

Analyzing the Literature on Seismic Resilience in Rammed Earth Construction: A Cartographic Approach

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Keywords: Historic Buildings, Cultural Heritage, Seismic Resilience, Rammed Earth Construction, Literature Map, Bibliometric Analysis

Abstract. The study explores the seismic impact on Rammed Earth Constructions through an analysis of various bibliographic factors. These factors encompass publication volume, authorship, geographical origin, institutional affiliations, and relevant scholarly journals. Employing a rigorous examination of bibliographic data retrieved from reputable databases such as Scopus, the research identifies a discernible uptick in pertinent publications since 2014. Moreover, it discloses prominent figures within this academic domain, delineating their geographical origins, institutional affiliations, and contributions to influential journals. Additionally, the investigation scrutinizes prevalent keywords in search queries and recurrent themes in research undertakings. The citation analysis is directed towards identifying noteworthy authors and seminal documents that hold substantive significance within this scholarly discourse. The principal aim of this inquiry is to discern primary areas of interest by analyzing co-citations among authors. Biased assessments have been systematically excluded, and the linguistic framework employed adheres to an objective and value-neutral stance. Technical terminology is elucidated upon initial usage, and conventional academic sections are seamlessly integrated into the narrative.

Introduction

Rammed earth housing, an enduring architectural tradition utilizing earth-based materials, encapsulates a rich cultural legacy and a nuanced understanding of local resources [1], [2]. This study scrutinizes the global landscape of structures, with a specific focus on rammed earth constructions, to elucidate their seismic resilience. The examination extends to evaluating the seismic performance of these structures in the aftermath of various earthquakes that have significantly impacted regions worldwide [3], [4]. Recent attention has been directed towards the seismic vulnerability of rammed earth constructions, prompting a comprehensive examination of their resilience. This research delves into the seismic history of rammed earth homes worldwide, highlighting instances where these structures demonstrated remarkable resistance to seismic forces. The vulnerability of rammed earth constructions to seismic forces underscores the imperative to implement robust seismic regulations. Recognizing this necessity, numerous countries have established seismic building codes and standards to safeguard both heritage and inhabitants. This article navigates through global seismic regulations, emphasizing their significance in mitigating the seismic risks associated with rammed earth constructions. Morocco, in particular, stands out for implementing seismic regulations tailored to earth-based constructions in 2011, reflecting a forward-thinking initiative to preserve architectural heritage while ensuring community safety [5]. This exploration aims not only to unveil the seismic challenges faced by rammed earth constructions but also to underscore the importance of regulatory frameworks in safeguarding these invaluable structures. By delving into global seismic experiences and spotlighting Morocco's proactive measures [6], [7], this article contributes to the ongoing dialogue



surrounding the seismic resilience of rammed earth constructions in our ever-evolving civil engineering landscape.

Furthermore, this study extends its inquiry by utilizing a cartographic analysis of the literature. By mapping out the existing body of knowledge on seismic resilience in traditional earth constructions, we provide a visual representation of the global progress and barriers in this field [8]. This analytical approach allows for a comprehensive understanding of the current state of research, identifying key trends, gaps, and areas for future exploration. As we navigate through the varied seismic experiences worldwide, it becomes evident that the challenges faced by traditional earth constructions are diverse and context-specific [9]. The nuanced nature of these challenges underscores the importance of a tailored and informed approach to seismic resilience. By amalgamating insights from diverse sources, our cartographic analysis aims to facilitate a holistic view, fostering informed discussions and guiding future research endeavors.

In the context of our exploration, the proactive measures taken by Morocco in implementing seismic regulations for earth-based constructions serve as a beacon of best practices [5]. In conclusion, our article not only contributes to the scholarly understanding of seismic resilience in traditional earth constructions but also advocates for a proactive and context-aware approach to safeguarding these structures. By combining historical perspectives, contemporary case studies, and a cartographic analysis of the literature, we hope to inspire ongoing efforts aimed at balancing heritage preservation and community safety in the dynamic landscape of seismic risk.

Methodology

To achieve the research objectives, a bibliometric analysis employing a quantitative approach was initially conducted. This methodology has gained popularity among researchers due to its utility in identifying emerging trends, reviewing outcomes in the specified research field, and establishing global collaboration networks among authors, institutions, and documents. The bibliometric approach enables the identification of research gaps, emerging themes, and the correlation of results in the specific scientific domain combined with relevant research areas [10].

Initially, publications were gathered using a specific database, widely recognized as one of the most comprehensive, and covering a greater number of academic documents than others. Query strings related to the study's topics were utilized with Boolean operators "AND" and "OR" to circumscribe the search. The initial search focused on articles published on traditional constructions. For the given query, 2965 documents were found in the dataset. While the substantial number of documents emphasizes the importance of the subject, it falls short in pinpointing the impact of the specific variable on the specific domain.

To address this, the variable "Seismic" was introduced, resulting in the modification of the query. The revised query encompassed the main keywords related to the study's topics and introduced the variable "seismic," broadening the scope of the research. The refined search, conducted until 2023, aimed to understand the seismic resilience of traditional houses. In summary, this research focused on the main keywords "rammed earth construction," "traditional construction," and "seismic."

This comprehensive selection incorporated a significant number of published studies dedicated to the specific domain that simultaneously address rammed earth construction and the impact of seismic activity on them. The use of asterisks allowed for the inclusion of all possible variants of the given words, accommodating differences after the asterisk.

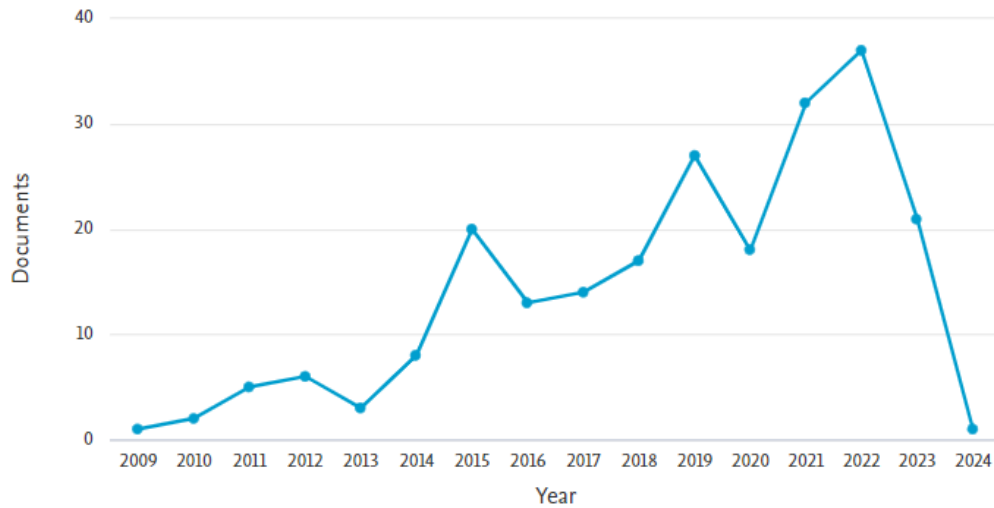


Fig. 1 Documents by year

Our findings reveal a gradual increase in publications from 2009 to 2013, followed by a second phase characterized by moderate growth in the number of publications between 2013 and 2020. Subsequently, there was a significant surge in research activity from 2020 onwards.

To achieve the research objectives, a bibliometric analysis employing a quantitative approach was conducted, with a focus on documents published until 2023. This analysis considered various criteria, including the typology of publication (conference paper, article, conference review, book chapter, and review), language of publication, distribution of publications by territory and institution, citation analysis, and keyword co-occurrence. The search, conducted in the Scopus database, resulted in a number of documents, all representing publications in their final stages [11]. These documents spanned various scientific disciplines, highlighting the interdisciplinary nature of the research. The typology of documents included various categories such as "articles," "conference papers," "conference reviews," "book chapters," and "reviews." Significantly, some documents featured bilingual content, emphasizing the global perspective of the research.

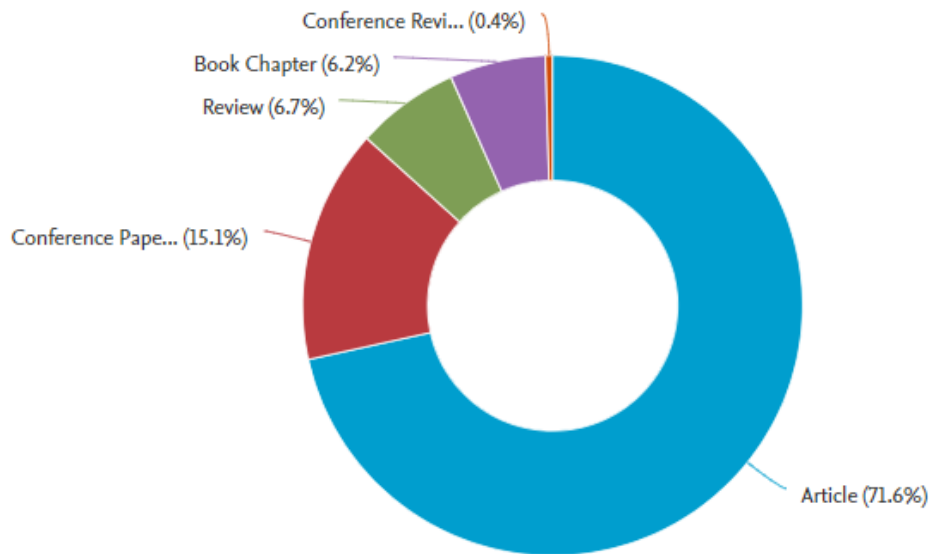


Fig. 2 Documents by type

In summary, this bibliometric analysis aimed to provide a comprehensive overview of the research landscape related to a specific intersection of topics. The methodology employed is

applicable across various domains, enabling researchers to adapt and apply similar approaches in different fields of study.

Following the initial data analysis conducted in Scopus, a more in-depth examination was carried out using VOSviewer. While several bibliometric tools such as BibExcel, CiteSpace, Sci2, or HistCite are available, VOSviewer was employed to analyze the data extracted from the Scopus database. VOSviewer, as a free software tool, is utilized for constructing and visualizing bibliometric networks that depict relationships between stakeholders such as authors, publishers, and institutions. These networks are established based on factors such as citations, keyword co-occurrence, and co-authorship within the scientific literature [12].

Results

To begin, Figures 3 and 4 illustrate the publication trends for the key territories contributing to research on the combined subjects. In the case of the combined research between “Traditional Building” AND “Seismic” (Fig. 3), the results indicate that Italy stands out as the primary contributor with the highest number of articles, accounting for nearly 10% of global publications until 2023. Following Italy, China contributed 123 articles, and Portugal contributed 63 articles. The United Kingdom, Japan, the United States, Turkey, Greece, India, and Iran are among the top 10 countries that have contributed. Morocco, on the other hand, has 2 articles on these subjects. This distribution highlights the global dissemination of research on the topic, with various countries making significant contributions to the knowledge base.

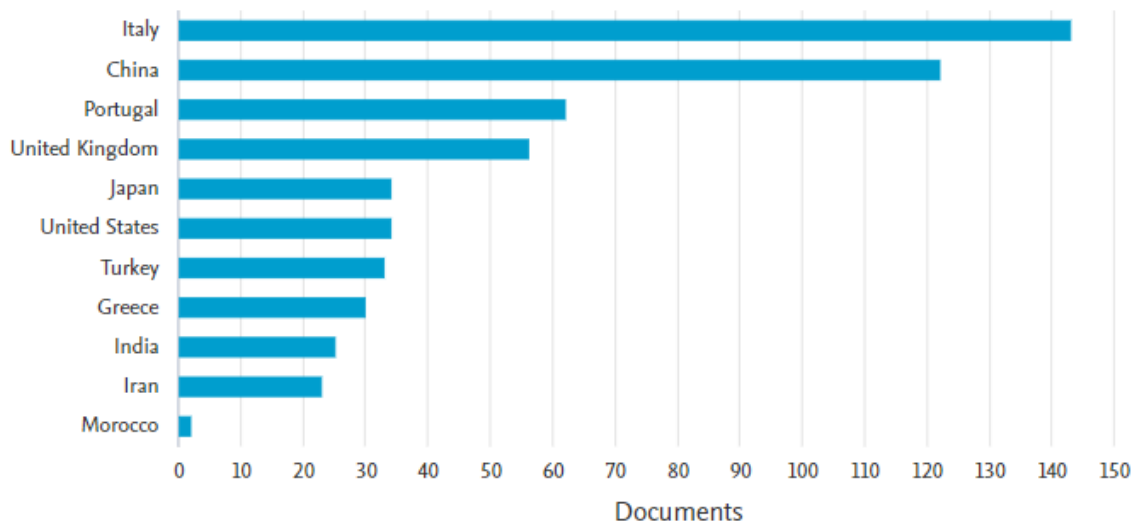


Fig. 3 Documents by country or territory: "Traditional Building" AND "Seismic"

Figure 4, on the other hand, depicts the results of the combined search for “Rammed Earth Construction” AND “Seismic”, where Portugal emerges as the leading country contributing with 53 articles. In the second position is China with 35 articles, followed by France with 27 articles in the third position. Morocco has 3 articles.

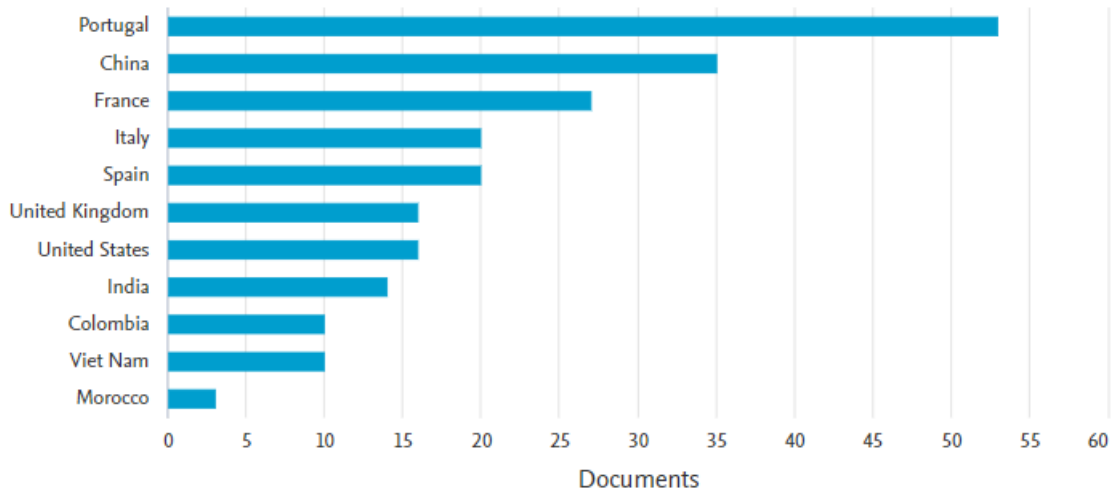


Fig 4. Documents by country or territory: "Rammed Earth Construction" AND "Seismic"

To determine the most frequently used expressions in the selected articles, a keyword analysis was conducted (Fig. 5). The aim of this study was to identify key concepts and research topics that have garnered significant attention in the discipline. The frequency and distribution of keywords were examined to gain insights into current research interests and priorities. Five unique clusters were identified after the keyword analysis, representing the main areas of interest for further studies. These domains cover important topics such as "Seismic Performance", with 55 links distributed across 5 clusters, "Rammed Earth", with 130 links in 1 cluster, "Compressive Strength", with 99 links, "Finite Element Method", with 70 links spread across 3 clusters.

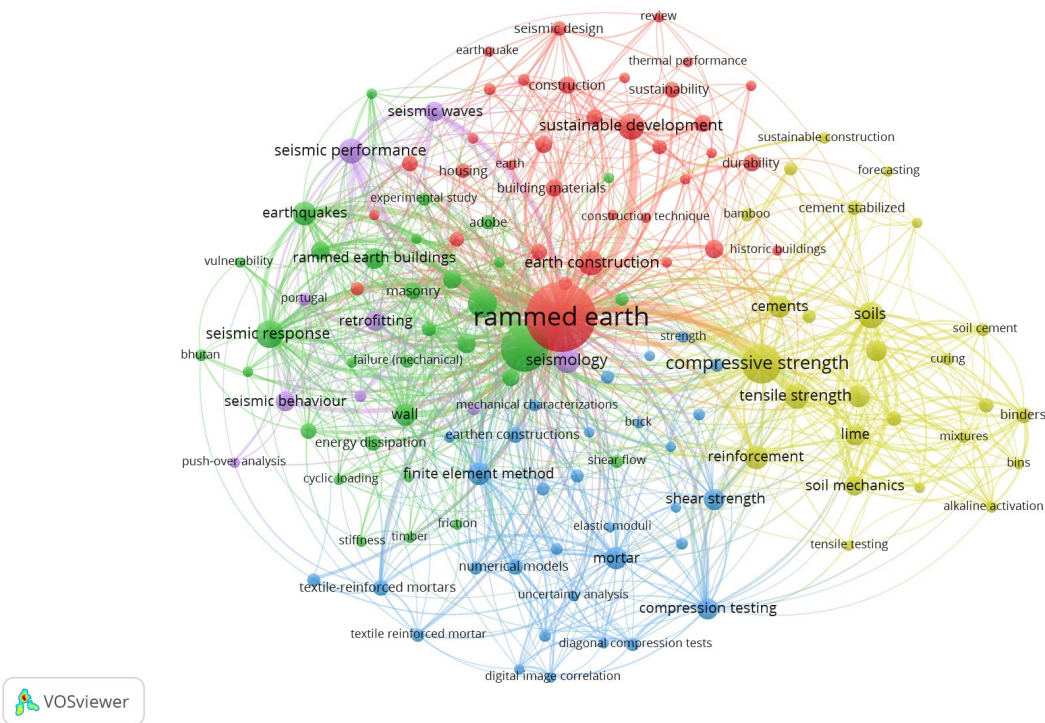


Fig 5. Keyword co-occurrence map, 5 clusters and 2784 links

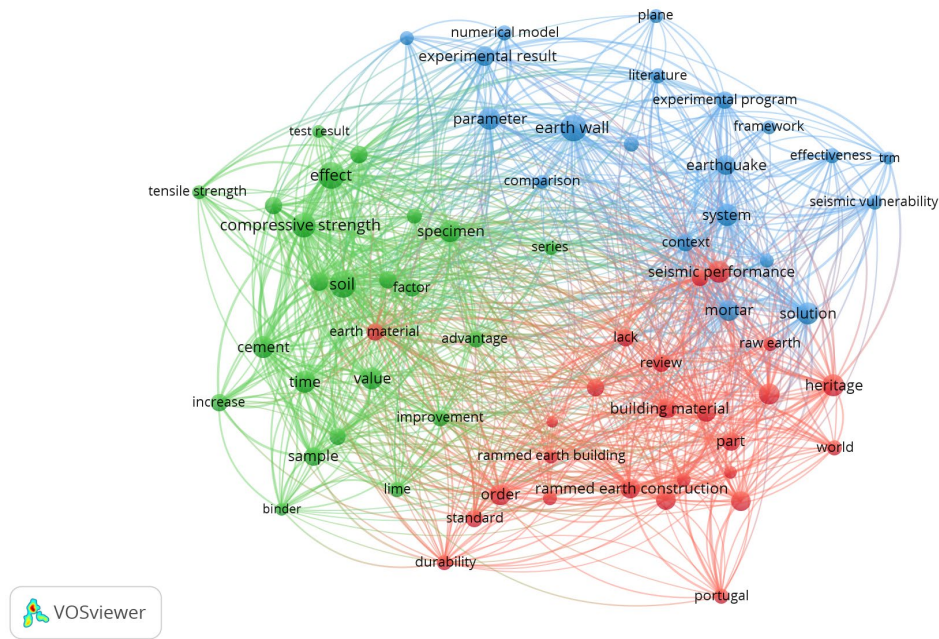


Fig. 6 Title and abstract fields

By conducting an analysis of recurring keywords in titles and abstracts (Fig. 6), we observe the repetition of the same keywords, supporting our initial analysis. Researchers with a high number of citations are often considered authorities in their field. Identifying experts in a specific subject and determining whether a particular country dominates that field can be a valuable endeavor, offering insights that can guide research. A co-publication analysis (Fig. 7) was carried out to identify the most influential authors. To assess the impact of individual documents and authors on the field, the number of citations received by each was examined. Through co-citation analysis, clusters of related studies and prominent research topics within the literature have been identified.

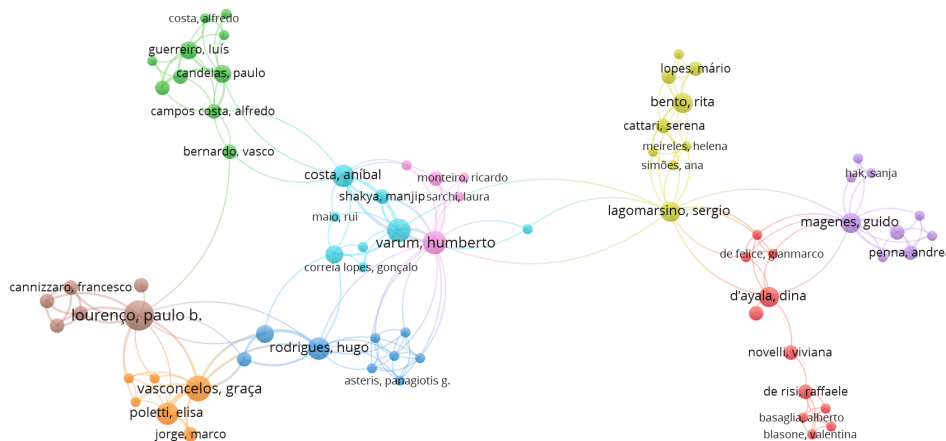


Fig. 7 Co-authorship map, 9 clusters and 241 links

On the illustrated graphical representation, it is evident that there are 9 distinct clusters of authors interconnected by a total of 241 links. Among these clusters, notable prominence is observed within two primary figures: Lourenço P.B., who is connected with 14 other authors and has contributed to 10 documents [13], and Varum H., who has authored 6 documents while maintaining connections with 16 other authors [14]. Identifying experts and assessing the dominance of countries (Fig. 8) in a specific subject can help target collaborations and investments in research areas where specific knowledge gaps exist.

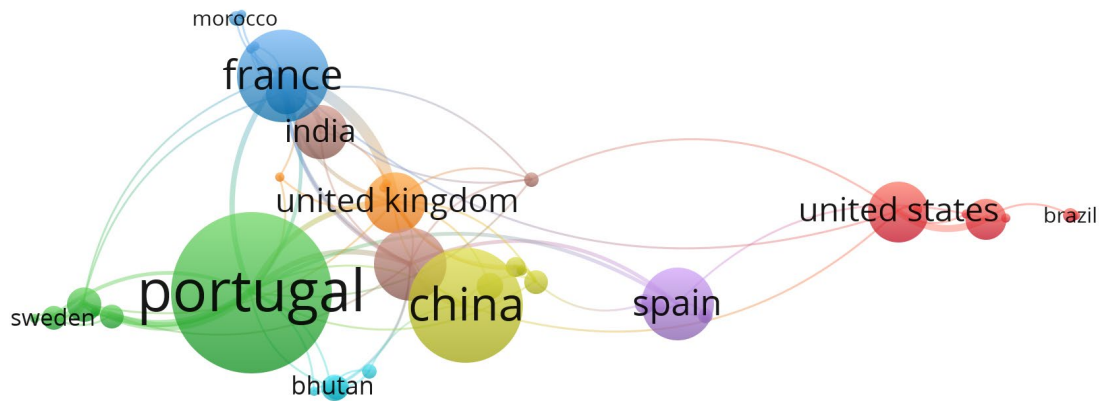


Fig. 8 Country co-occurrence map, 8 clusters and 90 links

The country-wise analysis unveils the presence of 8 clusters connected by a total of 90 links (Fig. 8). It is noteworthy that these clusters exhibit significant variations in terms of socio-economic conditions and respective regulatory frameworks. The countries displaying the highest interest in rammed earth constructions and seismic resilience are Portugal, China, and France. Morocco finds itself linked to France, contributing together to the origin of 3 documents.

Conclusion

In conclusion, this in-depth study on rammed earth constructions and their seismic resilience has provided an enlightening perspective on recent research trends in the field of civil engineering. By integrating bibliometric analyses, we have identified significant developments, established connections among influential researchers, and highlighted the evolution of study areas in this specific domain. This research underscores the growing importance of seismic resilience in the context of rammed earth constructions on a global scale. The compiled information provides a solid foundation to guide practitioners and researchers in understanding and enhancing the performance, sustainability, and operational resilience of rammed earth buildings.

By focusing on topics such as seismic regulations and proactive initiatives in certain countries, notably Morocco, this study offers valuable insights to steer future research and design practices. It also demonstrates the ongoing need to develop robust seismic standards to preserve architectural heritage while ensuring the safety of communities. Ultimately, this research contributes to the ongoing discourse on the seismic resilience of rammed earth constructions in a constantly evolving world. It paves the way for future advancements in the design, construction, and preservation of these structures, emphasizing the importance of reconciling tradition and innovation to address contemporary challenges.

References

- [1] S. Simou, K. Baba, N. Akkouri, M. Lamrani, M. Tajayout, and A. Nounah, "Mechanical Characterization of the Adobe Material of the Archaeological Site of Chellah," in *Recent Thoughts in Geoenvironmental Engineering*, H. Ameen, M. Jamiolkowski, M. Manassero, and H. Shehata, Eds., in Sustainable Civil Infrastructures, Cham: Springer International Publishing, 2020, pp. 118–130 . https://doi.org/10.1007/978-3-030-34199-2_8
- [2] S. Simou, K. Baba, N. Akkouri, M. Lamrani, M. Tajayout, and A. Nounah, "Mechanical characterization and reinforcement of the adobe material of the Chellah archaeological site," *E3S Web Conf.*, vol. 150, p. 03022, 2020 . <https://doi.org/10.1051/e3sconf/202015003022>
- [3] D. V. Oliveira, A. Romanazzi, R. A. Silva, A. Barontini, and N. Mendes, "Seismic Behaviour and Strengthening of Rammed Earth Constructions," in *Structural Analysis of Historical Constructions*, vol. 47, Y. Endo and T. Hanazato, Eds., in RILEM Bookseries, vol. 47.

- , Cham: Springer Nature Switzerland, 2024, pp. 1214–1225 . https://doi.org/10.1007/978-3-031-39603-8_98.
- [4] F. J. Baeza, L. Estevan, and S. Ivorra, “Seismic Retrofitting of Heritage Structures, Actual Techniques and Future Challenges for Earth and Masonry Constructions,” in *Structural Analysis of Historical Constructions*, vol. 47, Y. Endo and T. Hanazato, Eds., in RILEM Bookseries, vol. 47, Cham: Springer Nature Switzerland, 2024, pp. 1088–1101 . https://doi.org/10.1007/978-3-031-39603-8_87
- [5] M. of Housing and U. Policy, *The Moroccan Seismic Regulation for Earth Constructions* 2011. 2011.
- [6] Y. Razzouk, M. Ahatri, K. Baba, and A. E. Majid, “Optimizing Seismic Bracing Systems for Reinforced Concrete Buildings Based on Height and Seismic Zone,” *cea*, vol. 11, no. 6, pp. 3430–3450, Nov. 2023 . <https://doi.org/10.13189/cea.2023.110615>
- [7] Y. Razzouk, M. Ahatri, K. Baba, and A. El Majid, “Optimal Bracing Type of Reinforced Concrete Buildings with Soil-Structure Interaction Taken into Consideration,” *Civ Eng J*, vol. 9, no. 6, pp. 1371–1388, Jun. 2023. <https://doi.org/10.28991/CEJ-2023-09-06-06>
- [8] F. Orsini and P. Marrone, “Approaches for a low-carbon production of building materials: A review,” *Journal of Cleaner Production*, vol. 241, p. 118380, Dec. 2019 . <https://doi.org/10.1016/j.jclepro.2019.118380>
- [9] Q. Yang, M. Zhou, and K. Liu, “Seismic Performance and Vulnerability Analysis of Traditional Chinese Timber Architecture Considering Initial Damage,” in *Structural Analysis of Historical Constructions*, vol. 47, Y. Endo and T. Hanazato, Eds., in RILEM Bookseries, vol. 47, Cham: Springer Nature Switzerland, 2024, pp. 1114–1124 . https://doi.org/10.1007/978-3-031-39603-8_89
- [10] W. Rong and A. Bahauddin, “A Bibliometric Review of the Development and Challenges of Vernacular Architecture within the Urbanisation Context,” *Buildings*, vol. 13, no. 8, p. 2043, Aug. 2023 . <https://doi.org/10.3390/buildings13082043>
- [11] L. F. Cabeza, M. Chàfer, and É. Mata, “Comparative Analysis of Web of Science and Scopus on the Energy Efficiency and Climate Impact of Buildings,” *Energies*, vol. 13, no. 2, p. 409, Jan. 2020 . <https://doi.org/10.3390/en13020409>
- [12] G. Demir, P. Chatterjee, and D. Pamucar, “Sensitivity analysis in multi-criteria decision making: A state-of-the-art research perspective using bibliometric analysis,” *Expert Systems with Applications*, vol. 237, p. 121660, Mar. 2024 . <https://doi.org/10.1016/j.eswa.2023.121660>
- [13] R. A. Silva, D. V. Oliveira, L. Schueremans, P. B. Lourenço, and T. Miranda, “Modelling the Structural Behaviour of Rammed Earth Components,” presented at the The Twelfth International Conference on Computational Structures Technology, Naples, Italy, p. 112 . <https://doi.org/10.4203/ccp.106.112>
- [14] H. Varum, A. Costa, J. Fonseca, and A. Furtado, “Behaviour Characterization and Rehabilitation of Adobe Construction,” *Procedia Engineering*, vol. 114, pp. 714–721, 2015 . <https://doi.org/10.1016/j.proeng.2015.08.015>