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Investigation of Rammed Earth Research in the Context of Sustainable Building Materials with Performance Analysis

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Abstract – Throughout history, earth as one of the most basic building materials of architecture, has stood out as a culturally and environmentally sustainable resource thanks to its local availability, compatibility with natural cycles and renewability. Increasing environmental concerns and the search for sustainability have led to the re-evaluation of traditional earthen structures and their use as an alternative solution in modern architecture with contemporary techniques. In this study, academic research on rammed earth in the context of sustainable building materials is analyzed through performance analysis. Based on publications obtained from the Web of Science database, publication trends by year, most influential authors, institutions and countries are analyzed. The data obtained reveals that the topic of rammed earth has been addressed with increasing interest, especially in recent years, and has become an interdisciplinary research area. The study provides a holistic view of the place of rammed earth in sustainable architecture and aims to be a guiding resource for future research in the field.

Keywords – Rammed earth, soil, building material, sustainable material, architecture

I. INTRODUCTION

Earth has been one of the oldest and most widely used building materials throughout history [1]. It has played a fundamental role since the beginning of architectural history. In particular, in people's efforts to build structures that are compatible with environmental conditions, the earth has been the primary material of choice due to its accessibility and workability [2]. From ancient times to the present day, it has been used in various forms such as adobe, compacted earth, plastered surfaces, and compacted earth blocks across different regions, finding its place in both everyday structures and monumental architecture (Figure 1, Figure 2) [3]. The fact that soil is a natural, locally available, and low-energy production material that is biologically recyclable makes it valuable in today's sustainable architecture [4]. In contemporary architectural approaches where goals such as reducing energy consumption, lowering carbon emissions, and promoting environmentally compatible construction are prioritized, earthen materials have once again come to the forefront. Thus, earthen materials have gained importance not only as historical building materials but also as strategic architectural materials due to their environmental impacts.

Fig. 1 Global distribution of earth construction regions and key architectural sites on the UNESCO World Heritage List [5]

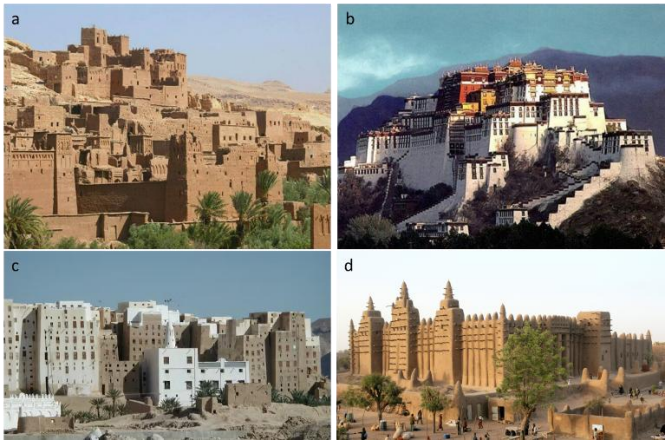

Fig. 2 Examples of land/soil structures throughout historical processes: Morocoo (a) [6], Tibet (c) [7], Yemen (c) [6], Mali (d) [8]

Today, the global climate crisis, increasing energy consumption, depletion of natural resources, and high carbon emissions from the construction industry have made sustainability an integral part of architecture [9]. In particular, the fact that the construction sector is responsible for a significant portion of global greenhouse gas emissions has been one of the key factors driving the search for alternative materials and techniques [10]. In this context, traditional construction techniques that offer environmental advantages, such as low energy requirements, the use of local materials, and recyclability, have regained importance in contemporary architectural discourse. Among these, the rammed earth method stands out for its compatibility with sustainability principles, as well as its high thermal mass, natural indoor comfort, and aesthetic integrity (Figure 3). Rammed earth is gaining attention in today's architecture not only as a nostalgic technique but also as a contemporary environmental solution due to its reduced dependence on industrial processes, lower

carbon footprint, and historical connection to cultural heritage [11]. This transformation also highlights the process of reinterpreting traditional approaches and integrating them with modern techniques and technologies.

Fig. 3 Contemporary examples of rammed earth applications [12]

In recent years, with the growing interest in sustainable building materials, numerous technical and material-focused studies have been conducted on rammed earth [13]. These studies generally focus on engineering-based topics such as the material's mechanical properties, thermal performance, moisture behavior, and structural strength. Technical details such as local additives, stabilization techniques, and modern application methods are emphasized [14]. However, despite this wealth of literature, there are limited studies that comprehensively and systematically address data such as the thematic areas in which rammed earth studies have concentrated over time, the leading researchers, institutions, and countries conducting the studies, the journals in which they were published, and the development trajectory of related research areas. This situation makes it difficult to assess the direction and trends of the existing knowledge base in the field and also fails to provide a strategic roadmap for new research. Therefore, examining academic production on rammed earth using performance analysis methods has become important both to address this gap and to provide researchers with an interdisciplinary perspective.

The primary objective of this study is to comprehensively evaluate the academic literature on "rammed earth," which has gained prominence in recent years due to the increasing interest in sustainable building materials and construction techniques. Within this scope, 1,326 publications obtained from a search using the keyword "rammed earth" in the Web of Science (WoS) database were examined, and the distribution of these publications by year, researchers, countries, institutions, journals in which they were published, and their relationship with sustainable development goals were systematically analyzed. This analysis, conducted using descriptive statistics, aims to reveal trends, research gaps, and interdisciplinary connections within the field. The original contribution of the study is that it maps academic production on rammed earth, thus serving as a guiding resource for both academics and researchers working in the field. This comprehensive approach, which is currently lacking in the literature, aims to establish a strategic foundation for future research while also enhancing the scientific visibility of alternative construction techniques that can contribute to environmental sustainability.

II. Materials and Methods

Within the scope of this study, data collection was carried out using only the keyword "rammed earth." This choice was made to obtain a clearer and more focused publication pool centered on the subject. The search was conducted in the Topic (TS) field of the Web of Science (WoS) platform and covered the title, abstract, and keywords (Author Keywords and Keywords Plus) sections. No additional keywords (e.g., "tamped earth," "compressed earth blocks," etc.) were included.

As of June 15, 2025, a total of 1,326 publications were identified through the search. These publications encompass various types, including articles, book chapters, conference papers, and review articles. The data was exported from the platform in Excel format, and the analysis process was conducted using this raw data file.

The collected data were evaluated using performance analysis methods (Figure 4). This type of analysis is a systematic method used to reveal the quantitative distribution, trends, and structural relationships of the literature on a selected topic. The evaluation was carried out according to the following criteria:

- Number of publications and citations by year
- Most productive authors and researcher profiles
- Countries and institutions with the most publications
- Journals and sources where publications appear
- Research areas and citation topics
- Relationship between publications and the UN Sustainable Development Goals (SDGs) [15]

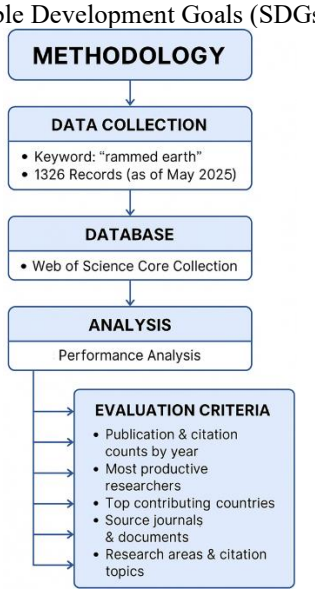

Fig. 4 Methodological flowchart of the bibliometric study on rammed earth research

The data obtained was first classified in Microsoft Excel and then visualized using frequency analyses and rankings.

The thematic grouping of research areas was carried out according to the "Research Areas" and "Citation Topics" classifications provided by the WoS system. SDG connections were made based on the "Sustainable Development Goals" section provided directly from the database.

The main limitation of this study is that it only uses searches with the keyword "rammed earth." Terms such as "compressed earth block," "tamped earth," and "stabilized soil," which refer to specific construction techniques in the literature, have been excluded, potentially leaving some publications out of the analysis. Additionally, the study focuses solely on the WoS Core Collection database and excludes other international platforms such as Scopus, Google Scholar, and ScienceDirect. However, WoS supports the validity of the study by providing access to publications with high-impact factors and high academic reliability.

III. RESULTS

This section presents the results of a performance-based bibliometric analysis of scientific publications focusing on rammed earth in the context of sustainable building materials. The analysis, conducted using data from the Web of Science Core Collection database, encompasses a multifaceted evaluation, including publication and citation trends by year, the most productive authors, institutions, countries, journals, subject headings, and the relationship with the United Nations Sustainable Development Goals (SDGs). The findings aim to reveal the development of rammed earth research over time, its interdisciplinary spread, and its place within the global research network. The micro-subject headings that rammed earth studies cite the most.

According to performance analysis, the distribution of scientific publications produced in the field of rammed earth over the years, along with the number of citations to these publications, shows a significant upward trend (Figure 5). In particular, academic studies published in this field were quite limited until 2005, and the annual number of publications generally remained in single digits. During this period, the subject was examined in the context of traditional construction techniques and addressed in limited disciplines. However, a noticeable increase in the number of publications began in the years following 2010. From 2020 to the present, the annual number of publications has peaked at over 120. This increase can be attributed to the growing interest in natural building materials, such as rammed earth, in the fields of architecture and civil engineering, driven by global themes including sustainability, energy efficiency, and reduced carbon footprint.

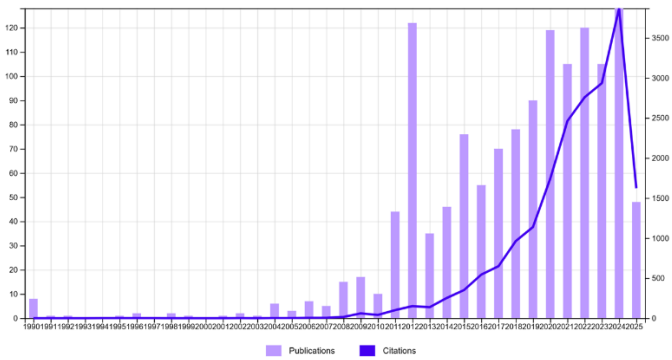

Fig. 5 The annual distribution of publications and citations on the topic of rammed earth

When examining the distribution of academic publications on rammed earth by research area, it is evident that studies are concentrated mainly in technical disciplines (Table 1). In particular, the fields of engineering, construction building technology, and materials science account for a significant portion of the total number of publications. This distribution indicates that rammed earth technologies are closely related to structural strength, material performance, and construction engineering applications. On the other hand, fields such as architecture and environmental sciences also address the subject in the context of sustainable design, natural resource use, and ecological building strategies. Furthermore, studies in fields such as archaeology and geology highlight the historical, cultural, and geotechnical aspects of rammed earth structures. This multifaceted distribution highlights the interdisciplinary nature of the subject and demonstrates that it has become an important area of research in the literature on sustainable building materials.

Table 1. Distribution of rammed earth-related publications by Web of Science research areas (Top 10 fields)

Research Areas	Count
Engineering	849
Construction building technology	655
Materials science	406
Architecture	163
Science technology other topics	115
Environmental sciences ecology	93
Archaeology	83
Geology	76
Chemistry	65
Energy fuels	62

The distribution of publications on rammed earth by country reveals that academic interest in this field is growing globally (Table 2). China ranks first with the highest number of publications, followed by Spain and France. These three countries are at the forefront of research on sustainable building materials, accounting for a significant share of the total publication output. Other European and North American countries such as the United Kingdom, Portugal, Italy, and the United States also make notable contributions. In addition to these leading countries, nations from various continents, such as Australia, India, Iran, Canada, and Brazil, are also actively contributing to the field. Furthermore, the inclusion of developing countries such as Colombia, Morocco, Vietnam, Sri Lanka, the Czech Republic, and Poland in the list demonstrates that rammed earth research is not limited to developed countries, but has also gained importance in regions that are developing, driven by environmental, cultural, and economic factors. Overall, rammed earth research has evolved into a multidisciplinary field of interest spanning different continents and socio-economic structures, garnering global resonance within the context of sustainable construction techniques.

Table 2. Country-wise distribution of publications on rammed earth (Top 20 countries)

Country	Count
China	849
Spain	655
France	406
England	163
Portugal	115

Italy	93
Usa	83
Australia	76
India	65
Germany	62
Iran	26
Canada	25
Brazil	25
Colombia	25
Japan	23
Morocco	22
Vietnam	20
Sri Lanka	19
Czech Republic	18
Poland	18

An analysis based on individual researcher performance in the field of rammed earth reveals the leading academics in the field. As shown in Table 3, Jean-Claude Morel stands out as the researcher with the highest number of scientific publications, with 31 publications. He is followed by Quoc-Bao Bui (30 publications) and Christopher Beckett (27 publications). These researchers are recognized for their studies on the load-bearing behavior of rammed earth structures, material performance, and sustainable construction technologies. Other notable names on the list include Fernando Vegas López-Manzanares, Camilla Mileto, Antonin Fabbri, and Daniel V. Oliveira, each of whom has over 20 publications to their name. The table highlights the presence of academics from Asia, South America, and Europe, who have made significant contributions, underscoring the strength of international collaboration in the field. Furthermore, the inclusion of names such as Deb Dulal Tripura, Rui Silva, and B. V. Venkatarama Reddy in the list demonstrates that rammed earth has evolved into a multidisciplinary field of research encompassing not only engineering but also architecture, building materials science, and cultural heritage preservation. The regular and adequate publication output of these researchers supports the growing academic impact of the field.

Table 3. Top 20 most prolific researchers in the field of rammed earth

Researcher Profiles	Count
Morel, Jean-Claude	31
Bui, Quoc-Bao	30
Beckett, Christopher	27
López-Manzanares, Fernando Vegas	26
Mileto, Camilla	26
Fabbri, Antonin	25
Oliveira, Daniel V.	21
Canivell, Jacinto	20
Ciancio, Daniela	20
Tripura, Deb Dulal	19
Silva, Rui	19
Reddy, B. V. Venkatarama	18
Hall, Matthew R	17
Ple, Olivier	16
Zhou, Tiegang	15
Augarde, Charles	15
WOLOSZYN, Monika	14
Mcgregor, Fionn	14
Perlot, Celine	14
Faria, Paulina	14

When examining journals that publish articles on rammed earth, it is observed that the academic platforms where the subject is concentrated are generally journals specializing in civil engineering, building technologies, sustainability, and architectural history (Table 4). The journal with the highest number of publications is Construction and Building Materials (171 publications), indicating that the field is evaluated in terms of technical, structural, and material performance. Second on the list is Rammed Earth Conservation (64 publications), highlighting its significance as a key publication platform, particularly in the context of the conservation and restoration of traditional structures. A notable number of publications can also be found in journals such as the International Journal of Architectural Heritage, Earthen Architecture: Past, Present, and Future, and the Journal of Building Engineering and Sustainability. These journals reveal that the topic of rammed earth is addressed from different perspectives, including architectural history, cultural heritage, and environmental sustainability. In addition, a significant number of publications appear in engineering-focused journals, such as the Journal of Materials in Civil Engineering, Materials and Structures, Engineering Structures, and Advanced Materials Research, demonstrating the prominence of technical topics like material strength, engineering applications, and structural analysis in the literature. This distribution clearly shows that the topic of rammed earth is represented in various journal categories, encompassing both its theoretical and historical aspects, as well as its experimental and applied dimensions, indicating an interdisciplinary nature.

Table 4. Top 20 academic publication titles on rammed earth research by number of publications

Publication Titles	Count
Construction And Building Materials	171
Rammed Earth Conservation	64
International Journal of Architectural Heritage	35
Earthen Architecture Past Present and Future	32
Sustainability	32
Journal Of Building Engineering	31
Buildings	28

Table 4 (continued).

Journal Of Materials in Civil Engineering	28
Materials And Structures	27
Advanced Materials Research	25
Engineering Structures	22
Chinese Archaeology	21
Materials	20
Energy And Buildings	18
Rilem Bookseries	16
Case Studies in Construction Materials	15
Journal of Cultural Heritage	15
Modern Earth Buildings Materials Engineering Construction and Applications	15
Woodhead Publishing Series in Energy	15
Building and Environment	14

When examining the micro-level subject headings referenced in rammed earth studies, it becomes apparent that the research is primarily related to sub-disciplines focused on earthquake resistance, material durability, energy efficiency, and building performance (Table 5). In particular, Seismic Masonry stands out as the subject heading with the most citations, with 852 citations. This indicates that rammed earth structures are being considered as an alternative building

system, particularly in regions prone to seismic risk. Headings such as "Biodeterioration," which ranks second, and "Building Energy Efficiency," which ranks third, demonstrate that rammed earth structures are the subject of detailed research in terms of both durability and energy efficiency. Technical subtopics such as Advanced Concrete, Unsaturated Soil Mechanics, Life Cycle Assessment, and Soil-Structure Interaction reveal that these structures are also being studied comprehensively in the contexts of engineering, materials science, and environmental analysis. In addition, the inclusion of topics such as Cultural Archaeology, Medieval Iberia, Holocene, Archaeometry, and Wood Properties demonstrates that rammed earth structures are supported by scientific references not only from a technical perspective but also from historical, cultural, and archaeological perspectives. This micro-level analysis shows that rammed earth research evolves alongside technical, environmental, and cultural themes beyond general engineering and sustainability.

Table 5. The most frequently cited micro-topics in studies on rammed earth

Citation Topics Micro	Count
Seismic Masonry	852
Biodeterioration	45
Building Energy Efficiency	39
Advanced Concrete	39
Unsaturated Soil Mechanics	13
Life Cycle Assessment	11
Cultural Archaeology	11
MICP	9
Soil-Structure Interaction	8
Holocene	8
Medieval Iberia	7
Seismic Concrete Structures	7
Infrared Thermography	7
Lidar and Photogrammetry	5
Geophysical Techniques	5
Phase Change Material	4
Archaeometry	4
Rangeland Dynamics	3
Soil Erosion	3
Wood Properties	3

An analysis of the alignment between rammed earth publications and the United Nations Sustainable Development Goals (SDGs) reveals that the topic is closely linked to several global sustainability priorities (Table 6). The most strongly associated goal is Goal 11 – Sustainable Cities and Communities, with 931 related publications. This demonstrates that rammed earth is widely regarded as a viable strategy for promoting sustainable urban development, affordable housing, and resilient infrastructure. The second and third most frequent associations are with Goal 13 – Climate Action (76 publications) and Goal 14 – Life Below Water (67 publications), indicating that rammed earth is increasingly discussed in the context of climate change mitigation and reducing environmental impact. Additionally, Goals 7 – Affordable and Clean Energy, 12 – Responsible Consumption and Production, and 15 – Life on Land are prominently represented, reflecting the relevance of rammed earth in promoting low-carbon, locally sourced, and resource-efficient construction practices. Further connections are observed with Goal 6 – Clean Water and Sanitation, Goal 9 – Industry, Innovation, and Infrastructure, and Goal 2 – Zero Hunger, suggesting a broader interdisciplinary interest in the technology's applications in rural and humanitarian contexts. However, connections with more socially focused goals, such as Goal 5 – Gender Equality, Goal 10 – Reduced Inequality, and Goal 1 – No Poverty, remain minimal, indicating that the current research predominantly emphasizes the environmental and technological dimensions of sustainability. Overall, the findings highlight the increasing importance of rammed earth in achieving multiple Sustainable Development Goals (SDG) targets, particularly in terms of environmental sustainability, energy efficiency, and resilient urban development.

Table 6. Distribution of rammed earth-related publications by Web of Science research areas (Top 10 fields)

Sustainable Goals	Count
Sustainable cities and communities	931
Climate action	76
Life below water	67
Affordable and clean energy	56
Responsible consumption and production	52
Life on land	31
Clean water and sanitation	18
Industry innovation and infrastructure	13
Zero hunger	12
Good health and well being	11

IV. DISCUSSION

The performance analysis conducted within the scope of this study has revealed that academic interest in rammed earth has increased steadily and significantly, especially over the past 20 years. The rapid increase in the number of citations, parallel to the increase in the number of publications, shows that this field has not only become a more studied subject but also a subject that is more frequently referenced and whose scientific impact is expanding. This trend is directly related to the growing interest in sustainable building materials and aligns with contemporary architectural and engineering practices that emphasize criteria such as low carbon footprint, use of natural materials, and energy efficiency.

The fact that China, Spain, and France are among the countries with the most publications indicates that rammed earth applications are concentrated in regions where they have both traditional roots and are compatible with modern construction technologies. The prominence of Europe- and Asia-based research indicates that this construction technique is undergoing a process of scientific and cultural rediscovery. These findings are supported by the work of influential academics in the field, such as Morel and Bui. Additionally, the analysis demonstrates the strong adoption of an interdisciplinary approach; contributions from various fields such as engineering, materials science, architectural history, archaeometry, and environmental sciences reveal that rammed earth is not only a technical but also a cultural and environmental research area.

The research results also show that this construction technique is highly relevant to the United Nations Sustainable Development Goals (SDGs). In particular, the strong links with the goals of “Sustainable Cities and Communities,” “Climate Action,” and “Responsible Production and Consumption” reveal that rammed earth construction has significant potential in terms of sustainable urbanization, environmental awareness, and resource efficiency. In contrast, the limited connection with socially themed goals such as gender equality, poverty alleviation, or reducing inequalities

indicates that the existing literature is technically focused and relatively neglects social dimensions.

V. CONCLUSION

With the intensification of climate change's impacts, the significance of sustainability-oriented approaches in the construction sector has increased, leading to a renewed evaluation of natural and locally sourced building materials. In this context, the transformation and differentiation of cultural structures over time have also had discernible implications in the field of architecture. The evolution of housing typologies and the acceleration of modernization processes have brought about significant transformations in building technologies and the procurement of construction materials. During this period, the use of climate-responsive and locally available earthen materials has gradually declined, being replaced by industrial materials such as reinforced concrete and glass, which possess high thermal mass and exhibit properties that absorb, store, and transmit solar radiation. This study conducts a comprehensive bibliometric analysis to evaluate academic interest in the rammed earth construction system. Based on data retrieved from the Web of Science database, a marked increase in scholarly attention towards this construction method has been observed since the 2010s, with a notable acceleration post-2020. This trend reflects a growing awareness of the role of local and natural materials in sustainable architecture.

In terms of research disciplines, studies on rammed earth structures predominantly concentrate on the fields of civil engineering, architecture, and materials science, with a particular focus on parameters such as thermal performance, mechanical strength, moisture regulation, and structural stability. Research concerning stabilization techniques and contemporary construction methods also constitutes a significant area of academic inquiry.

Geographical distribution analysis indicates that academic production in this domain is mainly concentrated in countries such as the United Kingdom, France, Germany, China, India, and Australia. This concentration is associated with both the traditional use of earthen architecture in these regions and their supportive sustainability policies.

Leading researchers in the field stand out in the literature due to high citation rates and tend to evaluate both the technical viability and environmental benefits of the system. A substantial portion of the publications appears in high-impact journals such as Construction and Building Materials, Sustainability, and the Journal of Cleaner Production, signifying that rammed earth is recognized not merely as a traditional technique but also as an integral component of contemporary sustainable architectural practices.

An analysis based on micro-topics and keywords highlights concepts such as "thermal performance," "mechanical properties," "stabilization," and "sustainability," indicating a concentrated academic interest in energy efficiency and material characteristics of rammed earth constructions.

In alignment with the Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), rammed earth buildings contribute to the achievement of these goals through low carbon emissions, the use of local resources, and durability.

In summary, academic studies on rammed earth reveal a growing emphasis on environmentally conscious approaches in the construction sector. Due to its low carbon footprint, high thermal mass, accessibility of local resources, and ecological harmony, rammed earth offers cost-effective housing solutions in developing countries, contributing to sustainable architectural practices in developed regions.

Future research is recommended to focus on multifaceted investigations concerning user comfort and thermal perception, performance analyses across different climatic regions, carbon footprint assessments of construction processes, and the integration of this system into local building regulations. Expanding applied studies based on numerical modeling, energy simulations, and life cycle assessments will further reinforce the role of rammed earth in sustainable building solutions. Moreover, developing strategies for the use of region-specific rammed earth that contribute to the preservation of vernacular architectural heritage is vital for fostering integrated approaches that combine sustainability policies with cultural continuity.

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