	678
Authors of single-authored docs	14

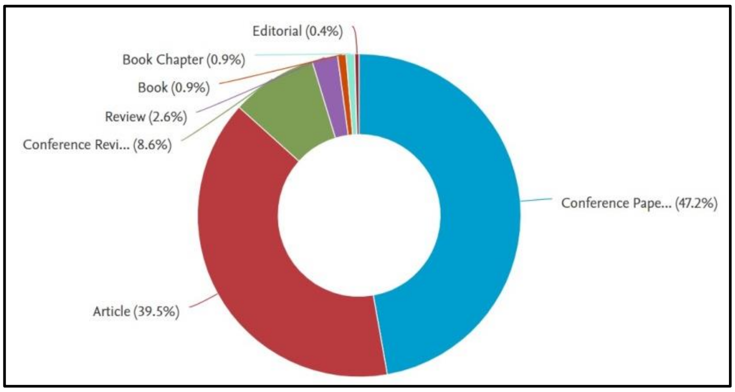

Fig . 1. Documents by type.

The graph portrays a fluctuating trend in publications on local materials in civil engineering from 2004 to 2024, with peaks around 2012 and 2024, suggesting varying research focus and interest over the two decades. Following 2012, there's a sharp decline, but the number of documents recovers somewhat, showing variability in subsequent years. The pattern is not consistently upward or downward but fluctuates, indicating that interest or research activity in the applications of local materials in civil engineering might be influenced by external factors or cyclical trends in the field.

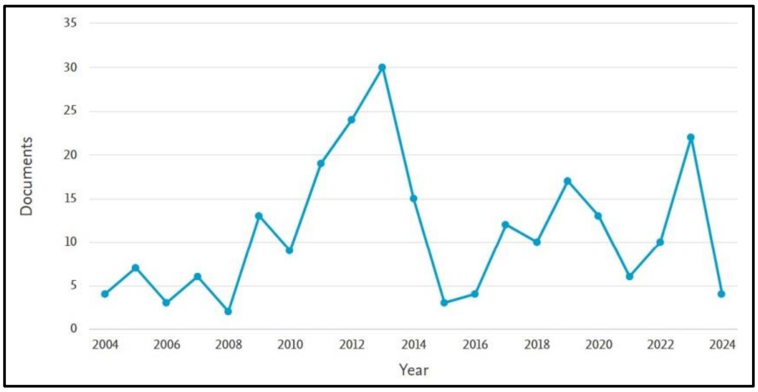

Fig . 2. Documents by year.

Fig. 3 categorizes documents by subject area, highlighting the interdisciplinary nature of research into local materials in civil engineering. Engineering dominates the chart with exactly half of the documents, underscoring its central role in this field of study. Materials Science also constitutes a significant portion at 18%, reflecting the importance of understanding material properties and applications. Smaller segments are represented by other disciplines like Computer Science (7.2%), Physics and Astronomy (5.8%), and Environmental Science (5.3%), suggesting that the topic intersects with these areas, potentially in aspects such as computational modeling, physical properties analysis, and environmental impact assessment. Notably, even fields traditionally distant from engineering, such as Mathematics, Chemical Engineering, Social Sciences, and Energy, have contributed to the body of literature, indicating a rich, cross-disciplinary dialogue that surrounds the application of local materials in civil engineering. The 'Other' category captures the remaining 2.4%, which might include niche fields or emerging areas of research not explicitly listed.

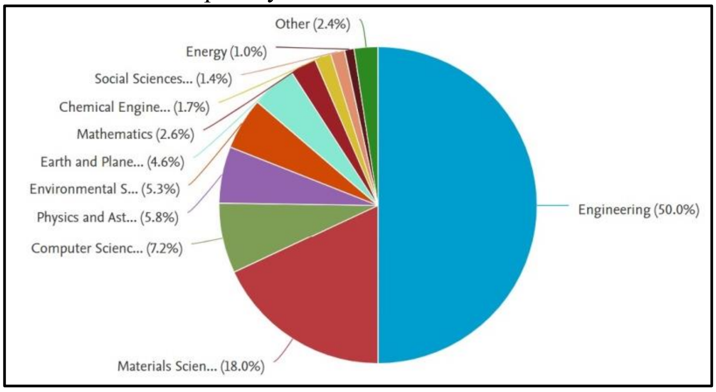

Fig . 3. Documents by subject area.

Fig. 4 visualizes the publication output of 15 authors in the domain of local materials and their applications in civil engineering. Smith, B.H. is the most prolific, with over 6 documents, followed by Hajjar, J.F., who has contributed around 4.5. The chart shows a descending order of productivity, with several authors like Arulrajah, A., Ou, J., and Yu, Y. in the mid-range, and others such as Horpibulsuk, S., and Piratheepan, J., with fewer publications. The varying bar lengths clearly illustrates a disparity in document production among the authors, suggesting differences in their research activity levels or prominence within the field.

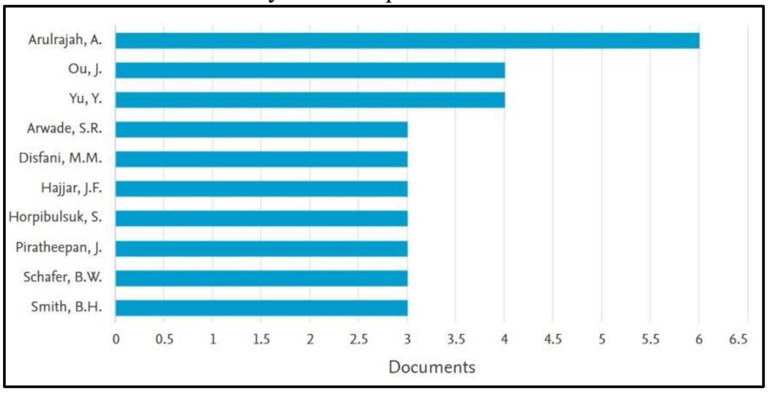

Fig . 4. Most relevant authors.

Fig. 5 compares the most relevant institutions. It appears that the Ministry of Education of the People's Republic of China leads significantly, with close to 8 documents, which could indicate a strong research emphasis or funding in local materials and their applications in civil engineering. Dalian University of Technology and Swinburne University of Technology follow each contributing just under 7 documents. Other institutions, including Southeast University and Harbin Institute of Technology, show a moderately high output. Meanwhile, Tsinghua University, Johns Hopkins University, and the remaining listed institutions contribute fewer documents, with the University of Massachusetts Amherst at the lower end. The distribution of documents across these affiliations highlights where research in this field is most active.

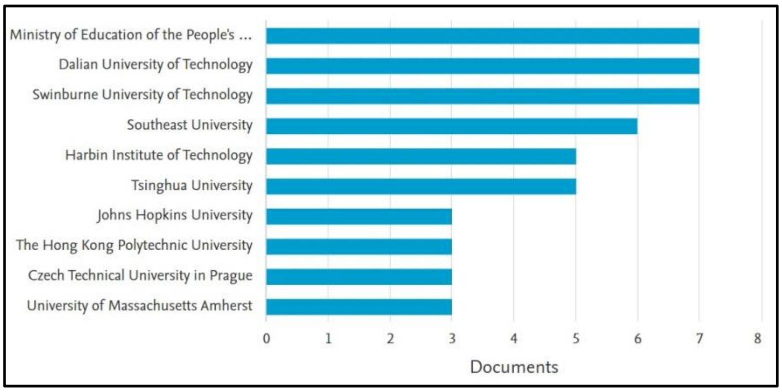

Fig . 5. Most relevant affiliations.

Fig. 6 displays the publication trends of five sources in the fields of local materials and their applications in civil engineering from 2008 to 2023. Advanced Materials Research peaked sharply around 2010 with over 10 documents but then dropped and remained relatively inactive. Geotechnical Special Publication shows sporadic activity, peaking at 4 documents in 2011 and dipping to 0 by 2023. Applied Mechanics and Materials appear to have a consistent but low level of publications throughout the years. Construction And Building Materials shows an upward trend starting from zero in 2008 to a steady output from 2019 onwards. Lecture Notes In Civil Engineering maintains a very low profile throughout the period, with negligible contribution. Overall, Advanced Materials Research and Construction and Building Materials are the most prominent sources, indicating their significant role in disseminating research in this field.

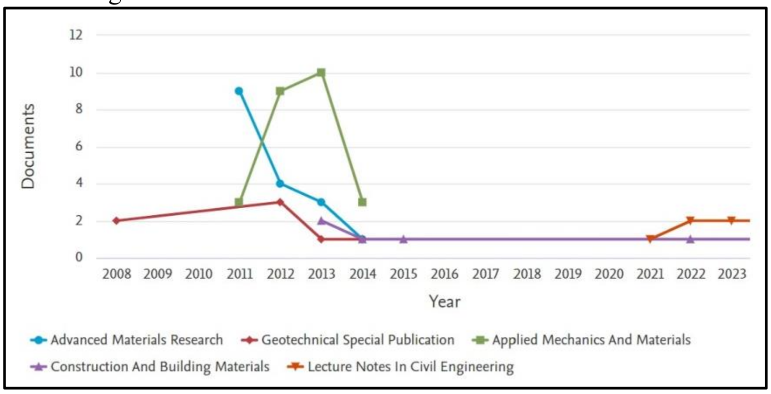

Fig . 6. Most relevant sources.

Fig. 7 shows the number of documents produced in the field of local materials and their applications in civil engineering by different countries. China leads by a significant margin, with around 65 documents, indicating a major contribution and possibly a strong research focus in this area within the country. The United States follows with about 20 documents, while Italy and Australia are close competitors with slightly fewer contributions. France, Germany, and the United Kingdom also show meaningful output. The remaining countries—Brazil, Canada, and India—have the fewest documents, suggesting they have a smaller presence in this research domain. The chart highlights the global spread of research in this field, with China's dominance suggesting a substantial investment or interest in local materials and civil engineering research.

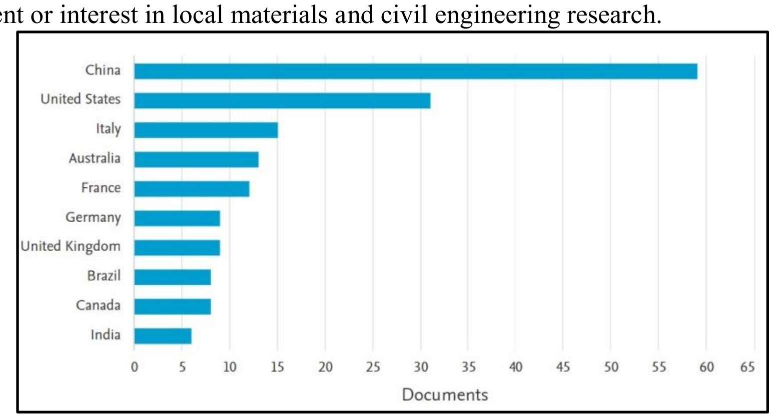

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Fig . 7. Most relevant Countries.

Fig. 8 a network map generated by VOSviewer, which is commonly used for analyzing co-occurrences of keywords within a particular field of research. In this case, the field is local materials and their applications in civil engineering. In the network, each node represents a keyword, and the size of a node indicates the frequency of the keyword's occurrence in the literature. Lines connecting the nodes represent co-occurrences, meaning the two keywords appear together in the same documents. The proximity of the nodes to one another suggests a stronger or more frequent association between the terms.

The central and largest node is "civil engineering," which acts as a focal point, indicating that it's the main subject of the research. Surrounding it are nodes such as "structural analysis," "building materials," and "finite element method," which are prominent topics within civil engineering research. The clusters of nodes in different colors represent subthemes or closely related topics: for instance, a cluster may focus on structural materials (like "concrete" and "steel"), while another might center on sustainable practices ("recycling," "sustainable development"). Clusters often imply interdisciplinary research areas where civil engineering overlaps with other fields like environmental engineering or materials science. Keywords such as "environmental engineering" and "sustainable development" suggest a focus on sustainability in civil engineering.

From this network map, one can infer that the most researched and discussed topics in this field are related to materials (like concrete and steel), structural considerations (like stiffness and reinforcement), and sustainability. This indicates an integrated approach to civil engineering that balances practical structural concerns with sustainable development goals.

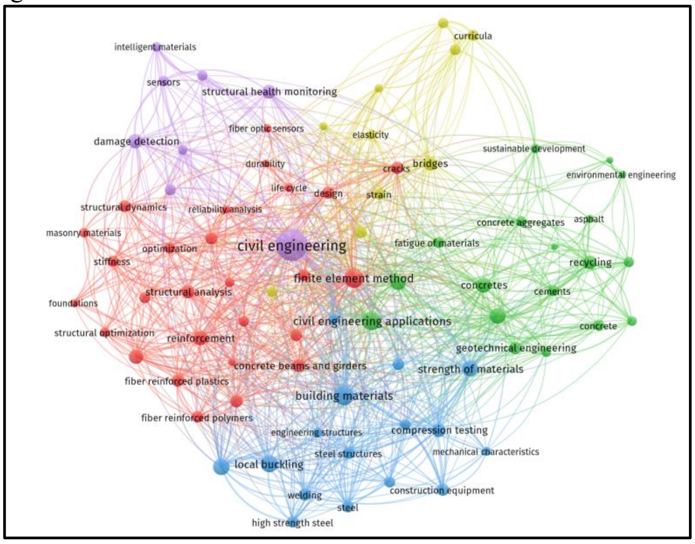

Fig . 8. Keywords co-occurrences.

5. Discussions

The bibliometric data spanning two decades reflects a field of civil engineering that is stable in terms of publication output, yet influential in academic circles. The average citation count per document suggests that, although the volume of research has not grown, the contributions made have resonated substantially within the scholarly community. This is indicative of a mature field where foundational work has been established and incremental advances are the norm. The authorship pattern reveals a robust culture of collaboration within the field. The prevalence of multi-authored papers over single-authored ones underscores the complexity and interdisciplinary nature of civil engineering research, necessitating diverse expertise. This collaborative trend is a positive indicator of healthy academic exchange and collective advancement in understanding and innovating with local materials.

The distribution of document types sheds light on the communication preferences within the community. The prevalence of conference papers highlights the field’s dynamism, with professionals and academics frequently engaging in forums to discuss evolving research and practical advancements. The substantial proportion of journal articles solidifies the field's commitment to rigorous, peer-reviewed research, ensuring that findings are thoroughly vetted before being added to the body of knowledge. Interdisciplinarity is a standout feature in the field's research output, as evidenced by the broad range of subject areas intersecting with civil engineering. This suggests that advancements in civil engineering are increasingly reliant on cross-disciplinary knowledge, from the material sciences that inform the properties and uses of construction materials to computer science, which contributes through computational models and simulations.

The analysis of key contributors—both individual authors and institutions—reveals centers of research excellence and possible funding patterns. The prominence of certain authors and the lead of specific institutions, like the Ministry of Education of the People's Republic of China, may reflect areas of specialized knowledge or increased investment in research and development.

Geographically, the dominance of China, with a substantial margin of document production, reflects the country's intensive focus and potential prioritization of civil engineering research. The contributions from other countries, such as the United States, Italy, and Australia, point to a global interest in the field, although with varying levels of intensity and focus.

Lastly, the keyword co-occurrence map offers a visual representation of the research themes' interconnectivity within the field. The central positioning of "civil engineering" with surrounding nodes like "structural analysis" and "building materials" indicates core research areas. The clusters around "sustainability" reflect a growing research niche that aligns with global trends towards sustainable development. This map serves as a testament to the field's evolving nature, showcasing the blend of traditional civil engineering concerns with modern environmental and sustainability challenges.

6. Applications of Local Materials

The utilization of local materials in civil engineering spans various applications, both structural and non-structural, highlighting the versatility and innovative potential of these resources.

Local materials play a pivotal role in the structural aspects of construction. Foundations, which bear the load of entire structures, often utilize locally sourced stone, gravel, or recycled concrete. Walls constructed from indigenous materials like adobe or rammed earth provides not only strength but also cultural significance [54-56]. In regions abundant with timber, wood is a primary choice for constructing resilient beams and columns that offer both structural integrity and aesthetic appeal [57, 58]. The use of local materials in these fundamental components of construction underlines a commitment to sustainable building practices that minimize transportation costs and environmental impact [59-61].

Applications Beyond the structural frame of buildings, local materials find diverse applications that contribute to functionality and comfort [62]. Finishes such as natural clay plasters or locally quarried stone add unique texture and character to buildings, while also utilizing resources that are readily available. Insulation is another critical application, where materials like straw bale or cellulose from recycled paper offer eco-friendly alternatives to synthetic insulants [62, 63]. In the realm of landscaping, the use of local materials harmonizes constructed spaces with their natural surroundings, using indigenous plants and rocks to create outdoor areas that are both sustainable and contextually appropriate.

The field of civil engineering is witnessing a surge of innovation as emerging technologies enable more advanced applications of local materials [60]. Techniques like 3D printing with earth-based materials are revolutionizing the way local resources are used, allowing for complex geometries and efficient material use. Self-healing concrete incorporates local bacteria or fungi that can repair cracks, enhancing longevity. Furthermore, the integration of smart sensors into locally sourced materials is paving the way for intelligent infrastructure capable of monitoring health and environmental conditions in real-time. These cutting-edge developments are propelling the application of local materials into the future, promising a new era of sustainable and intelligent civil engineering [64-66].

7. Conclusion: Towards Innovative and Sustainable buildings

This bibliometric analysis has illuminated the contours of civil engineering as it intersects with the use of local materials over a two-decade trajectory. Despite a static annual growth rate in published works, the persistent average citation impact attests to the enduring relevance of this research. The field thrives on collaborative efforts, evidenced by a predominance of multi-authorship, and this cooperative spirit is likely to further enhance the knowledge base and foster innovation in sustainable building practices.

The applications of local materials, both in structural and non-structural domains, are indicative of a sector responsive to both ecological and economic imperatives. Sustainable building practices, from using indigenous materials for structural components to integrating advanced technologies for improved efficiency and functionality, signal a shift towards greener, more adaptable construction methodologies.

The advent of innovative technologies like 3D printing and smart materials suggests a frontier of civil engineering that is rapidly evolving. These advancements are not merely technical achievements but are poised to revolutionize the way we conceptualize sustainability in building practices, pushing the boundaries of what is possible in constructing living and working spaces that are environmentally attuned, culturally relevant, and economically viable.

In summary, the synthesis of this bibliometric study and the identified trends point to a future where sustainable building is not an adjunct concern but a fundamental criterion integrated into every level of civil engineering projects. It is an approach that promises to deliver not only improved environmental outcomes but also enhanced societal value, setting a template for future developments that prioritize sustainable and innovative building techniques.

Conflict of interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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