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وزارة إعداد التراب الوطني والتعمير والإسكان وسياسة المدينة
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Ministère de l'Aménagement du Territoire National, de l'Urbanisme, de l'Habitat et de la Politique de la Ville

EARTH CONSTRUCTION KERPİC AKADEMİ
Prof. Dr. Bilge IŞIK I.T.U Faculty of Architecture Building Construction Technology Department - Kerpic Network

KERPİC'25

13th International Conference
PROCEEDINGS

"EARTHEN ARCHITECTURAL HERITAGE"

25-27 September 2025, Rabat / MOROCCO

Edited by,
Aysel TARIM,
Bilge ISIK and Khalid EL HARROUNI
Organized by,
Kerpic Akademi, Kerpic Network
Ecole Nationale d'Architecture, Rabat

13th International Conference PROCEEDINGS

25 September – 27 September 2025

Kerpic'25

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Ecole Nationale d'Architecture de Rabat / MOROCCO

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www.kerpic.org/2025

Edited by

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Graphic-Design

Aysel TARIM

Printing Office

Ecole Nationale d'Architecture
Rabat / Morocco

ISBN

978-9920-9058-3-1

THEMES OF THE CONFERENCE:

Main theme: **Exploring Earthen Architectural Heritage**

This scientific Conference, organized by Kerpic Akademi, Turkey, and the National School of Architecture of Rabat (ENA Rabat), Morocco, in partnership with its Doctoral Studies Center CEDoc "Architecture and related Disciplines", its research structure LabHAUT (Habitat, Architecture, and Urbanization of Territories Laboratory) and its UNESCO Chair "Education and Research in Sustainable Bioclimatic Urban Planning and Architecture", proposes to examine, on the one hand, the earthen architectural heritage production described as vernacular, appreciated for its diversity and richness, its specificities and singularities adapted to various environments and contexts. On the other hand, it will look at local building skills and techniques, analyzing their organization, use, adaptability, evolution, and durability. By extension, this conference explores the benefits and virtues of earthen architecture in eco-responsible practices and comfort, aiming to make it an invaluable source of inspiration for new construction.

It is also proposed to examine national and international experiences in protecting, restoring, and rehabilitating this essential earthen architectural heritage. Depending on the context, these rehabilitation initiatives are interpreted through various prisms, including Learning from earthen architecture in climate change;

Conference Sub-Themes

- Sustainability in building materials
- Sustainable architecture and sustainable cities
- Rebuilding cultural landscape after disaster, war
- Social, cultural, touristic reuses of heritage
- Researches on principles and methods of conservation
- Heritage site planning and management
- Repair and strengthening strategies and techniques Evaluation of Risk and Protection against environmental effects and disasters
- Traditional construction techniques
- Living spaces and local teachings
- Traditional materials and current research

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« Sauvegarder et gouverner : Ksour et Kasbah entre héritage architectural, développement durable et action publique »

Keynote Speaker:

M. Abdellah Hachimi,

Directeur du Programme de Valorisation Durable des Ksour et Kasbahs, Maroc

Résumé

Les ksour — villages fortifiés en terre du Maroc — condensent un millénaire d'échanges entre sociétés nomades et sédentaires, commerce transsaharien et agroécosystèmes oasiens. Sur le plan architectural, ils combinent des formes urbaines défensives avec des typologies d'habitat finement élaborées : maisons à patio sur plusieurs niveaux en adobe ou en pisé, planchers en bois de palmier, et vides lanternés régulant lumière, circulation d'air et confort. Sur le plan social, les ksour institutionnalisent une gouvernance collective (conseils, équipements communs, irrigation et greniers), la réciprocité et l'entretien partagé — des principes qui ont historiquement assuré à la fois la défense et l'habitabilité quotidienne.

La présentation retrace cette formation de longue durée et les points d'inflexion du XXe siècle — déclin des économies caravanières, logiques routières, nouveaux régimes administratifs, exode rural, et tournant symbolique vers le ciment — qui ont fragmenté les tissus compacts, affaibli les cycles de travail collectif et accéléré l'obsolescence technique. Elle passe ensuite du diagnostic à l'action à travers le **Programme national de valorisation Durable des ksour et kasbah**, conduit conjointement par le **Ministère marocain de l'Habitat** et le **PNUD**. Conçu comme une politique de résilience territoriale, ce programme articule conservation architecturale, gouvernance et moyens de subsistance par : (1) l'établissement d'un inventaire national et d'évaluations des risques et vulnérabilités multi-aléas ; (2) la formation et la certification d'artisans de la construction en terre ; (3) des opérations pilotes d'amélioration des logements et de restauration d'espaces publics et d'ouvrages fortifiés ; (4) la mise en place de financements inclusifs (Activités génératrices de revenus); et (6) l'alignement de la gouvernance multi-niveaux (nationale, régionale, communale) avec les **ODD 11/13** et le **Nouvel Agenda Urbain**.

"Safeguarding and Governing: Ksour and Kasbahs Between Architectural Heritage, Sustainable Development, and Public Action"

Keynote Speaker:

Mr. Abdellah Hachimi,

Director of the Sustainable Development Program for Ksour and Kasbahs, Morocco

Abstract

The ksour—fortified earthen villages of Morocco—encapsulate a millennium of exchanges between nomadic and sedentary societies, trans-Saharan trade, and oasis agroecosystems. Architecturally, they combine defensive urban forms with finely crafted housing typologies: multi-story patio houses made of adobe or rammed earth, palm wood floors, and lantern-lit voids regulating light, air circulation, and comfort. Socially, the ksour institutionalize collective governance (councils, common facilities, irrigation, and granaries), reciprocity, and shared maintenance—principles that have historically ensured both defense and daily habitability. The presentation traces this long-term formation and the turning points of the 20th century—the decline of caravan economies, road logic, new administrative regimes, rural exodus, and the symbolic shift towards cement—which fragmented compact fabrics, weakened collective work cycles, and accelerated technical obsolescence. It then moves from diagnosis to action through the National Program for the Sustainable Development of Ksour and Kasbah, jointly led by the Moroccan Ministry of Housing and the UNDP. Conceived as a policy of territorial resilience, this program articulates architectural conservation, governance, and livelihoods through: (1) the establishment of a national inventory and multi-hazard risk and vulnerability assessments; (2) the training and certification of earth construction artisans; (3) pilot operations for housing improvement and the restoration of public spaces and fortified structures; (4) the establishment of inclusive financing (Income-generating activities); and (6) the alignment of multi-level governance (national, regional, municipal) with SDGs 11/13 and the New Urban Agenda.

Legacy and Paleo-Innovation. Lessons from the Past Regenerate the Future of Earthen Architecture

Keynote Speaker:

Dr. Salima Naji,
Architect, anthropologist, and restorer, Morocco

Abstract

The reflection on raw earth is extremely fertile, particularly in heritage restoration projects, where structures are exposed. Various cases (Agadir Oufella, Ksar Assa, Ksours du Draa, heritage of Tessaoute and Imeghrane, Ismaili heritage of Meknes) of rescues have allowed us, in recent years, to show the value of this heritage, often through archaeology, or in an archaeology of the building. The "heritage" was also done, as soon as possible, to show the heuristic value of these earth technologies (ancestral paraseismic devices of Agadir and Tessaout) in an educational presentation to visitors. Moreover, the transmission to private and public operators was a place of another type of commitment, because it is essential to ensure this heritage is transmitted to future generations without being misused. The question of the future, since the Icomos charters, is posed for a heritage deemed fragile. We will conclude from concrete cases on the "lines of generation" dear to Tim Ingold, to continue the reflection on challenges affecting so-called contemporary implementations.

Restaurer pour transmettre: la réhabilitation des tighermines et des ighermans après le séisme d'El Haouz

Keynote Speaker:
Mohamed Boussalh
Directeur du Centre de Restauration et de Réhabilitation du Patrimoine Architectural des Zones Atlasiques et Subatlasiques, CERKAS, Maroc

Résumé

Les tighermines et les ighermans, greniers collectifs fortifiés des montagnes de l'Atlas, constituent un patrimoine architectural et social unique, reflet de l'organisation communautaire amazighe. Le séisme d'El Haouz en septembre 2023 a gravement endommagé nombre de ces édifices, posant avec acuité la question de leur sauvegarde et de leur transmission aux générations futures.

Cette communication, portée par le CERKAS, expose l'approche adoptée pour la réhabilitation de ces architectures de terre, fragiles mais essentielles à l'identité des territoires atlasiques. Elle met en avant l'importance d'allier savoir-faire vernaculaires (pisé, adobe, charpente en bois) et apports techniques contemporains afin de garantir à la fois l'authenticité patrimoniale et la sécurité structurelle.

L'accent est mis sur la participation active des communautés locales, véritables dépositaires des traditions constructives, et sur la dimension durable des chantiers menés après le séisme. À travers des exemples concrets, la communication montre comment la restauration peut devenir un vecteur de résilience, de cohésion sociale et de développement territorial.

Restoring to Pass on: The Rehabilitation of Tighermines and Ighermans after the El Haouz Earthquake

Keynote Speaker:
Mohamed Boussalh
Director of the Center for the Restoration and Rehabilitation of Architectural Heritage in the Atlas and Sub-Atlas Zones, CERKAS, Morocco

Abstract

Tighermines and Ighermans, fortified collective granaries in the Atlas Mountains, constitute a unique architectural and social heritage, reflecting Amazigh community organization. The El Haouz earthquake in September 2023 severely damaged many of these buildings, raising the acute question of their preservation and transmission to future generations.

This presentation, presented by CERKAS, outlines the approach adopted for the rehabilitation of these earthen structures, fragile yet essential to the identity of the Atlas regions. It highlights the importance of combining local know-how (rammed earth, adobe, timber framing) with contemporary technical contributions to ensure both heritage authenticity and structural safety. Emphasis is placed on the active participation of local communities, the true custodians of construction traditions, and on the sustainable dimension of the projects carried out after the earthquake. Through concrete examples, the presentation shows how restoration can become a vector of resilience, social cohesion, and territorial development.

Earthquake Resistance Research of Horizontal Flexibility Layered Rammed Earth-Gypsum Wall on: Shaking Table

Prof. Dr. Bilge Işık, Neslihan Işık

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ABSTRACT

This study summarizes the research on seismic performance **with horizontal flexibility layers** of rammed earth load-bearing buildings. Kerpic Org Earthquake safety studies for load-bearing earth walls have been ongoing at Istanbul Technical University since 1985. Laboratory experiment findings, developed at the İTÜ laboratory, and rammed earth construction techniques have been used on a fullscale real building. A rammed earth building in earth stabilized with 10% gypsum and 2% lime material was built in 1995 as TÜBİTAK INTAG TOKİ 622 research project at İTÜ Ayazaga Campus. This research building withstood the major earthquake that affected Istanbul in 1999 without any damage. The **horizontal flexibility layers**, built-in the research building rammed earth wall every 30 or 40cm sections providing energy dissipation, proved the earthquake resistance of the building at this earthquake. A full scale research paper was disclosed but have not resulted in government regulations.

Continuing this research in 2025, the aim is to develop industry standards and government regulations for Rammed Earth Horizontal Flexibility Layer Seismic Walls. At Istanbul Technical University, Faculty of Civil Engineering laboratories, we have built 3 rammed earth wall samples 150cm x 90cm h150cm. These samples were constructed using rammed earth technology with earth stabilization with 10% gypsum and 2% lime. All 3 walls were tested on a "Shaking table." One wall was built as a control unit, solid without any special layers. Horizontal Flexibility Layers were applied every 27cm on the second wall. The third wall was constructed as solid and after drying process horizontal flexibility layers were applied by partially puncturing the wall surface 5cm in depth. Tests on the shaking table at the Disaster Management Laboratory of Istanbul Technical University started with the three rammed earth walls after drying for 6 weeks.

The findings from these experiments showed that the previously developed knowledge reached the same positive results in current tests. Work is ongoing to report these findings and carry out the necessary administrative processes to include this information in the relevant regulations through the Ministry of Environment, Urbanization and Climate Change.

This research is particularly important for the need of housing demand, following the February 6, 2023 earthquakes in Turkey. The goal of this 40 year study is to use this technology with horizontal flexibility layers in load-bearing walls to dissipate the energy ofthe earthquake and diminish the impact on buildings constructed with load-bearing walls. The aim is to meet the need for 75,000 rural homes in the region. Knowledge gained by research will update the "National Earthquake Regulations" to verify the reliability of earthquake safety with the horizontal layer and stabilization of earthen construction material with gypsum and lime.

Keywords: Codes, regulations, standards, earthquake resistance, rammed earth-gypsum wall,horizontal flexibility layers, shaking table

Integrating Sustainability and Universal Design in Urban Development: Inclusive Cities

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ABSTRACT

The increasing urbanization of the global population has placed a significant strain on cities, raising concerns about their environmental, social, and economic sustainability. This study examines the intersection of sustainability and universal design, arguing that inclusive urban planning is essential for the creation of sustainable cities. The main objective of this study is to explore how universal design principles can be integrated into urban planning processes to promote both environmental sustainability and social inclusivity. The research seeks to assess the impact of universal design on the sustainability of cities, focusing on how accessibility, equity, and environmental performance can be mutually reinforced in urban environments. To achieve these objectives, the study employs a mixed-methods approach, combining a literature review of existing academic and professional studies on urban sustainability and universal design with case studies of cities that have successfully incorporated these principles into their planning frameworks.

The findings of this study indicate that the integration of universal design into urban development not only enhances accessibility but also contributes to broader sustainability goals. The implementation of inclusive design principles leads to more efficient use of resources, reduced carbon footprints, and improved social equity. These strategies also foster better community engagement, enhance public health outcomes, and reduce inequalities in urban environments. The article concludes by recommending that urban planners and policymakers prioritize universal design in sustainable development strategies to foster cities that are both environmentally responsible and socially inclusive, thereby promoting long-term resilience, economic growth, and improved quality of life for all inhabitants.

Keywords: Sustainability, Universal Design, Urban Development, Social Inclusion, Accessibility.

1 INTRODUCTION

Universal design principles aim to create environments that are accessible, understandable, and usable by all individuals regardless of age, ability, or status. Within the context of urban transformation, this approach offers opportunities not only to renew the physical environment but also to enhance social inclusion. The integration of universal design into spatial planning has become an essential part of sustainable urban strategies, particularly in the context of ecological resilience and democratic participation.

This paper evaluates key case studies in Turkey and Europe that reflect the convergence of universal design and sustainability in urban development. The focus is on four core themes: water recycling and accessibility, waste management and circular economy, natural energy production, and universal

design in urban transformation strategies. Each section highlights how inclusive spatial design contributes to ecological balance, social equity, and urban innovation.
The sustainability of inclusive cities is linked to the integration of universal design principles into essential urban systems such as water recycling, waste management, natural energy production, and urban transformation strategies. These domains not only support ecological resilience and resource efficiency but also shape the accessibility and usability of urban environments for all populations, including individuals with disabilities, the elderly, and other marginalized groups. For instance, accessible water recycling infrastructure ensures equitable access to clean water and sanitation, while inclusive waste management systems foster civic engagement through user-friendly collection and disposal mechanisms. Similarly, renewable energy facilities designed with universal access in mind democratize environmental education and enhance public interaction with sustainable technologies. Moreover, urban regeneration strategies rooted in universal design enable the transformation of complex topographies and historical urban fabrics into inclusive, livable environments without compromising cultural integrity or ecological sustainability. Together, these interconnected systems create a foundation for socially equitable and environmentally responsible urban development, aligning with global goals for sustainable, resilient, and inclusive cities [1].

1.1 Study Purpose and Sample Selection

This study aims to explore the integration of universal design principles into sustainable urban development practices within the Turkish context. In order to provide a comprehensive and regionally representative analysis, a selection of cities across Turkey—namely Istanbul, İzmir, Konya, Kayseri, Manisa (Soma), Bursa, and Safranbolu—were examined as case studies. Each of these urban areas was chosen for their distinct geographical, historical, and developmental characteristics, offering diverse contexts in which universal design and sustainability intersect. Istanbul was selected due to its status as a metropolitan hub with complex infrastructural challenges and leading-edge waste and water management systems. İzmir, with its Çiğli Green Infrastructure Project, represents a forward-thinking approach to ecological design in public spaces. Konya provides insight into pedestrian-focused urban regeneration, while also enabling comparative analysis through its housing developments. Kayseri illustrates the application of hybrid energy systems in public transportation infrastructure, aligning mobility with environmental goals. Manisa's Soma region represents renewable energy deployment through inclusive wind energy facilities. Lastly, Bursa and Safranbolu exemplify the application of universal accessibility standards within culturally and topographically sensitive heritage zones. The selection of these cities was intentional to capture a wide array of spatial scales, typologies, and implementation strategies, thus enabling a multidimensional understanding of inclusive and sustainable urban design practices in Turkey.

1.2 Research Methodology

The study adopts a qualitative, multiple-case study methodology supported by a mixed-methods framework. The core method involves a detailed literature review of peer-reviewed academic articles, municipal planning documents, and technical reports related to sustainability and universal design. This review is supplemented by visual and architectural analysis of selected urban interventions and infrastructures across the aforementioned cities. Comparative evaluation criteria include accessibility features, integration of renewable energy technologies, resource efficiency, and inclusive spatial strategies. By employing a cross-sectional analysis of different geographic and socio-economic contexts, the study identifies best practices and challenges in the implementation of universal design within sustainable urban systems. The methodological approach allows for the synthesis of interdisciplinary perspectives, incorporating architecture, urban planning, environmental science, and social policy to holistically assess the transformative potential of inclusive design in contemporary urbanism.

2 WATER RECYCLING: ACCESSIBILITY IN UNIVERSAL DESIGN

Water recycling is increasingly recognized as a cornerstone of sustainable urban development. Universal design plays a pivotal role in making these systems accessible to all citizens. The Ataköy

Advanced Biological Treatment Plant [Figure 1] in Istanbul processes 20,000 m³ of wastewater daily, providing reclaimed water for street cleaning, landscaping, and public spaces. The facility includes low-level faucets, accessible irrigation panels, and bilingual signage to ensure inclusive interaction with its water management system [2].

Figure 1. Ataköy Advanced Biological Treatment Plant-Technical Infrastructure Site Layout [3].

Similarly, the "Eco-City" scenario developed by Istanbul Technical University integrates greywater and rainwater systems into accessible public infrastructure [Figure 2]. The project proposes the use of digital panels and tactile navigational tools to facilitate user engagement. Simulation studies show that this system can achieve up to 64% water savings and generate 15 MWh of energy per day [4]. These examples demonstrate that accessibility is not merely a technical feature but a social imperative in sustainable water systems.

Figure 2. ITU Ekokent Scenario Layout Plan [5].

3 WASTE MANAGEMENT AND CIRCULAR ECONOMY: ACCESSIBLE PUBLIC INTEGRATION

Waste management has evolved beyond basic disposal, now serving as a driver for circular economies. Istanbul's Waste Incineration and Energy Production Plant in Eyüp processes 3,000 tons of waste per day, generating 175 MWh of thermal and 78 MWh of electrical energy [Figure 3]. The

site incorporates accessible information panels and user-friendly waste drop-off stations designed for wheelchair users and children alike [6].

Figure 3. Aerial schematic view of a waste-to-energy incineration plant (similar to Istanbul's Eyüp facility), showing main structures, energy conversion units, and surrounding green buffers — adapted from a case study by Stantec on the Istanbul Waste Power Plant project [7].

The ISBAK Smart Container Systems enhance public engagement through real-time information on container fullness, displayed via visual, auditory, and tactile interfaces [Figure 4]. These systems not only support inclusivity but also optimize waste collection routes, thus reducing carbon emissions [8].

Figure 4. İSBAK's Smart Container System: Example of IoT-enabled smart waste containers equipped with fill-level sensors and remote communication capabilities, akin to ISBAK's smart bin infrastructure [8].

In İzmir, the Çiğli Green Infrastructure Project introduces compost bins into public parks, with low-incline pathways and multilingual signage [Figure 5]. This initiative bridges the gap between waste processing and public education, creating a model for socially inclusive ecological urbanism [9].

Figure 5. The map showing planned green infrastructure arrangements in Çiğli, İzmir: GIS-based city sampling including green areas, tree cover density and habitat quality [10].

4 NATURAL ENERGY PRODUCTION: INCLUSIVE AND SUSTAINABLE DESIGN

Renewable energy facilities are increasingly designed as interactive, educational, and accessible environments. The Karapınar Solar Energy Plant, with a capacity of 1,300 MW, includes accessible walkways, tactile signage, and a visitor center designed by Bilgin Architects [Figure 6]. The architectural features, such as the dual-layer steel facade, minimize heat gain and reflect the landscape's character while enhancing user comfort [11].

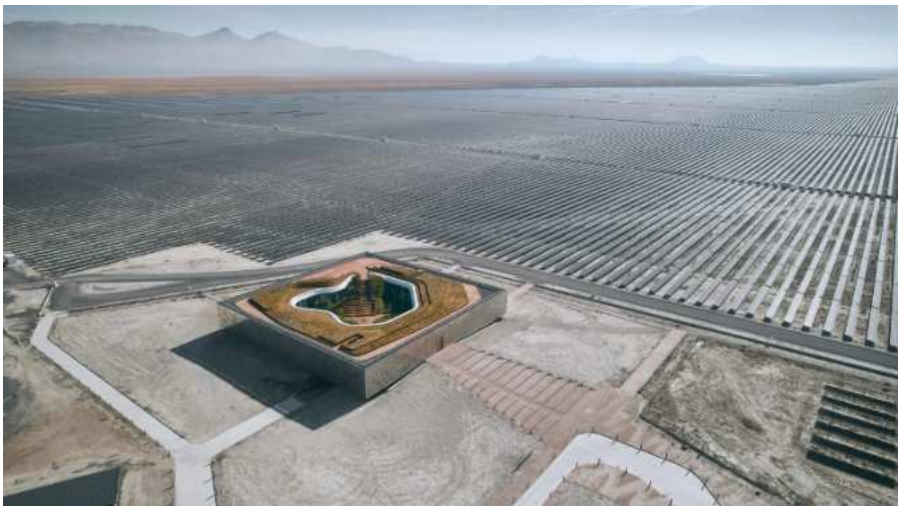

Figure 6. Aerial view of the central control building (hub) at Kalyon Karapınar Solar Power Plant, clad in reflective steel and integrated into the surrounding solar field. Brownish courtyard and surrounding solar arrays are visible, illustrating architectural integration with renewable infrastructure. Captured by Green Prophet [12].

The Soma Wind Energy Plant incorporates ramped access paths, audio-guided tours, and tactile displays to make the turbine zones accessible to all. These features foster public engagement with energy production and democratize environmental education [13]. Also, Kayseri's Hybrid Tram System integrates solar and biomass energy with storage solutions [Figure 7]. Its accessible

platforms, visual-audio systems, and intuitive design features meet the needs of diverse user groups, thereby advancing both sustainability and social equity [14].

Figure 7. Kayseri city tram [15].

At the national level, Turkey's goal to install 120 GW of renewable capacity by 2035 includes provisions for integrating these systems into public buildings and civic spaces with universal access [16].

5 URBAN TRANSFORMATION STRATEGIES THROUGH UNIVERSAL DESIGN

Universal design is critical in rethinking urban regeneration as a socially inclusive endeavor. The Zafer Pedestrian Zone in Konya [Figure 8] addresses grade changes with sloped ramps and multisensory navigation tools, creating a space accessible to people of all abilities [17].

Figure 8. Night view of the street converted into a pedestrian area in Konya Zafer Square [18].

Heritage sites like Safranbolu and Bursa illustrate the challenge of applying universal design in topographically and historically sensitive areas [Figure 9]. With thoughtful interventions—tactile paving, sympathetic ramps, and integrated signage—it is possible to balance preservation with accessibility [19].

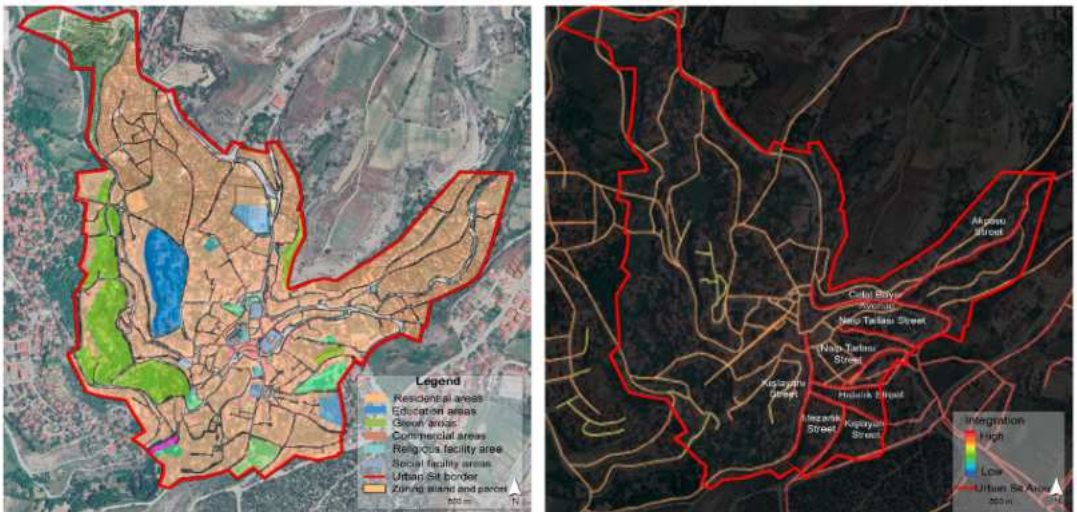

Figure 9. Integration map of the Safranbolu Urban Protected Area showing spatial accessibility metrics and street network integration levels [20].

Bursa Kent Meydanı, located in the historic core of the city, exhibits key features of ergonomic and sustainable urban design [Figure 10]. As a major public square, it integrates pedestrian-friendly infrastructure, promotes walkability, and supports high levels of public use, contributing to both environmental and social sustainability. The figure provides a spatially explicit representation of accessibility patterns within the square, emphasizing pedestrian flow routes, degrees of spatial integration, and critical walkability nodes. This visual analysis serves as an effective tool for assessing the implementation of inclusive design principles in dense urban environments. In particular, it demonstrates how concepts such as equitable access and walkable connectivity are operationalized in the context of Turkish city centers through strategic spatial planning and design interventions.

Figure 10. Connectivity, local integration, and global integration maps of Kent Meydanı (City Square) in Bursa. This Space Syntax–based analysis illustrates pedestrian accessibility patterns, indicating axes with high connectivity and movement potential—critical indicators of inclusive urban design in historic city centers [21].

6 DISCUSSION: EARTHEN ARCHITECTURAL HERITAGE AND INCLUSIVE URBAN FUTURES

Earthen architectural plays a critical role at the intersection of heritage, sustainability, cultural continuity and universal design. As cities turn to ecological resilience and inclusivity goals, earthen architecture, long practiced as a vernacular response to climatic, material and social conditions, offers important lessons for sustainable and accessible urban futures. Traditional earthen settlements seen in Anatolia, North Africa and the Middle East can adapt to the local environmental context with passive cooling systems, community-oriented spatial arrangements and construction methods with high resource efficiency [22]. These features strongly overlap with the principles of universal design, which aim to create human-centered environments that prioritize accessibility, usability and social interaction. For example, the compact planning and shaded public courtyards found in earthen urban fabrics naturally support walkability and social inclusion;

Moreover, the earthen heritage highlights the need to integrate cultural authenticity into sustainable design strategies. Safranbolu, a UNESCO World Heritage Site, provides a strong example of how earthen and stone-based architectural typologies can be preserved and transformed to comply with modern accessibility standards [23]. Recent interventions in Safranbolu and similar heritage cities demonstrate that universal access can be achieved through tactile surfaces, ramps and information signs applied without damaging the traditional aesthetics [19]. Such initiatives demonstrate that universal design is not opposed to heritage protection; on the contrary, it can serve as a bridge that harmonizes contemporary inclusive urban visions with the cultural values carried by historical places. When evaluated in terms of sustainability, earthen material has a renewable potential that directly supports global climate goals. Earthen structures, which stand out with their low embedded energy, recyclability and ability to regulate thermal comfort without the need for mechanical systems [24], contribute to strengthening urban resilience in both ecological and social dimensions when combined with universal design. In fact, community-based earthen construction initiatives not only reduce the carbon footprint; they also encourage participatory design processes that include different groups such as the elderly, disabled and children [25]. These participatory frameworks directly correspond to the "equal use" principle of universal design and ensure that sustainable heritage-focused design benefits broad user groups.

In the context of urban transformation strategies, the integration of earthen architectural heritage offers an important counterpoint to the homogenizing tendencies of globalizing urbanization. The adoption of earthen traditions with their material properties, spatial logic and cultural symbolism allows urban planners and policy makers to produce inclusive spaces that are not only sustainable but also contextually strong. This approach emphasizes that earthen architecture is a resource both structural efficiency and cultural identity [26]. In conclusion, the intersection of sustainability, universal design and earthen heritage reveals a holistic inclusive urban paradigm in which environmental responsibility, cultural preservation and social equality reinforce each other.

7 CONCLUSION

The integration of universal design with sustainable urban planning redefines city infrastructure, transforming it from a system of basic functionality into a framework that fosters inclusivity, equity, and resilience. The case studies presented in this study—ranging from Ataköy's reclaimed water systems and Kayseri's hybrid tram network to Çiğli's compost-based public parks—illustrate how diverse urban systems such as water management, waste processing, energy production, and regeneration strategies can be aligned with accessibility principles. These examples affirm that inclusivity and sustainability are not isolated objectives but mutually reinforcing components of effective urban development.

As cities across the globe confront the intertwined challenges of climate change, demographic shifts, and social inequality, the institutionalization of universal design must become a foundational element

of urban policy, rather than an optional or peripheral consideration. Embedding universal design at the core of planning processes enables cities to address both environmental and social objectives simultaneously. This approach supports the development of public spaces and infrastructures that are not only environmentally efficient but also accessible to individuals of all ages, abilities, and socioeconomic backgrounds.

In the context of global efforts toward carbon neutrality and ecological resilience, the convergence of universal design and sustainability provides a comprehensive and actionable framework for shaping equitable and livable urban futures. Policymakers and planners are thus encouraged to adopt this integrated perspective to ensure that future cities are not only sustainable in environmental terms but also inclusive and adaptive.

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Comparative Environmental Impact Assessment of Exterior Walls: Traditional Timber Framed Turkish Houses with Aerated Concrete Block

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ABSTRACT

The research aims to conduct a comparative carbon footprint analysis of the exterior walls of timber-framed houses and aerated concrete block walls, highlighting the eco-friendly attributes of timber-framed houses. In this study, in a size of 150 cm x 150 cm, 4 different types of hımış and the layers were determined based on a PhD thesis named "Hygrothermal Performance Assessment of Exterior Walls of Traditional Timber Framed Houses in Türkiye". In addition, an aerated concrete block wall and its layers are designed as a 150 cm x 150 cm sample for comparative analysis. This study conducts a comparative environmental impact assessment of traditional timber-framed walls and aerated concrete block walls, focusing on their carbon footprint, embodied energy, and life cycle performance. Using a Life Cycle Assessment (LCA) approach, the study evaluates key parameters, including material production emissions, operational energy efficiency, and end-of-life disposal. The results show that the aerated concrete block wall sample has the lowest total energy and total embodied CO_2 emissions compared to the traditional timber-framed wall samples. Additionally, the total energy and total embodied CO_2 emission increase when materials and layers are varied. Thus, usage of local materials in traditional timber-framed buildings' exterior wall samples represents crucial knowledge. Furthermore, wood materials have played a negative role in carbon emissions, in addition to their distinguished local material applications in vernacular architecture. The revival of traditional construction techniques can help mitigate the built environment's carbon footprint, promoting climate-responsive architecture and environmentally responsible building practices.

Keywords: Life Cycle Assessment (LCA), Carbon footprint, embodied energy, traditional timber framed, aerated concrete block

1 INTRODUCTION

The building sector accounts for roughly 40% of global energy use and is responsible for 36% of CO2 emissions worldwide, making it a key focus for climate change mitigation efforts [1]. In this context, the environmental impact of building materials has attracted significant attention, especially regarding their carbon footprint throughout their entire life cycle. The Life Cycle Assessment (LCA) methodology, formalized during the 2002 World Summit on Sustainable Development in Johannesburg, has become a vital tool in the construction industry for assessing environmental performance over a building's full life span [2]. This comprehensive approach measures resource consumption, energy use, waste production, and environmental impacts during the design, construction, and demolition phases. LCA supports informed decision-making by offering comparative analysis of design options, guidance on material selection, and benchmarking

performance against sustainability standards, ultimately aiding the development of more environmentally responsible building practices [3].

The choice of wall systems has a significant impact on the overall environmental performance of buildings. Recent comparative studies have demonstrated substantial variations in environmental impacts between different wall construction systems. The results of comparative research on the environmental impacts of a three-story reinforced concrete masonry single-family house and an identical timber building in Luxembourg indicate that the timber building has a 43.5% lower global warming potential than the concrete building, although the concrete building demonstrates a 15.6% reduction in primary energy demand [4]. A single-family house in Guayaquil, Ecuador, is analyzed comparing aerated concrete blocks and conventional materials. It is observed that the most contributing process was clinker production, generating 7,998 kg CO_2-eq for traditional housing and 5,113 kg CO_2-eq for non-traditional housing, thus reaching a difference of 36% in terms of time and cost efficiency in application [5].

Timber construction has regained interest as a sustainable building option because of its potential for carbon sequestration and lower embodied energy compared to traditional materials. Felmer et al. [6] showed that mass timber buildings in central Chile produced 42% less embodied carbon than equivalent reinforced concrete buildings. However, recent studies have pointed out complexities in the environmental benefits of timber construction, especially regarding the timing of carbon sequestration and biogenic carbon accounting in LCA studies [7, 8].

Traditional timber-framed buildings represent a significant part of vernacular architecture worldwide and embody centuries of sustainable building practices tailored to local climate and material conditions. In Türkiye, traditional timber-framed structures—locally known as 'hımış'—are distinctive examples of vernacular architecture that have evolved over centuries to achieve harmony with the local climate, topography, and available materials [9]. These buildings, composed of rectangular wooden studs filled with materials such as adobe, stone, brick, or left unfilled, can be categorized into four groups: (1) timber-framed adobe infill, (2) timber-framed brick infill, (3) timber-framed stone infill, and (4) unfilled timber frames [10]. They are unique designs that blend naturally with their surroundings. The use of timber, a natural material, combined with traditional knowledge, offers an environmentally friendly construction method. Given these factors, the paper focuses on the environmental impact assessment of the exterior walls of traditional timber-framed buildings, comparing them with walls made of aerated concrete blocks.

2 CASE STUDY: COMPARATIVE CARBON FOOTPRINT ANALYSIS OF THE SELECTED EXTERIOR WALLS

2.1 Method Application

This study presents a comparative environmental impact analysis of five external wall assemblies based on their embodied energy and embodied carbon emissions. The selected wall systems include both traditional timber-framed constructions with various infill types and an aerated concrete wall system. All assessments were conducted on a standard wall module measuring 150 × 150 cm (2.25 m^2). In size of 150 cm x 150 cm, 4 different types of hımış and the layers were determined based on a PhD thesis named "Hygrothermal Performance Assessment of Exterior Walls of Traditional Timber Framed Houses in Türkiye" [Fig. 1].

Figure 1. The selected 4 different hımış types of walls [11]

The wall samples and their layers are presented in Table 1.

Table 1. The layers of the selected walls.

Wall type	*Wall code*	*Wall layers from exterior to interior*
Timber framed stone infill	FM2.2 [12]	Timber framed stone infill 10 cm. Lathing 1 cm. Lime plaster 2 cm.
Timber framed adobe infill	SAM1.2[12]	Lime plaster 3 cm. Mud plaster 3 cm. Timber framed adobe infill 12 cm. Lime plaster 2 cm
Timber framed brick infill	SİM1.1 [12]	Timber framed brick infill 12 cm. Lime plaster 2 cm
Timber-framed unfilled	ZM1.2 [12]	Wood veneer 3 cm, Timber framed unfilled 10 cm. Lathing 1 cm. Lime plaster 2 cm.
Aerated concrete block wall	AC	Paint, Plaster 2 cm. Aerated concrete block 30 cm. Plaster 2 cm. Paint

This analysis examines the environmental impact assessment of traditional timber-framed walls and an aerated concrete block wall, focusing on their carbon footprint, embodied energy, and life cycle performance. By employing a Life Cycle Assessment (LCA) approach, the study examines key parameters, including material production emissions, operational energy efficiency, and end-of-life disposal. This research utilizes the Turcomdat database by Suratam and the ICE: Inventory of Carbon and Energy database (versions 2.0 and 3.0) to determine the per-unit embodied energy and CO_2 emissions associated with the façades of the selected examples [13]. The data for the materials used in the calculation are presented in Table 2. Even if the wooden materials vary for each wall sample, all the wooden materials are assumed to be wood, as specified in the dataset, for calculation purposes. The wall area of the selected examples is calculated to be 2.25 m². Then, for each wall sample, the wall materials are calculated based on their mass. The embodied energy (MJ) and embodied carbon emissions (kg CO_2-eq) for each wall type were calculated using a mass-based approach, taking into account the thickness and surface area of each material layer. The calculation steps are explained below.

Step 1: Mass of Material (kg)

$$m_i = A \times t_i \times \rho_i \quad (1)$$

Where:

- A: surface area of the wall (2.25 m²)
- t_i: thickness of material layer i (m)
- ρ_i: density of material i (kg/m³)

Step 2: Total Embodied Energy (MJ)

$$EE_total = \Sigma (m_i \times EE_{m,i}) \quad (2)$$

Step 3: Total Embodied Carbon Emissions (kg CO_2)

$$EC_total = \Sigma (m_i \times EC_{m,i}) \quad (3)$$

The system boundary is defined as cradle-to-gate, including raw material extraction and processing, but excluding transport, installation, operational energy, and end-of-life phases. The functional unit for comparison is 2.25 m² of wall area.

Table 2. The data for the materials.

Wall code	*Wall layers from exterior to interior*	*Density (kg/m³)*	*Energy (MJ/kg)*	*CO_2 (kg/kg)*	*Mass (kg)*	*MJ/kg*	*Energy (MJ)*	*CO_2/kg*	*Emisyon (kg)*
FM2.2	Timber frame	500	12	0.48	71.85	12	862.2	0.48	34.49
	Stone	2200	1.23	0.079	178.86	1.23	219	0.079	14.13
	Lathing	500	12	0.48	11.25	12	135	0.48	5.4
	Lime plaster	1600	5.3	0.78	72	5.3	381.6	0.78	56.16
						Total Embodied Energy (MJ)	1597.8	*Total Embodied Carbon (kg)*	110.2
SAM1.2	Lime plaster	1600	5.3	0.78	108	5.3	572.4	0.78	84.24
	Mud plaster	1730	0.45	0.024	116.8	0.45	52.6	0.024	2.80
	Timber frame	500	12	0.48	57.8	12	693.6	0.48	27.74
	Adobe infill	1730	0.45	0.024	266.1	0.45	119.7	0.024	6.39
	Lime plaster	1600	5.3	0.78	72	5.3	381.6	0.78	56.16
						Total Embodied Energy (MJ)	1819.9	*Total Embodied Carbon (kg)*	177.33
SİM1.1	Timber frame	500	12	0.48	55.68	12	668.2	0.48	26.7
	Brick infill	1800	2.5	0.22	285.48	2.5	713.7	0.22	62.8
	Lime plaster	1600	5.3	0.78	72	5.3	381.6	0.78	56.16
						Total Embodied Energy (MJ)	1763.5	*Total Embodied Carbon (kg)*	145.7
ZM1.2	Wood veneer	500	12	0.48	33.75	12	405.0	0.48	16.2
	Timber frame	500	12	0.48	40.96	12	491.5	0.48	19.66
	Lathing	500	12	0.48	11.25	12	135.0	0.48	5.4
	Lime plaster	1600	5.3	0.78	72	5.3	381.6	0.78	56.16

						Total Embodied Energy (MJ)	1413.1	*Total Embodied Carbon (kg)*	97.4
AC	Paint	1750	39.0	2.14	0.7875	39	30.71	2.14	1.69
	Plaster	1860	1.33	0.18	83.7	1.33	111.32	0.18	15.07
	Aerated concrete block	600	1.47	0.19	405	1.47	595.35	0.19	76.95
	Plaster	1120	1.22	0.07	50.4	1.22	61.49	0.07	3.53
	Paint	1350	59.0	3.14	0.6075	59	35.84	3.14	1.91
						Total Embodied Energy (MJ)	834.7	*Total Embodied Carbon (kg)*	99.2

2.2 Findings and Discussions

5 different wall samples are analyzed in terms of total embodied energy and the total embodied CO_2 emission. The total embodied energy and the total embodied CO_2 emission of the wall samples are illustrated [Fig. 2].

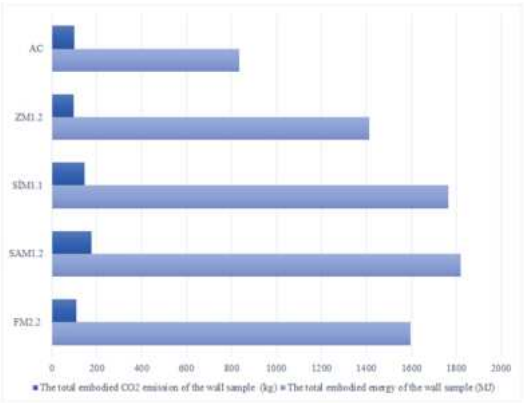

Figure 2. The total energy and total embodied CO_2 emission of the wall samples.

The results are summarized in the following:

- The aerated concrete block wall sample has the lowest total energy and total embodied CO_2 emission than the traditional timber framed wall samples.
- Considering the traditional timber framed wall samples, ZM1.2 has lower total energy and total embodied CO_2 emission than the other 3 different traditional timber framed wall samples.
- It is observed that the total energy and total embodied CO_2 emission increase when materials and layers are varied.

The results indicate that aerated concrete blocks have advantages in terms of carbon footprint analysis. The reason may be listed as:

- It consists of sand, lime, cement and a small amount of aluminum powder.

- Air bubbles are added to the mixture by chemical reactions to have very light and porous structure.
- Low density (~ 600 kg/m³) means less raw material is used for the same volume compared to other materials. It means less energy and CO_2 load per volume.
- Traditional timber framed buildings' exterior walls involve multiple materials: timber frame, stone/ adobe/brick infill, plaster, lathing, internal and external cladding.
- Each material needs to be produced and transported separately which means cumulative environmental impact increases even mostly local materials were used.
- Particularly, lime plaster is a high CO_2 emitter (~ 0.78 kg/kg) and although wood is a carbon storage material, it is an energy-dense material (~ 12 MJ/kg).
- Thanks to the standardized production chain, there is less waste, and less logistics needs.
- In addition, the use of thin-layer plaster and paint consumes less material than traditional plasters.

Even aerated concrete blocks have advantages compared to traditional timber framed buildings' exterior walls regarding carbon footprint analysis, traditional timber framed buildings are significant examples of cultural heritage.

3 CONCLUSION

This study presents a comparative carbon footprint analysis of the exterior walls of traditional timber-framed houses and an aerated concrete block wall. Four different types of traditional timber-framed exterior walls, as well as an aerated concrete block wall, are designed in a size of 150 cm x 150 cm for comparative analysis.

The results show that the aerated concrete block wall sample has the lowest total energy and total embodied CO_2 emissions compared to the traditional timber-framed wall samples. However, usage of local materials in traditional timber-framed buildings' exterior wall samples presents crucial knowledge. Moreover, wood materials have contributed to negative carbon emissions over the years. Additionally, these buildings are excellent examples of the application of local materials in vernacular architecture. Here, the critical issue is to discover positive effects of modern materials while conserving valuable traditional knowledge of vernacular architecture.

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Digital Technologies in Construction Material Waste Management

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ABSTRACT

The construction industry, while providing numerous positive contributions to human life, also has negative environmental impacts, including energy and resource consumption, waste generation, and carbon emissions. In the construction industry, natural resources such as sand, gravel, stone, clay, and wood are heavily utilized, while significant amounts of water are also consumed during material production, construction site activities, and building operations. Furthermore, a substantial amount of waste is generated, particularly during the construction and demolition processes of a building's life cycle. Improper management of waste materials such as concrete, steel, wood, bricks, and paint, which can either be eliminated or minimized, poses a significant threat to environmental sustainability. Therefore, waste management, which is at the core of the circular economy, has increasingly become a critical focal point for the construction industry.

A range of strategies and practices are being developed and implemented in the construction industry to prevent, reduce, and reuse material waste throughout the building life cycle, aiming to keep construction materials within circular processes. Moreover, these strategies and practices are increasingly supported by digital technologies. Digital technologies provide several benefits, such as monitoring waste generation processes, innovatively restructuring the material supply chain, accurately calculating and planning material needs, and categorizing materials in terms of waste suitability. Furthermore, digital technologies offer significant contributions by improving waste management through the simulation of construction and demolition processes, creating a virtual replica of the real world, and enhancing the optimization and coordination of processes by integrating project data and management procedures into digital platforms.

The aim of this study is to explore how digital technologies can be integrated into construction material waste management to minimize/eliminate it. To achieve this objective, a qualitative method known as content analysis was employed to examine studies from current literature. Key digital technology themes were identified, and the existing studies were evaluated. This study is believed to be significant in revealing the current state of digital technologies in construction material waste management, which plays a crucial role in the construction industry, and in identifying the potential needs of the industry in this regard.

Keywords: construction materials, digital technologies, digital waste management, material waste management, waste management.

1 INTRODUCTION

Due to the nature of the construction industry, a wide variety and large quantities of building materials are used. This situation also brings with it the problem of the construction industry generating the highest level of waste compared to other industries [1]. In the construction industry, where a high amount of waste is generated, it has become essential to manage waste through methods such as predicting waste from the earliest process of a building life cycle, reducing waste, developing and implementing new techniques and methods for waste minimization and recycling materials. In recent years, the gradual depletion of resources and the shift from linear economic model to a circular economy model have made it necessary to focus on waste management strategies [2].

Effectively identifying, generating solutions and managing the evolving and growing needs of people through data-driven approaches is important not only for ensuring a human-centered perspective but also for contributing environmental and economic sustainability. According to Top Bim Company's evaluation [3], in the construction industry as well, it is crucial for professionals to follow emerging technologies and design innovations, as this plays a critical role in the construction industry's development. This knowledge base is effective in anticipating changes in today's world and developing appropriate strategies. In this way, the industry will not only be able to adapt to evolving needs but also deliver long-term value through meaningful work. This process also makes a significant contribution to the overall advancement of the industry. Furthermore, this company mentions that construction technology trends watch in 2023-2030 will be focused ten technologies: sustainability and green building, Building Information Modelling (BIM), modular and prefabricated construction, virtual and augmented reality, robotics, 3D printing, autonomous construction equipment, Internet of Things (IoT), Artificial Intelligence (AI) and Big Data and Analytics [3]. However, despite the potential of digital technologies to support sustainability strategies, their implementation in construction waste management is still limited and challenged by various obstacles [4].

To reduce the negative environmental impacts of the construction industry, it is necessary to implement and monitor waste management practices throughout the building life cycle processes. In doing so, understanding the potential implementation areas of emerging and increasingly widespread digital technologies in the construction industry is essential for effectively integrating these technologies into the industry. Therefore, this study aims to investigate potential digital technologies applicable to construction waste management throughout the building life cycle from a holistic perspective. To achieve this, a content analysis method was employed to examine relevant studies from the current literature. Key digital technology themes were identified, and evaluated in relation to the main processes of the building life cycle: pre-construction, construction, and post-construction.

2 CONSTRUCTION WASTE MANAGEMENT AND DIGITAL TECHNOLOGIES

It is widely recognized that the construction industry generates a significant amount of material waste, which is classified as a type of physical waste. Construction and Demolition Waste (CDW) represents the largest share of total solid waste in many European Union countries [1]. Furthermore, according to the waste and recyling statistics 215 million tons of total waste were generated in the United Kingdom in 2024, of which 62% of belonged to CDW [5]. Also, in United States (US), EPA's [6] report shows that in 2018, 600 million tons of CDW debris were generated. According to the report, in the United States, concrete from CDW constituted the largest portion at 67.5%, followed by asphalt concrete at 17.8%. Wood products made up 6.8% of CDW, while all other materials combined accounted for the remaining 7.9% [6]. The same report shows that demolition waste has a greater impact compared to construction waste, whereas approximately 457 million tons were directed to next use, and over 143 million tons of CDW debris were sent to

landfills in 2018. The subsequent uses of these materials are evaluated as compost and mulch, manufactured products, fuel, soil amendment, and, in addition to these methods, aggregates and others as the most preffered usages, among others.

CDW has a crucial role for waste generation. Although recycling of waste generated during construction and demolition processes is possible, this represents only one step in waste management. Throughout the building life cycle, including the internal cycles of material production, strategies for waste prevention should be developed starting from the during pre-construction processes, including design process, and appropriate measures must be taken alongside proper planning. For successful waste management, the building life cycle, which includes the pre-construction, construction, and post-construction processes, could be evaluated from a circular economy perspective in accordance with the 10R strategies. These strategies focus smarter product use and manufacture (refuse, rethink and reduce), extend lifespan of product and its parts (reuse, repair, refurbish, remanufacture and repurpose) and useful applications of materials (recycle and recover) [7]. To apply these strategies within the framework of construction waste management, today's advanced technologies should be considered to enhance the effectiveness of the management process. A data-driven and well-structured waste management system must be developed through the integration of digital technologies. To illustrate, Zhao et al. [4] have put forward the idea that effective information management plays a critical role in construction waste management. In this context, material passports are increasingly recognized as a promising tool to enhance traceability and support circular resource strategies. They have also asserted that the implementation of material passports should be based on the integration of various technologies, including BIM, blockchain, and Radio Frequency Identification (RFID).

3 CONTENT ANALYSIS AND DISCUSSION

Digital technologies play a preventive, monitoring and optimization role in whole processes in the building life cycle. While foresight and design optimization are at the forefront in the pre-construction process, material management and process monitoring play an active role in the construction process, and technologies for recovery and documentation play an active role in the post-construction process [32]. Also, IoT technologies can be used to support waste management throughout all processes of the building life cycle. However, it is noted that the use of technologies such as robotic systems and waste management sensors remains low, pointing to limitations such as technology awareness, budget constraints and lack of training [8].

Table 1. Building project lice cycle processes and digital technologies.

Building Project Life Cycle Processes	*Digital Technologies*
Pre-construction Process	AI, Blockchain Technology, BIM, Digital Twin, IoT, Machine Learning, Material Passports (MPs), Mobile Applications and Smart Platforms
Construction Process	
Post-construction Process	

To have a general understanding of digital technologies integration into construction management throughout building life cycle, a content analysis was employed. Content analysis is defined as a data analysis method that adopts a systematic approach to examine textual, visual, or verbal communication data. Quantifying words, concepts, themes, phrases, characters, or sentences within a dataset helps draw meaningful conclusions from the information [9]. Therefore, this study reviewed the prominent digital technologies in the current literature, focusing on their intended applications in relation to the main stages of the building life cycle (Table 1).

3.1 Pre-construction Process

Pre-construction process is one of the most important processes for building life cycle because of designing and planning whole processes. In construction waste management, the aim during the pre-construction process is to reduce waste generation before it even begins, to predict material flows and to increase the potential for reuse and recycling [10]. In the pre-construction process, the prominent digital technologies and their intended uses for construction waste management are presented in Table 2.

Table 2. Pre-construction processes and digital technologies.

Digital Technologies	***Purpose***
Artificial Intelligence (AI)	-estimation of the amount of waste based on previous projects [4], [11]
Blockchain Technology	-enhancement of the traceability of the material source [4], [10] -waste information management [12]
Building Information Modelling (BIM)	-waste reduction [13], [14], [4], [15], [10], [16] -visual demolition waste management planning [17] -waste reuse [17] -waste recycle [17] -waste prevention [14] -provision of the basic data infrastructure for creating a material passport [4] -implementation of material logistics and inventory tracking, resulting in reduced losses [15] -waste information management [12], [11] -simulation of the demolition process for demolition waste management [18] -waste calculation for building demolition [19]
Digital Twin	-prediction of waste generation [20] -waste estimation [20] -waste quantitative assessment [18] -demolition process planning [18] -optimal disposal route selection [18] -waste management strategy [18]
Internet of Things (IoT)	-real-time monitoring of waste generation and tracking of components enabled by Radio Frequency Identification and sensors [15], [8] -support for blockchain technology in waste information management [12] -provision of data for resource utilization and logistics strategies [11]
Machine Learning	- optimization of materials incorporating waste-derived components [21], [22] -prediction of waste generation [23]
Material Passports (MPs)	-guidance of design decisions based on the reusability and recyclability of building components throughout their life cycle [24], [15] -provision of sustainable material criteria such as product content, toxicity, durability, and reuse potential [24], [15] -contribution to data standardization from product level to building level [15] -providing information for future dismantling processes [25]
Mobile Applications	-
Smart Platforms	-ensuring transparent information flow between all actors through electronic tendering, browser tagging, and online communication tools

	(e.g., email, social media), contributing to the prevention of erroneous decisions and resource waste [8]

According to Table 2, BIM, digital twin and MPs are the preferred and range usage area for pre-construction processes. On the other hand, for waste data information blockchain technology, IoT and smart platforms are preferred whereas mobile applications are not preferred. Also, digital technologies are commonly used for waste prediction, waste estimation and construction and demolition processes planning.

Digital technologies play a role in making decisions that prevent waste generation in the pre-construction process. With BIM, the amount of waste can be predicted at the design process and material selection can be optimized. AI develops waste prediction models by learning from past projects. Blockchain enables secure and transparent management of material passports [4]. MPs enable designers to make decisions based on criteria such as material selection, modularity of building components and disassembly potential. By creating a transparent information infrastructure in the preconstruction process, it enables the reuse of products and systems [24]. Blockchain ensures that material and component information is recorded in a transparent, verifiable and traceable manner during the pre-construction process [10]. In a study addressing the waste management of plastic-based materials, BIM was proposed as a tool to analyze potential waste generation during the construction process in advance, enabling more efficient planning. MP were recommended to provide essential information on the identity, durability, and reusability of the materials used. Additionally, AI-supported decision-making systems were suggested for developing scenarios that minimize waste generation by considering parameters such as material selection, modularity, and design flexibility [26]. Also, IoT plays a significant role in pre-construction processes for planning, resource allocation and material tracking [8].

Digital technologies can be applied to various types of materials, such as earthen materials, recycled materials, or new materials in the pre-construction process. Similarly, these technologies can be utilized for different types of buildings, including new constructions and heritage buildings. For example, BIM helps create 3D models of each type of structure, which can be used for material quantity calculations and structural analyses aimed at waste reduction and waste information management. Additionally, AI and machine learning assist in analyzing structures and determining the best design options for waste management by transferring historical and environmental data. Furthermore, digitally recording the properties and origin of each material used aids in tracking material waste across all types of construction and monitoring how, where, and in what manner these materials are reused or processed.

3.2 Construction Process

Construction process is a key process which has high material usage and produces waste because of implementation. Table 3 presents the key digital technologies and their intended applications for construction waste management during the construction process.

Table 3. Construction processes and digital technologies.

Digital Technologies	***Purpose***
Artificial Intelligence (AI)	-high-accuracy automatic classification of waste enabled by the combined use with image analysis [4] -prompt-guided waste segmentation [27], [28] - data collection on material usage [29]
Blockchain Technology	-ensuring transparency by recording information about when and where materials were used or converted into waste on the blockchain [10] -waste information management [12] - tracking recyclable waste [10], [11]

	- monitoring logistics processes [10] - secure data sharing between authorized users [10] - use of smart contracts for transparency and accountability [11]
Building Information Modelling (BIM)	-waste reduction [14], [11] -waste reuse [17] -waste recycle [17]
Digital Twin	-waste quantitative assessment [18] -demolition process planning [18] -optimal disposal route selection [18] -waste management strategy [18]
Internet of Things (IoT)	-real-time monitoring of material utilization and waste generation at the construction site [4], [16], [11] -support for blockchain technology in waste information management [12] -data collection on material usage [29], [11]
Machine Learning	-prediction of waste generation [20] -vision language model for waste classification [30] -material waste sorting [31] -waste estimation [32]
Material Passports (MPs)	-identification of each individual material and component on site thanks to material passports, reducing over-ordering and waste [24], [15] -provision of information on proper storage of materials arriving on site and prevention of material loss [24], [15]
Mobile Applications	-categorization of waste generated in the field and initiation of the recycling process through mobile applications [26], [16] -on-site data entry [33] -waste tracking [33] -waste reporting [33]
Smart Platforms	-ensuring worker safety during the construction process with smart watches and health sensors, minimizing work accidents and damage requiring reconstruction [8]

According to Table 3, AI, blockchain technology, machine learning and mobile applications have high usage area in the construction process. are the most preferred and range usage area for pre-construction process. Mobile applications are generally preferred for waste tracking, waste reporting and blockchain technology is generally used for waste information management whereas AI and machine learning are preferred for waste prediction and waste sorting.

During the construction process, IoT sensors instantly monitor material mobility and waste generation. Computer vision and deep learning are used for automatic identification and classification of waste. BIM is used in material tracking, inventory management and integration [4]. MPs provide transparency in the supply chain, contributing to waste reduction and proper resource utilization [24]. Blockchain records material movements, waste generation and on-site processes during the construction process and ensures secure data sharing [10]. Also, within the context of managing plastic-related waste, QR code systems, mobile applications, and IoT-based sensors are proposed during construction process [26]. During the construction process, IoT-based applications reduce waste generation by enabling real-time monitoring and improving occupational health and safety [8].

In the construction process, generally digital technologies help to follow any type of building's material flow for waste management processes and steps like waste tracking, waste reporting, on-site data entry, reduction, reuse, recycling. To illustrate, when digital twin creates a copy of building, it gives an opportunity to follow all materials in terms of waste, too. Also, IoT makes real-time monitoring of material utilization and waste generation at the construction site. This can be important, especially for heritage sites to follow original materials and reuse. Mobile

applications can support this system to create a general communication network for historical materials and preservation.

3.3 Post-construction Process

Due to activities such as demolition and site clearance, the post-construction process results in substantial material waste. To ensure effective waste management, the prominent digital technologies associated with this process are listed in Table 4.

Table 4. Post-construction processes and digital technologies.

Digital Technologies	***Purpose***
Artificial Intelligence (AI)	-use of demolition data to estimate waste quantities and recovery potential [15] -prompt-guided waste segmentation [27], [28]
Blockchain Technology	-securing material mobility by creating transparent records in the waste disposal process [4], [10], [11] -material tracking and secure data sharing [15], [10], [11] -waste information management [12], [11]
Building Information Modelling (BIM)	-visual demolition waste management planning [17], [11] -waste reuse [17] -waste recycle [17] -calculation of the amount of waste, carbon emissions, and recyclable ratios occurring after building demolition with Life Cycle Assessment (LCA) integration [4] - waste quantity assessment, optimal disposal routes and waste management strategy selection [18]
Digital Twin	-waste quantitative assessment [18] -demolition process planning [18] -optimal disposal route selection [18] -waste management strategy [18]
Internet of Things (IoT)	-support for blockchain technology in waste information management [12] -early detection of structural damage through Structural Health Monitoring, preventing demolition or major repairs [8] -provision of data by waste management sensors for recycling, separation, and waste volume reduction [8]
Machine Learning	-contactless assessment of in situ building materials for reuse potential [34] -vision language model for waste classification [30] -material waste sorting [31] -waste estimation [32]
Material Passports (MPs)	-support for the post-demolition recovery process through providing information on material composition, reusability, and recyclability [4], [24], [16] -increase in the transferability of materials used to new projects [24], [15] -integration of material passports (MPs) into second-hand material markets through digital platforms [24], [15]
Mobile Applications	-on-site data entry [33] -waste tracking [33], -waste reporting [33]
Smart Platforms	-

As shown in Table 4, mobile applications, IoT, AI, and blockchain technology and MPs are commonly used to provide and track data for waste information management, whereas smart platforms are not utilized in the post-construction process.

BIM and LCA integration in post construction evaluates material recycling potential after demolition. MPs provide material history for reuse and recycling processes. Big data and blockchain support traceability of waste streams [4]. MPs enable selective demolition processes by providing information on where and how materials can be removed during the demolition process. It acts as a digital bridge for material banks and systems working in connection with the secondary use market [24]. Also, blockchain can be used to ensure digital accuracy for the recovery and reuse of components at the end of a building's life cycle during the post-construction process [10]. Furthermore, as part of an analysis on how to manage plastic-based materials more sustainably, blockchain-supported MPs are recommended to identify the plastic components present in the building, along with their properties and reusability potential during the demolition process [26].

In the post-construction process, digital technologies help increase the transferability of materials used to new projects. This can be a great advantage, especially for historical buildings during restoration processes. In demolition projects, these technologies can support waste tracking, waste reporting, waste information management, and even the use of vision-language models for waste classification.

4 CONCLUSION AND FUTURE STUDIES

Construction and demolition waste represents a significant share of the world's total waste and poses serious environmental risks. Consequently, effective waste management throughout the main processes of the building life cycle remains a critical challenge within the construction industry. Establishing a data-driven and well-structured waste management system utilizing digital technologies is essential. Automated and optimized strategies for construction and demolition waste management are key to advancing 10R strategies.

In the pre-construction process, digital technologies such as AI, digital twin, BIM, machine learning are preferred for waste estimation. On the other hand, blockchain technology, IoT, MPs and smart platforms are used to provide waste information management. These technologies are generally implemented for waste segmentation and waste tracking in construction and post-construction processes. Also, all these technologies provide significant contributions to waste tracking and management of all types of materials in both historical and new buildings. Using these technologies like AI, BIM, IoT, and digital twins, it becomes possible to reduce waste, monitor materials, and enable their reuse. These technologies support sustainable construction and restoration processes.

There are a wide range and effective usage areas of these digital technologies in construction waste management. However, the current approach to construction waste management remains largely conventional. Digital technologies have significant potential to transform construction and demolition waste management. Especially with the rapid development and increasing widespread use of digital technologies, their application in the construction industry is becoming essential. This is particularly important for construction waste management due to limited resources and the need to ensure environmental and economic sustainability as well as promote a circular economy. In future studies, case studies can be conducted on the application of digital technologies across different building types—such as historical and newly constructed buildings—and various material types, including earthen, recycled, and modern materials, throughout the building life cycle processes. Additionally, the barriers to better integration of these technologies into the construction industry can be identified and analyzed.

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Bitudobe: A Waterproof Adobe Brick

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ABSTRACT

Adobe is one of the oldest environmentally friendly construction materials for many years. However, adobe, as a soil-based material, is directly affected by weather conditions such as rain and humidity. Therefore, these are the critical factors for using adobe in buildings considering durability. Bitudobe is a stabilized earthen construction material developed from traditional adobe bricks. The aim of this paper is to examine historical background of bitudobe by searching building examples in California considering the material properties and environmental impact.
Between the late 1940's into the 1980's, "Adobe revival" building period had been occurred as impacts of bitudobe and Federal Housing Assuring (FDA) required construction codes. One of the simple formulas for caladobe includes water, emulsified asphalt, clay and loamy sand. The crucial distinction lies in its stabilization using asphalt emulsion (bitumen) instead of additives like cement or lime. Approximately 5-15% of bitumen supplies adequate protection to various soils. The amount of bitumen may change depending on the contents of silt and clay of soil. Accordingly, bitudobe becomes more water-resistant and structurally durable, especially in wet climates where regular adobe might degrade. Bitudobe buildings benefit from excellent thermal mass, reducing heating/cooling needs. Lower energy inputs during manufacturing compared to cement-based materials. It has been researched and promoted as a low-cost, sustainable building material, particularly for arid and semi-arid regions where conventional materials may be expensive or environmentally harmful. However, due to the emulsified asphalt as ingredient of bitumen, environmentally friendly material characteristics of adobe have been discussable.

Keywords: Bitudobe/ caladobe, Waterproof, Adobe, California, Environmental impact

1 INTRODUCTION

The concept of bitudobe was based on developing weakness of adobe construction: water vulnerability. Adobe is an excellent building material in terms of thermal properties and availability, its susceptibility to water damage limited its practical applications. Bitudobe was introduced as a waterproof adobe brick in California. Therefore, it is named also as caladobe based on its origins. Bitudobe was produced by the American Bitumuls Company, in the 1940's and it was testing in the mid 1930's. After World War II, the interest in alternative building materials increased with the effects of California's housing boom. By this time, the technology had been refined and standardized, making bitudobe accessible to both commercial builders and do-it-yourself enthusiasts. American Bitumuls Company was the leading actor of developing and promoting this new construction material by establishing standards and certification processes for commercial brickyards, ensuring consistent product quality across different manufacturers. American Bitumuls Company has the patent and license of bitudobe. The Hans Sumpf yard in the Fresno area, and the L R Green yard in Escondido are two certificated firms for caladobe, there are many others were produced bitudobe. An informative visual material for bitudobe [Fig. 1].

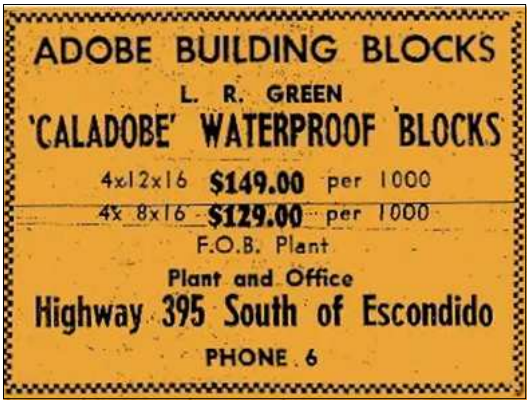

Figure 1. This An informative visual material for bitudobe [1].

This study is concentrated on bitudobe as a construction material through its material properties and environmental impact with building examples.

2 BITUDOBE: A CONSTRUCTION MATERIAL

Bitudobe was presented as a good alternative to adobe. American Bitumuls Company specified standards for brick quality including the criteria for soundness, cracks, moisture, absorption, erosion, compression and modulus. The fundamental formula of this brick is rooted in 12 parts of water, 1 part of emulsified asphalt, clay, loamy sand [1]. The key innovation lies in the addition of asphalt emulsion, a water-based mixture of asphalt particles suspended in water with emulsifying agents. This formula creates a waterproof matrix within the dried brick without compromising the material's breathability or thermal properties. Especially, with its resilience to water and moisture, bitudobe gained a specific material property. It is suggested that 5-15% asphalt emulsion may supply water resistance for various soils [2]. Before adding water to the mixture, asphalt emulsion should be mixed well with the soil. Adobe and bitudobe are compared [Table 1].

Table 1. Comparative analysis of adobe and bitudobe.

	Adobe	*Bitudobe*
Asphalt emulsion content	0%	5-15% [2]
Water resistance	Poor – vulnerable to water and moisture	Good - waterproof properties
Durability	Moderate - requires regular maintenance	High
Applications	In dry climates	For various climates
Skill Requirements	Traditional knowledge	Specialized mixing and testing knowledge
Cost	Low	Moderate - Asphalt emulsion content

The asphalt emulsion additive makes the material durable without the requirement of maintenance. Also, it gives the opportunity to use the material not only in dry climates but also in various climates. Here, it may also be added that the asphalt emulsion makes bitudobe elastic than adobe. However, due to the high cost of asphalt emulsion, bitudobe is not cost-effective as adobe. Traditional knowledge has been rooted for adobe through years while bitudobe is produced with specialized

mixing and testing knowledge. Despite its advantages, bitudobe construction faced several challenges listed below:

- Quality Control: Ensuring consistent asphalt emulsion content and proper mixing required careful attention to detail and quality control measures.
- Skilled Labor: Proper construction techniques required specialized knowledge that was not widely available.
- Code Compliance: Building codes in many jurisdictions lacked provisions for stabilized adobe, requiring special approvals and inspections.

Even bitudobe has some positive advantages as a construction material, it remained primarily a California phenomenon based on the following reasons:

- The specialized knowledge required for proper production and application remained concentrated in California.
- Established building industries in other regions, particularly concrete and lumber interests, sometimes actively opposed alternative building methods.

3 BITUDOBE: ARCHITECTURAL EXAMPLES

Bitudobe can be used both as loadbearing and nonloadbearing material in the buildings. The 1946 American Bitumuls Company publication "Bitudobe water-resistant soil bricks for modern building" provides detailed technical specifications and application guidelines [3]. American Bitumuls Company determined the criteria and details for bitudobe application in building. The construction processes of masonry buildings with bitudobe are presented. [Fig. 2].

Figure 2. The construction processes of masonry buildings [3].

The Golden Gate International Exposition had been held in San Francisco California between 1939-1940. The Golden Gate International Exposition featured a notable demonstration of bitudobe technology, including a reproduction of a typical "Old Adobe" structure of California Nursery Company's garden exhibit. The original building was built as a dwelling approximately in 1853 by the Mexican owners. This building was designed with thick adobe walls of 4"x 12"x 18" sun-dried bitudobe, rough beam supports for the roof, and the quaint interior furnishings [4] [Fig. 3].

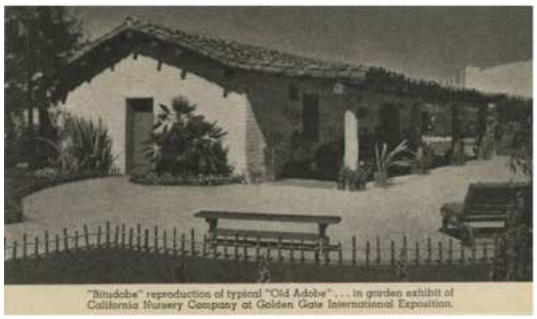

Figure 3. This a reproduction of a typical "Old Adobe" structure of California Nursery Company's garden exhibit [5].

Inside of the building façade, bitudobe may leave as it is or it may be covered with plaster and paint depending on space atmosphere [Fig. 4].

Figure 4. The interior of buildings constructed with bitudobe showing brick outline [3]

There is an example of bitudobe applied in a bathroom. It is declared that the adobe wall, which have been used for 48 years without problem, was covered with mortar wash coating then a coating of pool paint [6] [Fig. 5].

Figure 5. Bitudobe application in a bathroom [6].

As a construction material, bitudobe, has been a fascinating chapter in the history of building material and technology. It illustrates the complex interplay between technical innovation, economic interests, and cultural preservation in the development of building practices. Understanding these dynamics provides valuable context for contemporary efforts for building technologies and preserving traditional building knowledge.

4 ENVIRONMENTAL IMPACT OF BITUDOBE

The environmental evaluation of bitudobe reflects a nuanced interplay between the low-impact characteristics of traditional adobe and the environmental concerns introduced by the addition of asphalt emulsion as a stabilizer [1]. While adobe is widely considered an environmentally sustainable building material due to its minimal processing needs and the use of locally sourced soils [7], the incorporation of bitumen substantially alters this profile. On the one hand, bitumen emulsions used in bitudobe require less energy to produce than traditional hot-mix asphalt, allowing for lower energy use and reduced emissions during production [8,9]. Furthermore, because bitudobe is manufactured at ambient temperatures, unlike cement-based materials that demand high-heat processing, it exhibits considerably lower embodied energy when compared to conventional masonry products such as concrete or fired bricks [10,11]. The durability and longevity offered by asphalt stabilization extend the service life of adobe buildings, minimizing the frequency of repairs and reducing material waste and environmental costs over time [3,6,12]. In addition, bitudobe maintains adobe's thermal mass and moisture-regulating qualities, contributing to improved passive climate control and lower operational energy demand throughout the building's use phase [1,7,13]. Although early versions of bitudobe did not utilize recycled inputs, modern emulsified asphalt has the potential to incorporate reclaimed asphalt pavement (RAP), thereby opening opportunities for resource recovery in future applications [14,15]. However, there are clear drawbacks: the use of petroleum-based emulsion introduces fossil carbon into a material that would otherwise be nearly carbon-neutral [16, 17, 18], and the refining processes involved in asphalt production release substantial greenhouse gases [19, 20]. Additionally, asphalt-based materials can emit VOCs and other pollutants, raising concerns regarding both environmental and indoor air quality, especially during the curing period [4, 16, 9, 21]. From a life cycle perspective, bitudobe's stabilizer content shifts its carbon footprint considerably higher than that of traditional adobe, contributing more substantially to the emissions of a building sector already responsible for 23–40% of global greenhouse gas output [22, 23, 2, 18]. Moreover, unlike adobe, which decomposes naturally and can enrich soil, bitudobe resists biodegradation, complicating waste management and long-term sustainability [7, 12, 24]. Nevertheless, when benchmarked against industrial materials like fired brick, concrete, or steel, bitudobe remains a relatively low-impact solution due to its earth-based composition and reduced manufacturing energy [13, 18, 10, 11]. Its use of emulsified rather than heated asphalt represents a more environmentally favorable variant of bituminous stabilization [9]. In the context of climate change adaptation, bitudobe's enhanced resistance to moisture makes it valuable in regions facing intensifying weather extremes [3, 25, 24]. While its use supports sustainability goals through local material sourcing and long-term durability [12], its reliance on petroleum-derived binders limits its renewable resource potential [26].

4 CONCLUDING REMARKS

Bitudobe represents a significant innovation in how traditional materials and methods can be enhanced through new technology considering material properties. This new way of material development bridged the gap between ancient earth building traditions and contemporary performance requirements. The development and application of bitudobe technique in mid-20th century California points out the potential for innovation within traditional building methods. While technology never achieved widespread geographic adoption, its technical success and documented performance provide valuable insights for contemporary building practices in terms of innovation of a traditional material. However, due to its asphalt emulsion the environmental impacts of bitudobe are required to be examined for future studies.

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A Natural and Sustainable Alternative: Post-Disaster Adobe Buildings

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ABSTRACT

Meeting the need for shelter after disasters rapidly and sustainably is of critical importance from both humanitarian and environmental perspectives. In this paper, the use of adobe in post-disaster settlements will be examined along with its advantages, disadvantages, and different applications. Temporary buildings made using adobe offer advantages such as fast production and construction process, low cost and on-site production, natural ventilation and thermal comfort, structural flexibility and sustainability with low carbon footprint. However, the suitability of these structures to climatic conditions and their long-term comfort are limited. Since adobe is used as a traditional material in many cultures, preserving cultural ties and architecture can strengthen the sense of belonging after a disaster and make individuals feel at home. To increase durability, particularly in seismic regions, it must be supported by engineering advancements and contemporary construction methods. In this context, solutions such as using wooden or bamboo frame systems, increasing strength by adding lime cement or natural polymer additives, and preferring low-rise buildings with light roofs to reduce weight can be applied. Examples of this can be found in areas like Iran and Afghanistan that are at a high risk of earthquakes. Experiences from past disasters show that safe, environmentally friendly and long-lasting structures can be created by combining adobe with modern techniques. In this regard, it is important to promote the inclusion of sustainable and conventional building materials, such as adobe, in disaster management plans.

Keywords: Sustainability, Post-Disaster Shelters, Adobe, Earthquake, Cultural Heritage

1 INTRODUCTION

The need for emergency shelter in the aftermath of natural disasters often necessitates quick and inexpensive solutions. However, these solutions can cause environmental, economic and social problems in the long term. In this scope; adobe brick, a natural, economical and easily produced material from local resources, is generally considered an important alternative for temporary and permanent housing solutions after disasters [1]. Adobe brick can also be used in permanent housing by reinforcing it with traditional techniques or modern engineering methods [2]. In Turkey, the earthquake centered in Kahramanmaraş on February 6, 2023 caused widespread destruction and forced many people to seek refuge. Tents, containers and prefabricated structures came to the fore to meet the urgent shelter needs after the earthquake. In terms of psychological recovery after a disaster, adobe material has various advantages such as increasing social solidarity by providing a warm, natural, safe and participatory environment. Given that it is a substance that speeds up rehabilitation from both an individual and social perspective, it should be taken into account in housing developments constructed after a disaster. This paper discusses the place of adobe

buildings in post-disaster shelter systems, their advantages, limitations and their potential for integration with modern engineering. The first material that humans sculpted and used in construction was soil. It has been an essential component in shelter construction since the dawn of human civilization. For instance, it is thought that the New Mexico Houses were built between 1000 and 1450 years ago. They are constructed of a substance similar to Adobe (Fig. 1), which is frequently utilized in arid areas, and are presently inhabited by 150 people.

Figure 1. An example of Adobe structures found in the Santa Fe region in New Mexico

Since ancient times, the practice of constructing with earthen materials has been employed, having evolved via trial and error. For many years, people have been using this method to construct clay structures because of the raw material's abundance, simplicity of access and processing, high level of thermal comfort it offers inside buildings, the healthy interior environments it creates, and its ease of repair [3].
People have started to leave their houses as a result of technological advancements, societal variety, and rising demands. High-rise development is now required due to factors including growing urban populations and land constraints [4].
The influence of migration to the city has been seen to have the opposite effect on rural areas. These regions have also shifted away from earthen constructions due to the forgetfulness of the building tradition and the incapacity to manufacture materials.
Earthen building materials have returned to the agenda due to advancements in earth construction techniques and rising environmental degradation. Thirty percent of people on the planet still live in unbaked earth homes today. People who live in largely rural areas of emerging nations, including cities and suburbs, make up about 10% of this population [5].
Around the world, contemporary earthen structures for a variety of purposes are being built. There are several instances of mudbrick in every province of Turkey, with the exception of the major cities, which indicates that it has a significant position in our traditional building culture and that our building stock is sizable enough.
Adobe houses are still widely utilized in the rural parts of Southeastern, Eastern, and Central Anatolia. They gained attention after the Elazığ and Van earthquakes.
The majority of mudbrick structures in Anatolia were built using half-masonry and masonry systems. For instance, the half masonry system was far more advanced and used in the walls of the structures discovered in Troy [6] (Fig. 2). This system is a strong, self-supporting brick-filled framework [7].

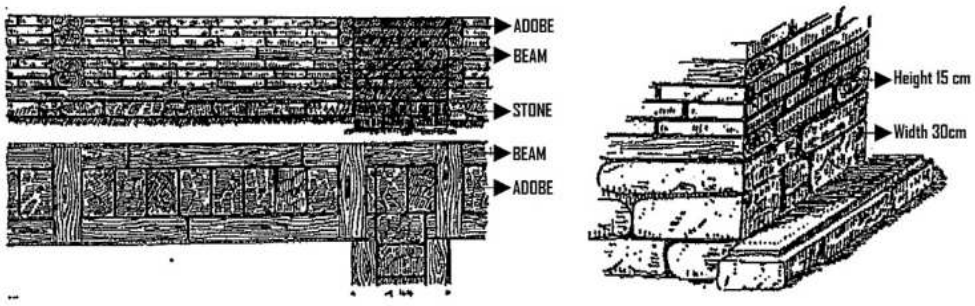

Figure 2. The semi-masonry system used in the ancient city of Troy [6,7]

Examining the distribution of earthen structures around the world reveals that one of the most significant building types in antiquity, they were temporarily abandoned due to factors like migration, industrial development, etc., but have since returned to widespread use because they are more environmentally friendly than other building materials used today and don't produce any waste or harmful gases during construction. It is possible to draw the conclusion that areas with a continental climate are typically the ones where earthen structures are preferred. Given the abundance of protected earthen structures in Mesopotamia and Africa, it is particularly favored there. This is because the continental climate's hot, dry summers and cold, rainy winters are balanced by the inherent structure of adobe. In continental climes, mudbrick houses are preferable because their interiors are warm in the winter and cool in the summer. There have been various developments in Turkey recently in terms of the protection and development of earthen structures. While studies on this subject are being carried out in some workshops (Natural Building Materials Association DYMD, Earth Construction Kerpiç Akademi, etc.), projects on the importance of earthen structures are also being produced around the world (Builders Without Borders, Auroville Earth Institute, CRATerre, Earth Building UK and Ireland, The UNESCO Chair Earthen Architecture, Ithaca Institute Switzerland, Earth Building Association of Australia, Red Iberoamericana Proterra, etc.).

2.PROPERTIES AND ADVANTAGES OF ADOBE BUILDING MATERIAL:

Adobe brick is created by drying a mixture of dirt, clay, water, and straw in the sun. Its fundamental characteristics can be categorized as follows:

1) Low energy consumption: Usually sun-dried during manufacture, it does not require high-temperature kiln drying.
2) Low carbon footprint: Cement and other binders are used less or not at all.
3) Indoor temperature balance is achieved by the thermal mass effect.
4) Suitable for local production: boosts employment locally by lowering carbon emissions and shipping expenses.
5) Biodegradable: At the end of its life, it doesn't contribute to environmental damage.

The advantages in terms of post-disaster sheltering can be summarized as follows:

Rapid production and construction; the ability to produce building elements in a short time by using the soil available in the disaster area,
Community participation and psychosocial support; participation of disaster victims in adobe construction, supporting post-traumatic recovery,
Sustainability and low cost; being a cheap, accessible material, it is suitable for emergency sheltering projects with budget constraints,
Physical environmental control; providing thermal comfort especially in hot and dry climates.

Steps to Take in Order to Address Shelter Needs After a Disaster:

A safe place to live is one of the most basic demands following a disaster.It fosters collaboration in society, psychological recovery, and a sense of security in people.Shelter solutions must therefore be rapid, dependable, and long-lasting.The following is a summary of the actions that need to be made in this regard.

Are local materials available?
↓
Yes → The use of brick
No → Alternative material
↓
Risk Analysis (Earthquake, Rain)
↓
Is engineering reinforcement necessary?
↓
Yes
↓
Reinforcement + Cement additive + Waterproofing
↓
Application

3 STRENGTHENING ADOBE BUILDINGS AND MODERN APPROACHES:

The usage of adobe constructions in disaster areas carries a number of concerns. Given that the material is susceptible to the effects of rain and water, the most significant of these is the seismic risk that could arise if engineering precautions are not taken. The second is the possibility of material erosion and loss of load-bearing capacity if insulation is not done correctly. The following engineering strategies are recommended in literature to ensure the safe use of adobe in post-disaster permanent or temporary housing:

1) **Reinforcement:** Increasing horizontal-vertical stability with wood, bamboo or metal reinforcement.
2) **Use of adobe blocks with cement additive:** A certain amount of cement additive to increase compressive strength and water resistance.
3) **Wood, metal framing systems:** Supporting adobe walls with rigid frames.
4) **High foundation applications:** Building on a stone or concrete foundation to prevent contact with water.
5) **Water-repellent surface coatings:** Natural lime plaster or coatings with water-repellent additives, especially on exterior surfaces.

Table 1. Reinforcement methods used in adobe construction and their purposes

Reinforcement Method	*Purpose*
Wood/bamboo reinforcement	Lateral stability
Cement additive	Pressure strength and water resistence
Concrete / stone foundation	Moisture protection
Roof with wide eaves	Reducing the effect of rain
Lime plaster or water-repellent coating	Surface protection

Table 2. Advantages and disadvantages of adobe construction

Advantages	*Disadvantages*
Local material	Earthquake sensitivity
Low carbon footprint	Weak against water
Low cost	Engineering reinforcement is required
Community involvement	
Thermal comfort	

Gernot Minke's research indicates that dirt is not a suitable building material in areas that are prone to earthquakes [8]. The primary cause of this is that soil is seen as a building material for the impoverished and that the soil walls utilized in contemporary homes are not earthquake-resistant. However, according to studies conducted by the El Salvador government after the January 13, 2001 earthquake (magnitude 7.6 on the Richter scale), adobe houses were not affected by the earthquake more than those made of brick or natural stone.
On the other hand, many historical clay buildings have survived several strong earthquakes in the last few centuries, such as the houses in Fujian Province in China produced in Hakka architecture (Figs 3 and 4).

Figure 3. Topographical view of houses

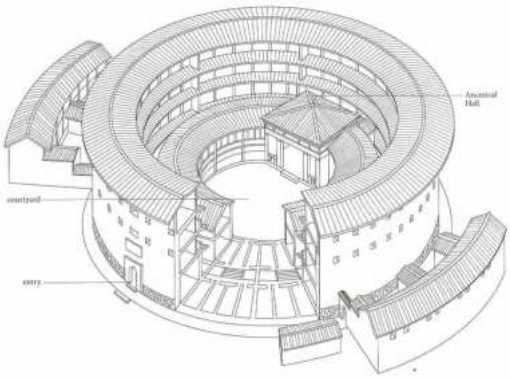

Figure 4. Layers of the buildings

At the same time, houses with lightweight and flexible roofs have survived earthquakes due to the flexibility of mud walls. Therefore, according to Minke, the primary culprit for structural deterioration is not the clay itself, but the building's topographical location, the shape of the ground plan, the building design, and the design of window and door openings. Following the 7.7 magnitude Richter scale earthquake that struck Nepal in 2015, Minke collaborated with Hans-Peter, who focused on solutions for small-scale rural structures using local materials and resources, to contribute to the Nepal earth bag homes Project [9]. A construction method of earth-filled sacks was chosen for the walls. A circular shape with a rectangular floor plan was chosen. The circular house proved easier to build and offered greater seismic stability. The 6-meter-diameter structure provides living space for a farming family of six to eight. Because the farmers spend most of their time outdoors, the house is used primarily for sleeping, cooking, and storage (Figs 5 and 6)
The "Earthbag homes" project used a concrete ring beam, with the wall system reinforced with steel. This type of structure is known as a "ductile structure," and it absorbs energy by exhibiting flexible behavior during shaking.

Figure 5. Construction of houses

Figure 6. Production with community participation

In the December 2003 earthquake in Bam, Iran, almost all buildings, regardless of their material or construction method, collapsed. However, interestingly, some vaulted adobe houses remained partially standing. From this, Minke developed the idea of the prestressed clay barrel vault.
Another method used in this context is to leave space between panels in earthen structures to ensure movement during an earthquake. In buildings where the vertical structure is made of a material other than adobe, such as bamboo, the ceiling is mounted in a different way to prevent it from falling on people in case of tremors; it is planned to move separately from the wall in the event of an earthquake. Sheepwool and lime are used together as insulation materials against microorganisms. From a fire hazard perspective, handmade bricks can be classified as fire-resistant building materials, and sometimes holes are drilled on them to make them lighter.
A mixture of straw and soil is commonly used to fill walls in various structures. Compressed earth blocks stabilized with cement are also sometimes used to increase strength. In this context, earthquake-resistant structures can be created by combining a load-bearing cob mix with an insulating light earth mix. For instance, the CobBauge House in Fakenham, Norfolk, is the first domestic property in the UK to be built using CobBauge [10]– a pioneering new form of low-energy earth building (Figs 7 and 8).

Figure 7. Details from interior

Figure 8. Exterior views of the building

4 POST DISASTER PSYCHOLOGICAL EFFECTS OF ADOBE MATERIAL

The building materials and construction methods used in post-disaster sheltering processes not only meet the physical shelter needs but also directly affect the psychological recovery process of disaster victims [11].

Increasing Community Participation: Adobe production requires the direct participation of the local community. This process transforms disaster victims from passive aid recipients into active producers. Building one's own shelter strengthens a sense of self-sufficiency. Social relationships are strengthened, and feelings of loneliness are reduced, thus increasing morale, motivation, and hope [12]. According to the disaster psychology literature, "one of the most important steps in psychological recovery is for individuals to gain a sense of control over their own lives after a disaster" [13].

Strengthening Traditional and Cultural Connections: Adobe is a traditional material in many regions. Its use helps individuals rebuild their cultural identity and sense of belonging. This accelerates the psychosocial recovery process.

The Healing Effects of Naturalness and Contact with Soil: Psychological research emphasizes the anxiety-reducing effects of contact with soil and natural materials. In recent years, the literature on ecotherapy and biophilic psychology has frequently emphasized the psychological benefits of contact with soil and natural materials. Jordan [14] summarizes this effect by stating that "physical contact with the earth reduces anxiety levels and restores a sense of security and stability."Working with elements such as clay, straw, and water in adobe construction reconnects us with nature and contributes to the alleviation of post-traumatic stress.

Indirect Effect of Thermal Comfort: The fact that adobe provides cool indoor spaces in hot climates and mild indoor spaces in cold climates increases the physical comfort of the people living there. This reduces chronic stress levels and improves sleep quality. According to the World Health Organization, "Physical comfort is one of the fundamental determinants of psychological well-being" [15].

4 CONCLUSION:

Adobe buildings stand out as a natural, cost-effective, and eco-friendly alternative in the face of an increase in natural disasters and the need for sustainable reconstruction. This building material provides rapid and culturally appropriate answers to post-disaster psychological and sheltering needs because it is affordable, locally accessible, and has ecological qualities. Adobe structures are especially useful in post-disaster processes because they offer thermal insulation, are simple to apply, and are easily adopted by communities. However using this material in a post-disaster shelter without taking local climate conditions and engineering standards into account can lead to major security issues. Sustainable and resilient communities can be built by combining traditional knowledge with contemporary engineering methods to improve structural durability. Seismic-resistant adobe applications developed in different countries show that this material can be successfully integrated into modern disaster housing. Similarly, in Turkey, local building traditions should be integrated with current earthquake regulations. As a result, if necessary precautions are taken against fires and heavy rainfall, adobe buildings not only meet immediate shelter needs but also form the basis for long-term disaster-resistant, environmentally sound and community-based solutions.

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Traditional Building Techniques of Jordan: Regional Diversity and Adaptive Transformation

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ABSTRACT

This research documents and analyzes the diverse vernacular construction methods across Jordan's distinct regions, dating between 1850 and 1970, examining how these practices have evolved in response to environmental conditions, social changes, and economic challenges. Contributing to heritage conservation and sustainable architecture dialogue, the study reveals the adaptive capacity of traditional building knowledge in changing contexts.

The investigation employed a multidisciplinary approach combining field surveys, typological classification, material analysis, and oral history interviews with elders. Findings identify four principal regional construction techniques according to the construction material: northern highland stone masonry; central part stone with mud mortar; Jordan Valley adobe structures; and desert- adapted Bedouin goat-hair tents reflecting nomadic traditions.

The study traces temporal transitions in these practices, documenting community responses to material availability shifts, lifestyle changes, climate challenges, and modernization effect. Notable transformations include the gradual integration of concrete elements into Jordan Valley adobe construction and the decline of certain stone masonry traditions following industrial material introduction.

This research demonstrates that Jordan's traditional construction systems represent both regional diversity and historical adaptability, embodying sophisticated environmental knowledge and cultural expression. Understanding these patterns of continuity and change is crucial for developing appropriate conservation strategies and sustainable architectural approaches that respect vernacular wisdom.

Keywords:
Adobe Buildings, Vernacular Architecture, Built Heritage

1 INTRODUCTION

Vernacular architecture in Jordan is a product of local wisdom, which cleverly dealt with diverse environmental, cultural, and socio-economic conditions. These houses, built without architects and shaped by generations of lived experience, are source of knowledge—efficient, sustainable, and deeply rooted in place. Despite their cultural value, many are now threatened by abandonment, demolition, or harmful renovation.

This paper explores regional vernacular traditions in Jordan, aiming to document building techniques, understand their evolution, and highlight their relevance to current sustainability discourse. It draws on a wide range of sources: fieldwork, oral history, archival records, and published literature, to present sufficient understanding of the local building practice, the continuity and change over the years.

2 REGIONAL TYPOLOGIES AND MATERIAL SYSTEMS

Traditional dwellings in Jordan align closely with environmental zones and available resources, they can be classified into four dominant systems:

- Bedouin tents (Bayt AlSha'ar) that can be easily dismantled for seasonal migration. the Bedouin tent has been used for thousands of years by nomadic and semi nomadic Bedouins . The material from which tents are made is densly woven goat hair, which was available as the Bedouins raise livestock such as sheep, goats and camels. The tent is usually supported by wooden poles and tied to the ground to resist wind loads. The tent comes in variable sizes and divided into rooms (2-6 rooms) with flexible functions [1] (Fig.1.1).
- Adobe Blocks Dwellings : Thick adobe walls with flat mud roofs (Fig 1.2) or conical domes (Fig 1.3), mostly common in the Jordan Valley area to adopt with the hight temperature and high humidity, in addition to the dwellings and settlements near the Hijazi Railway stations (Fig 1.4).
- Combined systems of stone masonry with mud mortar walls covered with flat mud and reed roofs, supported by arches or wooden and steel beams, mostly common in the central and southern areas in Jordan (Fig 1.5).
- Masonry structures using limestone with vaulted stone (barrel vaults or cross vaults), mostly common in the north part in Jordan (Fig 1.6).

Figure 1.1- Bedouin Tent - AlMafraq.

Figure 1.2- Adobe walls covered with earthen plaster, lime wash flat mud roof.

Figure 1.3- Adobe school with conical dome roof- AlJafer [2].

Figure 1.4 – Distribution of Adobe Dwellings.

Figure 1.5- Stone masonry with mud mortar- mud flat roof.

Figure 1.6- Stone walls with stone cross vaults.

Figures 1- the main construction sytems in Jordanian Vernaculr Architecture

3 FROM TENTS TO WALLS: THE TRANSITION TO PERMANENCE

The transformation from nomadic tent life to permanent settlements marks a significant socio-cultural shift in the architectural history in Jordan. Traditionally, Bedouins constructed goat-hair tents (bayt al-sha'ar) for seasonal mobility. These tents, supported by wooden poles and oriented according to prevailing winds, provided flexibility, breathability, and insulation from harsh desert climates, while at the same time, it was easy to dismantle and reassemble when necessary.

In the late 19th and early 20th centuries, under Ottoman and later British rule, nomadic and semi-nomadic communities in Jordan began to establish permanent or semi-permanent settlements instead of moving seasonally. This shift was driven by two main factors. The first was the introduction of the Ottoman "Land Code" in 1858, which aimed to regulate land ownership and encourage sedentary agriculture [3]. The second factor was the Ottoman policy of settling Bedouin tribes to secure the Hajj route, which led to the emergence of agro-pastoral villages in Jordan around 1880 (Schriwer, 2002). Provincial Ottoman officials sought to establish villages near reliable water sources and fertile grain lands [4]. Another significant motivation during this period was the construction of the Hijaz Railway [5].

Initial structures were simple structures or one-room compounds, often built near tent sites from available materials, either clayey soil from near the site, mixed with straw or manure to form adobe blocks , or, in more resource-rich areas, stone and lime. Another typologies were the linear houses with multiple rooms and the courtyard houses [6].

This transition created shifts in identity, livelihood (from herding to farming or wage labor), and relationship to land.

4 CASE STUDIES ACROSS JORDAN (Earthen Architecture)

In this section, the main features based on the site visits, field surveys and interviews with the locals in three regions are presented, Maan, Jurf Addarawish and teh Jordan Valley [8].

4.1 Maan

Located in the southern part of Jordan. the old town of Ma'an consisted of two main quarters, the Hijaziyyeh (Southern Part) and the Shamiyyeh (North part). The name is derived according to the

proximity of the destination (Hijaz or Damascus (AS-sham) on the pilgrimage route and later along the railway. The city used to flourish during the Hajj (Pilgrimage), where the pilgrims between Mecca and Damascuss used to stop in the city of Ma'an to have a rest and to feed the camels and horses.

In the old city of Maan , remnants of adobe walls surrounding the gardens (Fig 2.1), adobe watch towers (Fig 2.2) and adobe residetial units (Fig 2.3) are still standing. İn this section description of adobe dwellings is presented.

Most of the dwellings that belong to the same family/ extended family share a courtyard that serves as the hub for the outdoor activities and represents an extension of the home.

4.1.1 Adobe blocks
The materials used for construction is a mixture of clayey local soil *(As-Samga)* and sheep manure, covered to ferment for three days until a slimy texture is obtained. This mixture is used for the blocks and mortar. It was claimed that this method increases the bond between the particles leading to stronger blocks and improves the resistance to moisture.

4.1.2 Plaster
As for the plaster, wheat straw is added to the mix to control cracks, hydrated lime wash *(Al Sheed)* was applied to the interior face of the walls, which helped in creating brighter indoor space and reducing insects attacks as the hydrated lime is very alkaline.

4.1.3 Foundations
Stone is used for the foundations as well as for the arches *(Qantara)* in mud blocks houses. Ma'ani people used to quarry the stones from the edges of the Wadi and surrounding hills. The material was also locally available. However, the extraction process limited the use of stone to significant elements (Fig 2.4).

4.1.4 Roof
Wood, usually Juniperus Excelsa (lazzab) is used to support the roofs, by installing closely spaced joists (Usually 2 m) spanning over either a stone arch (Qantara) or a thicker, stronger main wooden girder. On a later stage, after the destruction of the Hijazi railway during the Great Arab Revolt , where the steel sections were reused in construction , the steel girders replaced the wooden one.
The size of the available trees controlled the dimensions of the rooms. Wood of smaller size is usually used to support opening through the lintel beams.
The second layer of the roofing is usually made out of a mat of woven reed, which is widely available in the areas of water accumulation, laid over the wooden joists (Fig 2.3) .

4.1.5 Openings
Openings are characterized by being small not exceeding 0.5x0.5 m this might be due to the difficulty in supporting big openings, not affecting the integrity of the bearing wall, and controlling the indoor environment by minimizing areas of the openings. Openings could take the shape of square (Fig 2.5) or triangular shape, influenced by the Hijazi architecture (Fig 2.6) .

Figure 2.1- Gardens adobe boundary walls.

Figure 2.2- Remnants of adobe watch towers.

Figure 2.3- Adobe dwellings / Flat roof.

Figure 2.4- Stone base.

Figure 2.5- Square openings in adobe wall.

Figure 2.6- Traiangular opening in adobe wall.

Figures 2- Main Features in Maan vernacular architecture

4.2 Jurf Addarawish

Jurf Addarawish is located between the capital city of Amman and Ma'an, it is located close to the desert highway that connects Amman to the southern part of the kingdom. The Hijazi railway station (AlJurouf) was established in 1904, the station itself was built out of stone (Fig 3.1) at that time, while the dwellings of the workers who used to work in the station or the maintenance of the railway came mainly from Maan and resided in mud block houses across the station (Fig 3.2)
Jurf Addarawish is located opposite to an accessible cliff, from which, the workers could obtain the clayey soil for adobe blocks, the mortar and the coating. There are multiple indicators that this residential area was built in different phases and different time spans such as the difference in the roof levels, the composition of the blocks, where some blocks were noticed to contain significant amount of starw while others had no natural fibers at all, the blocks with straw are most likely sieved as no gravels or small stones were observed, while in other blocks large gravels are exposed indicating that no sieving used to take place and large stones are removed only during mixing the soil with water (Fig 3.3) .

The south west elevation showed a very interesting construction technique where the mud block façade is completely cladded with natural stone. According to the locals this technique was introduced to proptect the façade from the heavy rain that is usually associated with the dominant wind coming from the west during the winter season. This might also have a further effect on achieving the thermal comfort as introducing the stone layer increases the wall thermal mass (Fig. 3.4).

Figure 3.2- Jurf Addarish station.

Figure 3.1- Jurf Addarish Station & The residential Area.

Figure 3.3- Unsieved soil used for the blocks and coating.

Figure 3.4- Natural stone cladding on the west elevation of adobe house.

Figures 3- Main Features in Jurf Addarwish vernacular architecture

4.3 Jordan Valley:

The land plots in the vicinity of the Jordan River is characterized by fertile soil. The traditional houses are usually located in the midst of farmland and are built with adobe blocks, since the clay is available locally and the high thermal mass of the adobe walls can help regulating the temperature and the humidity inside the houses, which creates a comfortable indoor environment despite the extremely hot weather conditions during the summer days.

4.3.1 layout

- Most of the houses in the Jordan River region are modular with flat-roofed.The base module is almost square shaped with small windows or openings. The number of rooms vary from 2 to 5 rooms arranged "in-line". Each room has both a separate entrance from the outside and small internal door connecting the rooms (Fig. 4.1) [7].
- Roofs are supported by main wooden or steel beams supporting closely spaced joists topped with the reed mat, a layer of plant leaves and compacted mud (Fig. 4.2) .
- Most openings are supported by segmental arches with very little cases on rectangular openings supported by wooden lintels (Fig 4.3).

- Windows are usually placed on at least two walls to enhance the air circulation.
- Some houses have open patios that separate the house into two parts, the house and the animals shelter. The patio's roof is usually covered with the same system as in the rooms (Wooden beams and reed mats) and it is open from the sides (Fig 4.4).
- The wall thickness varies from 50 cm to 100 cm in some modules. The walls are built with suffiecient bond pattern between the blocks , however, the bond pattern at the corners is not well implemented in many modules and corner detachment have been observed .

4.3.2 Materials

Adobe blocks composed of clayey soil, usually unsieved, and straw . The foundations are made of locally sourced stone that is almost dry stacked or with minimal amount of mud mortar (Fig 4.5) . Plaster mixes are prepared from the clayey soil and straw on both the exterior (Fig. 4.6) and the interior faces of the walls. The interior face is covered with a final finish of lime wash *(Al Sheed).*

Figure 4.1- General Layout.

Figure 4.2- Roof Details.

Figure 4.3- Arched Openings.

Figure 4.4 - Covered Patio.

Figure 4.6- Stone Base.

Figure 4.5 - Plaster Coomposition.

Figures 4- Main Features in Jordan Valley vernacular architecture.

5 DESIGN PRINCIPLES AND ENVIRONMENTAL STRATEGIES

Traditional architecture in Jordan includes distinctive construction elements that reflect deep understanding of the local climate, available resources and the culture requirements. Some of the key components that helped with the passive design are:

- Thick adobe walls: Provide thermal mass and helps with regulating the temperature and humidity inside the houses.
- Earthen plaster: that is compatible with the adobe blocks, breathable and helps with the moisture and temperature regulation in the indoor environment.
- Small and opposite openings: Reduce solar gain, improve security and enhances cross ventilation.
- Courtyards: Serve as light wells, social spaces, and climatic buffers.
- Covered patios that help reducing the heat gain during hot summers

6 CONCLUSION

Jordan's vernacular earthen architecture illustrates a comprehensive integration of local materials and passive design strategies to achieve durability and thermal comfort in a demanding hot, arid climate. Thick earthen walls and carefully oriented openings, minimized the need for active mechanical systems and thus reduced the energy consumption. Using stone for the base or as a cladding material in addition to the plastering sacrificial layer is strong evidence of the local wisdom in responding to the durability threats and challenges. These vernacular solutions represent an advanced local knowledge system that addressed environmental challenges long before the concept of sustainability was formalized, they are valuable knowledge resource for low-energy, climate-responsive design in countries with limited resources.
Equally important to the technical aspects are the social dimensions of construction traditions. Building with earth was historically a social, collective activity, where communities were the source of the labor and the skills. This practice contributed to reducing the construction costs and made housing accessible to all. This practice enhanced knowledge sharing, strengthened social cohesion, and provided a resilient solution to one of the most basic human needs: adequate shelter. In the present context of rising construction costs and energy scarcity, conservation initiatives should focus on safeguarding both the technical and social dimensions of this heritage, identifying the areas of good practice that can be adopted on modern, contemporary construction.

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A Discussion About Concepts of Sustainability, Traditionalism and Ecological in the Context of Building Materials[1]

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ABSTRACT

Various criteria have been established for the construction sector within the framework of sustainability. Many studies have shown that traditional building materials such as stone, wood, and adobe, and buildings constructed with these materials meet the criteria. This situation thoughts that the concept of sustainability does not go beyond defining our traditional values with a new name. These building materials are also referred to with adjectives such as eco-friendly, natural, green, and ecological. Multiple definitions lead to conceptual chaos. Similarly, a systematic approach to how we define traditional and which building materials are classified as traditional has not been encountered in literature reviews. Considerable amount of tendency in society to view traditional as the opposite of modern, for in case especially adobe, as outdated/primitive/ something that should be abandoned. On the other hand, the question of whether every traditional material is ecological also comes to mind. Whichever discipline we consider — sociology, psychology, economics, design, construction, even politics — these lines of reasoning lead us to the concept of 'value'. From this point of view, the study includes an intellectual discussion of the concepts of sustainability, traditional and ecological by utilizing social sciences. Prepared by literature review method, the aim is to create awareness regarding the questions of what, why, how, when, and for whom we are doing something. Thus, the goal is to develop a holistic view of the world we live in as people involved in design, construction, and consumption, and to make our actions and choices more conscious.

Keywords: Sustainability, Traditional, Ecological, Construction Materials, Values

1 INTRODUCTION

The concept of sustainability, which emerged in the last quarter of the twentieth century, has become a critical determinant in the development policies of contemporary nations. The Enlightenment movement—triggered by the Renaissance and Reformation in Europe—is widely accepted as the intellectual foundation that paved the way for the Industrial Revolution. The Industrial Revolution led to mass production, transformed societal structures, and constructed the capitalist 'modern' world. As a result, living spaces shifted from rural to urban settings, and to accommodate the dense urban population in relatively small areas, buildings evolved into multi-story apartments and even skyscrapers. Driven by the dominant mechanistic Cartesian worldview, which posits that 'man is the master of nature, resources are infinite, and exist solely for human use,' this rapid transformation has

[1] This paper is prepared from the PhD thesis titled "A Qualitative Consideration on Extension of The Traditional and Ecological Building Materials in Construction Sector: Case Study of Adobe" which is being written by the first author at Konya Technical University, Faculty of Architecture and Design.

rendered modern urban life increasingly incompatible with human nature. The uncontrolled consumption of resources, the accumulation of waste due to unregulated production, and greenhouse gas emissions from fossil fuel-based services such as transportation have necessitated a paradigm shift. For such a transformation to take place, societal values—and more importantly, the individual at the core of society—must rediscover their essence.

In this context, the study has been structured to partially summarize the conceptual framework of an ongoing doctoral thesis. The aim is to develop a holistic view of the world we live in and raise awareness to make our actions and decisions more conscious. Prepared by literature review method, the study first outlines a framework in which the basis concepts, sustainability, concepts associated with the environment (e.g., ecological, green, natural) and sociology (e.g., modern, traditional). Then, two basic questions were examined within this framework. These are: (1) can all traditional materials be considered ecological? (2) Does sustainability merely a rearticulation of what is traditionally known? Finally, through architecture and materials, drawing on the explained concepts and the given examples, discussed to identify what is truly needed for a healthy and robust future and recommendations are presented.

2 CONCEPTUAL FOUNDATIONS: SUSTAINABILITY, ECOLOGY, AND TRADITION IN THE BUILT ENVIRONMENT

*"*Why do most people, most of the time, act as though a threat of such magnitude can be ignored?*"* [1]. Giddens' question refers to greenhouse gas emissions within the widely discussed and increasingly severe context of climate change and global warming. Over sixty years have passed since environmental concerns first emerged in the 1960s. The current state of affairs, however, remains deeply alarming. As Giddens warns, unless more effective and transformative actions are taken, "our civilization could self-destruct… the apocalypse is no longer a religious or spiritual event but an imminent possibility within our society and economy" [1]. To better understand how we have arrived at this critical point, it is helpful to examine the key concepts. Accordingly, this section briefly addresses the notion of sustainability by engaging with terms related to both environmental (e.g., ecological, green, natural) and social sciences (e.g., modern, traditional) dimensions.

2.1 Consumer Society and the Concept of Sustainability

The motto "increase production to increase consumption" underpins the conventional model of economic growth or development. Baudrillard argues that in a growth-driven system, it is not autonomous needs that define production but rather the demands of growth itself. Consumption, he notes, is structured not around the functional value of objects, but around "sign values" (status, prestige, belonging, etc.) that reflect psychologically constructed and manipulated desires. Production, in turn, is merely the shaping of needs in accordance with the prevailing value systems of society [2]. Bauman emphasizes that consumer culture turns individuals into beings who are in constant pursuit of temporary pleasures, remain perpetually dissatisfied, and are engaged in an ongoing quest for identity. He argues that "only a thorough and radical reconsideration and transformation of our way of life and the values that underpin it can bring about meaningful change" [3]. A study that revisits Thorstein Veblen's 1899 concept of "conspicuous consumption" concludes that consumption today is perceived as both a requirement for a "good life" and the foundation of social identity, with fashion playing a central role in promoting conspicuous behavior [4]. Adorno states that what is presented as an innovation is actually a disguise of what is always the same, and what does not change is motive of profit. He describes advertising as the "elixir of life for the culture industry," where systemic dominance is concealed behind illusions, and consumers continue to purchase and use cultural commodities despite being aware of their falsity "with a desire that is difficult to suppress," even though they see that they are fake. [5]. As the advertising industry has recognized the power of values in shaping behavior, consumers are now targeted through narratives infused with meaning. The same is true for the concept of sustainability. Ciravoğlu (2006), succinctly states that "a concept originally intended to critique consumer societies has itself become an object

of consumption" [6]. It appears that when a society becomes alienated from itself and seeks meaning through consumption, it simultaneously *devalues the very object it once ascribed worth to* and embarks on a search for a new object of consumption. Over the past sixty years, the latest such object of consumption seems to be the concept of sustainability.

From the late 13th century to 1965, the concept was used to mean "to provide the necessities of life, to support (an effort or cause), to endure, to tolerate." Since 1965, there has been a shift in meaning to "sustainable or preservable at a certain level" [7]. Among the reasons for this are key moments such as the publication of Rachel Carson's Silent Spring in 1962 and the emergence of environmental movements in the same period. Similarly, Svante Arrhenius demonstrated in 1896 that climate change could occur due to the accumulation of CO_2 in the atmosphere [8, 9]. However, initiatives (!) only began in 1973 following problems with access to oil. Ironically, the modern concept of sustainability may have originated not from a concern for people or nature, but from the desire of producers to sustain economic growth. In other words, the priority was maintaining development, with human and environmental concerns appended later.

2.2 Environment-Related Concepts

In daily life, one frequently encounters advertisements using descriptors such as green, eco-friendly, natural, nature-compatible, or ecological, attached to a wide range of products—from detergents and household appliances to building materials and residential complexes. While some of these claims may reflect reality, others are distorted or misleading, amounting to what is referred to as "greenwashing" [1]. Löwy draws attention to such advertising strategies as manifestations of "green capitalism" [10]. The ecological validity of construction practices themselves is also a matter of ongoing debate.

Schttich (1997) argues that constructing new buildings is not an ecological approach, asserting that the resources consumed in the production of a new structure will negatively impact the environment and that this concept contradicts sustainability principles, with the potential effects only being minimally mitigable [11]. Within the context of conventional construction systems and building materials, it is impossible to disagree with Schttich. In 2023, buildings accounted for "32% of global energy demand and were the largest contributor to CO_2 emissions at 34%" [12]. Among the reasons for this are the fact that the primary industries supplying inputs to the construction sector are classified in the literature as dirty industries, and the construction sector utilizes these products as building components. These materials continue to pollute our planet not only during production but also during their use and waste phases. These impacts were only identifiable in the twentieth century, leading the industry to emphasize various descriptors to claim that it does not harm the environment—that it is, in a sense, *valuable* and *sensitive*. In this context, it is necessary to briefly address these concepts.

2.2.1 The concept of ecological

Odum and Barrett (2008), in their foundational work Fundamentals of Ecology which examines ecology and ecosystems from a comprehensive perspective, explain that "the term ecology is derived from the combination of the Greek words oikos (meaning house or household) and logos (meaning science, study, or research)" and they emphasize that in this context, "the concept of house refers to the environment that sustains life - encompassing all living organisms and the various interactions and processes occurring within it". It was first proposed by German biologist Ernst Haeckel in 1869 as "the study of the relationships between living organisms and their environment."[2] The term ecosystem was later introduced by British ecologist Sir Arthur G. Tansley in 1935 to describe systems in which living and non-living components interact through cyclical exchanges of matter and energy [13].

[2] Haeckel, 1869 in: Odum and Barrett, 2008:3

Considering these definitions, for building material to be described as ecological, it should ideally participate in a natural cycle within the environment. The definitions of eco-design and life cycle in the EU Regulation 2024/1781, which was revised and came into effect in 2024 [14], fully reflect this criterion for natural materials. The nuance lies in the case of artificial materials. Life cycle assessments often include synthetic materials, such as plastics produced using chemicals. Therefore, labelling non-natural materials as ecological solely on the basis of circularity is questionable. It is suggested here that ecological character should be predicated on naturalness.

2.2.2 The concept of natural

Etymologically, the term natural is defined as "existing in nature as a result of natural forces (i.e., not caused by accident, human activity, or divine intervention)" [15]. In the context of materials, natural ones may have limited lifespans and, in the case of organic substances, may not be reusable in their original form once degraded. However, as long as their seed/core remains intact and environmental conditions allow, they could regenerate themselves (e.g., wood, straw, stone, earth, cork, etc.). In this context, what is *natural* is also *ecological*. The use of the term *natural* to characterize materials can lead to misleading expectations regarding performance or properties. Therefore, to avoid conceptual confusion, it is recommended to use the more inclusive term ecological instead of natural when describing materials.

2.2.3 The concept of environmentally friendly

According to etymological sources, the term environmental is derived from "environment + -al and first appeared in 1887 meaning surrounding. It took on its ecological meaning by 1967, and the combined phrase environmentally friendly (or eco-friendly) became common by 1993" [16]. This phrase evokes materials that either do not harm the environment or originate from natural resources but gain new properties when processed. An example might be cross-laminated timber. However, as mentioned in Section 2.2.1, both in academic literature and recent EU legislation, many materials labeled environmentally friendly do not fully align with this implication. In fact, in all the products we use (including chemically produced, completely artificial products), the raw materials are derived from nature. Thus, characterizing a material as *eco-friendly* or labelling it with terminology containing *eco* simply because its raw material originates from nature appears conceptually problematic. This practice seems more indicative of distortions perpetuated by consumer society and capitalist systems. A parallel critique applies to the use of the term *green* in this context.

2.2.4 The concept of green

The term green has become widely adopted across multiple domains - from economics to politics, and from building materials to everyday products - much like the terms sustainable and ecological. Porritt (1988) argues that, he "finds the use of green more favorable due to the term ecology sounding too scientific and specialized" [17]. The widespread adoption of the term *green*, both in public discourse and in academic literature, is likely influenced by its political presence. Nonetheless, beyond critical evaluations of so-called green products or companies, cases of *greenwashing* are increasingly being identified. Hickman[3] has demonstrated that many supposedly green products on the market are no better for the environment than their non-green counterparts [18]. When examining the criteria used to define green building materials, one finds they are virtually identical to those used for materials described as sustainable or environmentally friendly. Therefore, using the term sustainable in place of green is considered more appropriate.

2.3 Concept of Modern and Traditional

The concepts of *modern* and *traditional* are often used in opposition. *Modern* typically signifies innovation, while *traditional* is often employed to describe dogma or backwardness. This dichotomous perspective has significantly shaped both societal structures and individual preferences.

[3] Martin Hickman, "Why Eco-Friendly Products Are Not as Green as They Appear", *The Independent* (UK), April 29, 2010. In: Foster and Magdoff, 2014:135

2.3.1 The concept of modern

The term *modern* is etymologically derived from "the Latin word *modo* (meaning "just now" or "in a certain manner")", evolving into the "Late Latin *modernus*, and eventually into the French *moderne*, which came into usage around the 1580s with the meaning pertaining to the present or recent times" [19]. There are opinions that it is *temporary* because it refers to the present [20, 21].

2.3.2 The concept of traditional

The term *tradition* derives directly from "the Latin traditionem (nominative traditio), meaning that which is handed down, delivered, or bequeathed from the past participle stem of trader" [22]. "Traditio refers to the process of transmission, while traditum denotes the object being transmitted" [23][4]. One of the most comprehensive definitions can be found in a sociology dictionary; "Tradition is a set of social practices associated with rituals or other symbolic behaviors, generally widely adopted, which instill specific behavioral norms and values and maintain continuity with a real or imagined past*"* [24].

It has been argued that tradition is not solely concerned with the past, but also with the present and future, if a tradition has persisted to the present day, it can be considered contemporary, and even the modern period itself can be seen as one of many produced traditions [25, 26]. Mangion (2015) similarly asserts that, "traditions are dynamic, in that they create the conditions necessary for the ongoing reproduction of society" [27]. From this perspective, and based on Özbudun's statement that a practice may be classified as a tradition if it [23]:

*"*1. Has been sustained for at least three generations (Gross 1992:10);
2. Implies, at least implicitly, a value judgment—thus serving a normative or regulatory function;
3. Creates a sense of continuity between past and present."

Gross's reference to *three generations* introduces ambiguity when considering variations in human lifespans. To resolve this uncertainty, Shils proposed that "the tradition must persist for at least three generations, regardless of whether this period is long or short"[5]. Consequently, the temporal framework initially established by Gross and subsequently refined by Shils appears methodologically valid for situating the definition of tradition within a linear temporal paradigm.

In terms of building materials, the term *traditional* typically refers to materials such as stone, wood, earth (or adobe), brick, lime, gypsum (as plaster), glass, and iron. However, it is worth noting that steel was invented around 1800 BCE [28, 29], pure steel ingots were produced as early as 300 BCE [30], and both the Greeks and Romans developed early forms of cement and concrete using lime and sand—leading many to consider them the first inventors of cement and concrete [31]. However, according to Akman's citing[6], archaeological studies conducted in Anatolia, Israel, and Jordan suggest that concrete flooring with strengths up to 35 MPa may have been produced as early as 7000 BCE, indicating that the first use of concrete is likely far older than traditionally assumed. In light of this information, materials such as steel, cement, and concrete may also be classified as *traditional*. If we apply the "three-generation" criterion for tradition to building materials, then materials developed after the Industrial Revolution—including industrial steel, iron, concrete, cement, aluminum, industrial byproducts, and also polymers— may also be classified as traditional. The widespread global use of these added materials indicates that, irrespective of their temporal origin, they have acquired the status of traditional within the framework of the contemporary period.

[4] Gross, D., 1992, The past in ruins. Tradition and the critique of modernity, The University of Massachusetts Press, Amherst, s.9. In: Özbudun, 2003.
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[6] Malinowski R., Garfinkel Y., 1991, "Prehistory of Concrete", ACI Concrete International, March, ss.62-68. In: Akman, 2003.

2.4 Can All Traditional Materials Be Considered Ecological?

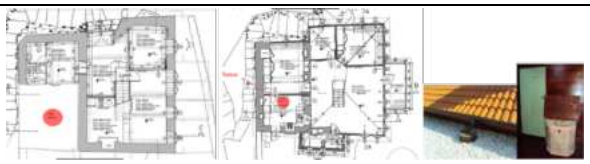
As previously concluded in Section 2.2.1, for a material to be classified as ecological, it must participate in a natural cycle in nature. Traditional construction materials can be categorically considered ecological, particularly those existing naturally in usable forms (stone, wood, earth) or those created through environmentally benign composite techniques using natural constituents, as exemplified by adobe (sun-dried earth bricks). Gypsum can be classified as an ecological material since its production process requires relatively lower heat input and no ancillary chemicals, while its application and post-use phases demonstrate minimal environmental impact. While both brick and lime utilize natural raw materials and demand high-temperature processing, they remain reusable even when fragmented and are ultimately biodegradable. By contrast, materials such as iron, steel, cement, concrete, and glass - although composed of naturally sourced raw materials - cause significant environmental damage at every stage of their life cycle. For example, the cement industry alone is responsible for approximately 7% of global CO_2 emissions [32] making it difficult to classify such materials as ecological. Similarly, while aluminum and polymers originate from natural raw materials, their extraction and processing involve highly intensive chemical procedures and resource consumption, disqualifying them from being considered ecological. From this perspective, many building materials that are now widely used and have become *traditional* are, in fact, not ecological. Nonetheless, there are ongoing efforts—by responsible manufacturers, researchers, and policymakers—to minimize the environmental impact of such materials. These initiatives are highly valuable but must become more widespread and intensive to effect meaningful change.

2.5 Does Sustainability Merely a Rearticulation of What Is Traditionally Known?

Although the concept of sustainability contains various internal contradictions (see Section 2.1), its support for preserving nature, locality, culture, and diversity for future generations is undeniably beneficial for the continuation of life. The point the author wants to draw attention to is that the principles of sustainable construction are perceived as if they are a new concept, as if they offer a new perspective, as if they are practical solutions found by modern people.

Some examples of sustainable design parameters that already exist in traditional/historic buildings and settlements are shown in Table 1. In Figure 1, there are restoration projects, roof gutter and in-kitchen well visuals showing the rainwater harvesting system, which exist under the building accessing from the kitchen with a well system in a restored traditional house in Alanya [33]. The double-layered window visual designed for heat conservation in the cold climate zone is presented in Fig. 2(a), which can be considered as the prototype of the current double-glazing systems [34]. In Figure 2(b) includes walls built by filling rubble/crushed stone between two ashlar layers in the ancient city of Aigai, which as the predecessor of the wall system called sandwich today. Examples of settlements designed for considering climate and geography are shown in Fig. 3 and the choice of local and ecological building materials can be seen in Fig. 4 [35]. Finally presented in Fig. 5, the roofs of the Vikings period as an early example of the 'green roof' that we often see in modern, especially characterized that 'green' buildings, and the hanging gardens of Babylon, perhaps one of the most iconic structures where landscape elements are added to the balconies or terraces of buildings [36], can be considered as striking examples of the fact that sustainable design parameters are not new at all. Although not shown in the table, when the literature is surveyed, there are interesting studies showing that, for example, passive building techniques exist in local buildings today and that they meet comfort conditions with minimum energy consumption [37-39]. Tohidi has also shown that healthy and affordable passive ventilation systems could be developed for existing concrete buildings in cold climates, based on teachings from vernacular buildings [40]. Examples can be multiplied. Such findings appear as examples showing that what exists in the tradition may have been reproduced with the label of sustainability in a way that confirms Adorno. In other words, it can be considered as an indication that we are emulating tradition with labels such as sustainable, green, ecological and passive design. From this point of view, it can be concluded that we should realize the traditional is modern or contemporary, and actually that we should remember what we have forgotten with modernity and the imposition of consumer society.

Table 1. Figures showing that some of the sustainable design parameters already exist in the traditional. Table compiled by the Author. References are from: Fig. 1 [33]; Fig. 2(a) [34]; Fig. 3 Google Earth; Fig. 4(b) [35]; Fig. 5 [36]; 2(b) and Fig. 4 (a,c,d) by Author.

Fig. No.	*Some Sustainable Design Parameters*	*Traditional Design Examples*
1	Rainwater harvesting	 A restored traditional house in Alanya, Turkey.
2	Energy efficiency Figures: (a) Double windows for heat preservation, (b) Sandwich wall system	(a) Traditional Houses of Sivas, Turkey (b) Aigai Ancient City of, Manisa, Turkey
3	Climate-, geography- and sun-oriented settlements that enable passive design	(a) Ait-Ben-Haddou, Morocco (b) Safranbolu, Turkey (c) Old city of Mardin, Turkey
4	Use of local, ecological, recyclable, reusable materials	(a) Brick&wood Kathmandhu, Nepal (b) Wood&stone Rize, Turkey (c) Adobe&wood Van, Turkey (d) Stone Mardin, Turkey
5	Green roof + floor gardens	(a) Vikings Period Grass Roof (b) Hanging gardens of Babylon

4 DISCUSSION

This study examines the concepts of *sustainability*, *traditionalism*, and *ecology* within their historical, sociological, and environmental contexts, revealing that despite being frequently expressed through new terminology today, these concepts are fundamentally rooted in the knowledge, values, and practices of the past. Traditional architectural understanding reflects a way

of life based on local resources, in harmony with nature, and integrated with the social structure; however, the production-consumption cycle that developed with modernization weakened this integrity and led to a deep disconnect between individuals and their environment. Sustainability discourses are increasingly commercialized today, moving away from a value-based understanding and becoming reduced to superficial window dressing focused on status and formality.

One of the important findings of the study is that sustainability is often a rebranding of traditional production methods using modern concepts. Adjectives such as *green*, *eco-friendly*, and *environmental* have been transformed into marketing strategies within today's consumer culture, replacing value-based approaches with formalistic and status-oriented preferences. It is so, the commodification of 'modern sustainable design', its market dominance, presentation as an innovation and ignoring tradition seems to have turned into an effort by researchers working in this field to show that 'non-modern(!)' traditional buildings are also sustainable. There are numerous studies of this in literature. Certainly, some traditional buildings may need to be made resistant to effects of climate change, global warming and earthquakes. But it's also the same for some 'modern' buildings. Precisely this point indicated the phenomenon this study wants to demonstrate. It is thought that neither denigrating the traditional nor glorifying the sustainable/modern will carry us safely to the future, and that the perspective we need to transform is the concepts of "value" and "attribution of value". Additionally, many materials widely used in the construction sector and developed after the Industrial Revolution have become traditional yet it can be seen that they cannot be classified as ecological due to their environmental impacts. In this context, it should be emphasized that the traditional is not solely confined to the past but is a long-term concept that also encompasses the future and assumes an instructive role that of nature.

Especially, researches such as into soil blocks obtained by compressing Martian soil, which have been shown to be more durable than steel [41], demonstrate that, soil could be a material that transcends time (timeless) and space (spaceless), this also obligating a re-evaluation of modern society's value judgments regarding natural materials that it considers '*primitive*'.

Ultimately, the concept of sustainability must be approached not as a technical matter confined to engineering metrics, but rather as an instrument for ethical, cultural, and philosophical paradigm shift. Instead of status-oriented material preferences imposed by the consumer society, education and awareness policies based on self-worth should be developed to raise social awareness. The integration of traditional knowledge and practices - compatible with local and circular systems - into contemporary design processes holds critical importance both for reducing environmental burdens and ensuring cultural continuity. In this context, it is argued that sustainability should be based on a holistic transformation that is nourished by tradition but oriented towards the future against the crises created by modernity.

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Ecological Breath Within the City: The Agroecology Climate School as a Sustainable Educational Space in Diyarbakir

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ABSTRACT

Environmentally friendly and low-carbon footprint building materials have become one of the cornerstones of contemporary sustainable architecture. In this context, adobe, with its thousands of years of history, stands out as a prominent building material. Made entirely from natural materials (earth, straw, and water), adobe is frequently used in traditional Anatolian architecture. With its breathable structure, it provides natural humidity and temperature balance in interior spaces; it is easy to produce and repair, and it is environmentally compatible. This material is at the core of the Agroecology Climate School project implemented by the Diyarbakir Metropolitan Municipality. Built on a 7,000 m² area, the school is designed as a holistic environmental and educational space that offers nature-based learning opportunities for children and the broader community. Enriched with adobe workshops, a seed library, vegetable gardens, greenhouses, fruit orchards, and areas for medicinal and aromatic plants, space also includes renewable energy systems such as solar and wind power, harvesting rainwater, and composting infrastructure—reflecting an ecological cycle in its design. In this study, the architectural, pedagogical, and environmental components of the Agroecology Climate School were evaluated using qualitative analysis methods. While the project presents an opportunity to be implemented as a replicable model in other cities, urbanization pressures and the increasing impacts of climate change are considered potential threats.
In conclusion, the Agroecology Climate School is regarded as a unique example of a public space that integrates sustainability with therapeutic architecture. It offers an opportunity to reconnect with nature within the urban environment and demonstrates the transformative potential of nature-based solutions in terms of both architectural and societal benefits.

Keywords: adobe, sustainable, Diyarbakir, agroecology, climate school

1 INTRODUCTION

The word "agroecology" is derived from the Latin "agro" (meaning agriculture or land) and the Greek "ecology" (the science that studies the relationship between living organisms and their environment). Agroecology refers to an approach that considers agricultural production in conjunction with natural systems, operating in harmony with soil, water, air, climate, biodiversity, and human communities. It is a holistic approach that centers not only on sustainable agricultural production but also on social justice, local knowledge systems, ecosystem integrity, and food sovereignty. Agroecology is defined both as a scientific discipline and as a movement and a practice [1].
The primary goal of agroecology is to promote locally adapted practices tailored to specific ecosystems and the socio-cultural needs of communities, rather than relying on standardized technologies applied uniformly across all areas. This approach is based on a set of socio-ecological principles [2]. In line with these principles, agroecologists advocate for the use of locally sourced

materials that are compatible with nature. In this regard, adobe—defined as unfired earthen bricks—is essentially produced by mixing natural soils rich in clay and limestone with water [3]. Adobe can thus be seen as a spatial and structural expression of agroecology, reflecting local ecosystem compatibility, low external dependency, community-based knowledge, and a mindset aligned with a circular economy.

This study examines how agroecological principles are spatially and structurally embodied within an urban context through the example of the Agroecology Climate School established in Diyarbakir. The main objective is to demonstrate that agroecology is not only an agricultural production model but also a holistic approach that shapes sustainable living practices and alternative educational spaces. Within this framework, the study analyzes how the use of Adobe—a locally sourced building material—aligns with agroecological principles in ecological, cultural, and socio-economic dimensions. Using a qualitative research method, data obtained through on-site observations are interpreted to explore how agroecological transformation can be made possible at the urban scale.

2 EXAMPLES OF AGROECOLOGY CLİMATE SCHOOLS FROM AROUND THE WORLD AND TURKEY

Escuela Campesina de Agroecology) – Küba

One of the leading institutions in agroecology education in Cuba is the Rural Agroecology Schools, established under the leadership of the National Association of Small Farmers (ANAP). The primary goal of these schools is to enable farmers to learn agroecological production methods through direct practice and to implement this knowledge within their local contexts. The educational model is based on the "farmer-to-farmer" approach, meaning that knowledge is shared not through academic instruction, but through hands-on production experience. This approach promotes horizontal knowledge exchange and facilitates the spread of agroecological transformation at the community level. In Cuba, this model is considered a foundational component not only of agricultural production but also of the country's food sovereignty strategy [4] [Fig. 1].

Figure 1. Cuba Agroecology Climate School [4]

La Vía Campesina's Agroecology Schools (International)

The Agroecology Schools promoted globally by La Vía Campesina are shaped in collaboration with local farmer networks across Latin America, Asia, Africa, and Europe. The primary aim of these schools is to empower communities around food sovereignty, agroecology, and farmers' rights through a people-centered learning approach. One of La Vía Campesina's prominent educational centers, the Escuela de Agroecología de la CLOC–Vía Campesina, operates in Latin America. The Nyéléni Agroecology School is a key example in West Africa. The methodology applied in these schools is rooted in a pedagogy that emphasizes participation and social movements. The educational process goes beyond the transmission of technical knowledge; it is carried out with a perspective focused on social transformation and collective solidarity. In this way, agroecology is seen not only as a mode of production but also as a political tool for struggle [5] [Fig. 2].

Figure 2. La Vía Campesina's Agroecology Schools [5].

Agroecology and Sustainable Food Systems Summer School – Norway & Germany

The Agroecology and Sustainable Food Systems Summer School is an international program organized in collaboration between the Norwegian University of Life Sciences in Norway and the University of Kassel in Germany. This summer school brings together young people, farmers, and students from various countries around the world, aiming to foster the exchange of knowledge and experiences on agroecology at a global scale. The core themes of the program include climate change, agroecology, and political ecology. Within an interdisciplinary and hands-on educational model, participants explore the ecological, social, and political dimensions of food systems. This approach offers a holistic learning experience that encompasses both academic knowledge production and grassroots struggles [6] [Fig. 3].

Figure 3. Agroecology And Sustainable Food Systems Summer School [6].

On Agroecology and Climate Schools in Turkey

In Turkey, educational activities based on agroecology are primarily carried out by civil society organizations, local initiatives, and universities. The Buğday Association for Supporting Ecological Living offers training in ecological farming, permaculture, seed saving, and food sovereignty. At the same time, the Kazdağı Ecological Life School conducts programs focused on nature-based living and community-based climate resilience. Initiatives such as Permakamp (Şile) and the Datça Permaculture Collective also organize hands-on agroecology camps. Additionally, organizations such as Çiftçi-Sen and agricultural cooperatives advocate for agroecological production and conduct awareness-raising activities. In academia, institutions such as Boğaziçi University's Climate Center, Ege University, and Middle East Technical University (METU) conduct research on climate adaptation, sustainable agriculture, and nature-based solutions, and some faculties of agriculture offer courses on agroecological practices.
Despite these developments, a significant need remains in Turkey for the establishment of a comprehensive Agroecology and Climate School, grounded in practical and participatory pedagogies. This school aims to enhance rural resilience against climate change, protect food sovereignty and local seeds, and actively engage women and youth in the process.

3 DIYARBAKIR AGROECOLOGY CLIMATE SCHOOL PROJECT

The Agroecology Climate School, implemented by the Diyarbakir Metropolitan Municipality's Department of Climate Change and Zero Waste, has been designed as a pioneering educational and living space that aims to connect children with nature and equip them with ecological awareness and sustainable living skills. The school, which will be built entirely with natural and recycled materials, is planned to cover a large area of 7,000 square meters. The project prioritizes the explicit use of traditional and eco-friendly construction materials, such as adobe. Composed of a mixture of earth, water, and straw, adobe aligns perfectly with the school's educational philosophy due to its energy-efficient and environmentally harmonious nature.
Adobe-built workshops will allow children to physically interact with nature while also introducing them to climate-friendly architecture. With their natural insulation properties—cool in summer and warm in winter—adobe structures reduce energy consumption and directly exemplify a lifestyle in balance with nature [Fig. 4].

Figure 4. Diyarbakir Agroecology Climate School Hair Tent (Diyarbakir Metropolitan Municipality Archive)

At the Agroecology Climate School, additional production and interaction spaces will be designed, including a greenhouse, vegetable garden, fruit and medicinal-aromatic plant gardens, a seed library, natural play areas, a chicken coop, barn, boranhane (pigeon house), duck pond, hair tent, traditional tandoor oven, and a fire circle. With the integration of solar panels, wind energy systems, rainwater harvesting infrastructure, and composting units, children will be taught nature-friendly energy use and waste management through hands-on activities [Fig. 5, 6, 7].
In this way, students will be involved in the production process from seed to harvest, learn how to build living spaces through recycling, and gain a firsthand understanding that a life in harmony with nature is indeed possible.

Figure 5. Diyarbakir Agroecology Climate School Adobe Boranhane (Pigeon House) Example (Diyarbakir Metropolitan Municipality Archive)

Figure 6. Diyarbakir Agroecology Climate School Adobe Workshop (Diyarbakir Metropolitan Municipality Archive)

Figure 7. Diyarbakir Agroecology Climate School Hair Tent, Medicinal-Aromatic Plant Gardens, Seed Library (Diyarbakir Metropolitan Municipality Archive)

The Diyarbakir Agroecology Climate School constitutes an inspiring and pioneering example for the institutionalization and societal dissemination of agroecological education in Turkey. With its nature-compatible architecture, use of local and recycled materials, hands-on learning approach targeting children, and a curriculum centered on sustainable living skills, it is more than just an educational space. It serves as a model that raises public awareness in the face of the climate crisis and blends local knowledge with modern environmental pedagogy. In this respect, the school offers a strong example for other municipalities and educational institutions in Turkey on how to design agroecology-based, environmentally compatible, and community-centered learning environments. Moreover, it lays the foundation for a multifaceted educational approach that can produce impactful outcomes in areas such as rural development, children's relationship with nature, and climate justice.

4 CONCLUSIONS

The Diyarbakir Agroecology Climate School stands out as a holistic sustainability model that aims to reestablish a connection with nature within an urban context. At the same time, its spatial expression materialized with adobe—a traditional and eco-friendly material. Adobe aligns directly with the spatial principles of agroecology, not only due to its ecological benefits but also because of its cultural significance, support for community-based production, and energy efficiency. The decision to use Adobe in the school extends beyond a simple architectural choice; it serves as a pedagogical tool integrated into the curriculum, providing both children and the broader community with direct experience of sustainable construction and the practical application of local knowledge systems.

The school's features—such as greenhouses, vegetable gardens, renewable energy systems, and a seed library—create a layered learning environment where agroecological cycles are both taught and lived. Adobe structures form the material and symbolic foundation of this cycle. The circular nature of Adobe— "from earth to earth"—reinforces the school's message of living in harmony with the environment through spatial design.

In this context, the Diyarbakir Agroecology Climate School is not merely an educational project; it is a pioneering public space that demonstrates how adobe architecture can merge with agroecology to inspire urban-scale transformation.

In conclusion, this adobe-built school in Diyarbakir stands as a powerful example of how nature-based solutions, local materials, and agroecological knowledge can be integrated into urban life. It offers an inspiring model for other local governments and educational institutions in Turkey within the framework of sustainability. The architectural and pedagogical bridge established through adobe redefines both how environmentally harmonious ways of living can be constructed and how they can be learned.

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Evaluation of the Current Status of Studies on Adobe in Turkey

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ABSTRACT

Adobe is being investigated as an easy-to-source, economical and malleable material, as well as an important alternative that can contribute to reducing environmental impacts. On the other hand, traditional adobe, which requires constant maintenance, is sensitive to moisture and water and generally has poor earthquake resistance, is the subject of scientific research in order to eliminate these disadvantages. In this context, adobe is scientifically investigated within the scope of its physical, chemical and mechanical properties in order to improve and develop its properties.

Considering the positive relationship, it establishes with nature during its life cycle, scientific research in this context is very important. Adobe buildings are an important part of cultural heritage with the advantages of adobe material, traditional construction techniques and unique features, and are scientifically researched in terms of conservation, maintenance, repair and strengthening.

In this paper, it is aimed to evaluate the state of scientific research on adobe material and adobe structures in Turkey. For this purpose, postgraduate thesis studies, articles, book chapters or papers carried out in Turkey constitute the scope of the study. The current situation on this subject has been revealed by examining the literature on adobe works. It is thought that this study can guide the researchers in their future studies and provide an idea about the extent to which the studies on adobe are not studied in the literature and are incomplete.

Keywords: Adobe, adobe structure, traditional adobe material, modern adobe material.

1 INTRODUCTION

Adobe is an economical and easily available material. As a moldable, earth-based material, adobe is environmentally friendly and sustainable, but it is also a traditional material that is vulnerable to water, moisture, and earthquakes. Nevertheless, adobe structures are in harmony with nature throughout their life cycle. Under current conditions, mixtures are prepared using natural materials such as soil, water, and straw without the need for transportation, then molded and dried. In addition to its low carbon emissions during use, it is an effective building material in ensuring thermal comfort conditions in structures. In the post-use phase, it is a material that leaves no waste in nature due to its complete recyclability. Adobe structures constitute an important part of our cultural heritage. This building material and its construction techniques, whose use in traditional buildings dates back to ancient times, need to be known and brought into the literature.

Considering global environmental issues, scientific research conducted to develop adobe and improve its negative characteristics has the potential to increase the use of natural and ecological building materials. Scientific research conducted to document the characteristic features of adobe structures, which are part of our cultural heritage, and to develop recommendations for their

preservation will contribute to the identification of rural settlement identity. In this context, the extent to which adobe is included in scientific research and the progress it has made to date are important points of focus. Within this focus, studies on adobe in Turkey have been compiled and a comprehensive review has been conducted. It is believed that this study will contribute to literature by providing an overview of studies conducted in recent years and offering a rich reference list on the subject.

A compilation of studies on adobe was prepared in 1983. This publication, titled "Açıklamalı Kerpiç Bibliyografyası," was revised and expanded, with a second edition published in 1987 [1]. In addition, studies published between 1995 and 2025 in the National Thesis Center and Google Scholar databases were examined. Among these studies, no work was found that examined and compiled scientific studies on adobe, and a gap in literature was identified in this regard. In this respect, it is believed that this study will contribute to the literature by revealing the current state of studies on adobe.

2 METHOD

This paper aims to evaluate the current state of studies on adobe in Turkey. To this end, the term "Kerpiç" was searched in Turkish in the National Thesis Center and Google Scholar databases as of July 16, 2025. The listed studies were first examined based on their titles, and those deemed unsuitable for inclusion were excluded. In the next stage, studies deemed suitable based on their titles were examined in terms of their content, and a decision was made on whether to include or exclude the study. Studies evaluating adobe, particularly in the field of architecture, were included in the analysis. On the other hand, scientific studies evaluating adobe in the archaeological field were not included in the analysis and were excluded.

Initially, 53 results were listed in the National Thesis Center. Then, filtering was performed by entering the word "Architecture" in the "Subject" column on the far right, resulting in a list of 35 thesis studies. The 35 thesis studies listed were first examined based on their titles, then analyzed in detail by reading their contents, and a total of 34 studies dealing with adobe in the field of architecture were included in the analysis. The thesis study that was not included is about the preservation of archaeological adobe.

An advanced search was selected on Google Scholar, using the filters "with all of the words" and "in the title of the article" listing a total of 182 studies containing the word "adobe" in the article title. A specific date range of 1995-2025 was set, listing 140 studies. The 140 listed studies were first examined based on their titles. Subsequently, studies accessible through the database were examined in detail in terms of their content. As a result, 27 research studies conducted in the field of architecture and accessible through the Google Scholar database were included in the scope of the study. A compilation study was conducted by analyzing the literature on adobe-related studies.

3 SCIENTIFIC RESEARCH ON ADOBE

3.1 Scientific Research on Adobe Materials and Components

In order to improve the disadvantages of adobe, various materials are added to the adobe mixture, and various experiments are conducted to determine the physical, chemical, and mechanical properties of the resulting product (Table 1). The use of alternative materials such as fiber, wheat straw, styrofoam, pumice, and clay in adobe production has been investigated [2]. Samples obtained by adding fiber, polyester, and straw at various ratios to different clays [3] were analyzed. In another study, the use of plastic fiber and textile fibers as reinforcing materials and pumice, gypsum, and cement as binders was investigated [4]. The effect of pine needle use in adobe material on its physical and thermal properties was investigated, and it was stated that pine needle

use has potential [5]. In a study focusing on adobe bricks produced by adding polypropylene fibers to the mixture, the physical and mechanical properties of the samples were examined. Since clay soil swells when absorbing water and shrinks when losing water, it was predicted that adding a flexible additive to the material would not cause cracking and would increase strength, which is why polypropylene was chosen. According to the study results, it was stated that an increase in fiber additive ratio and length reduces volume loss, increases compressive strength, and increases bending damage loads [6]. The preservation of Turkey's adobe architectural heritage, ensuring its sustainability, and investigating the possibility of constructing new buildings using modern techniques have been studied. In this context, the usability of different stabilizers such as lime, gypsum, cement, lime and cement, lime and pozzolan, and cement in earth block production has been examined [7]. An experimental study was conducted on the addition of additives such as waste glass powder, pumice, marble powder, gypsum, slaked lime, and volcanic tuff to the adobe mixture, and the dispersion of the obtained material in water, compressive strength, ultrasonic wave velocity, density, and thermal conductivity were investigated [8]. The use of recycled paper waste in adobe material resulted in lighter samples compared to traditional adobe material. It has been stated that this advantage could support increased public participation in the construction process [9]. The physical and mechanical properties of adobe material obtained with the addition of sunflower stalks were examined, and it was stated that the compressive and flexural strength of the final product increased [10]. In a study where adobe products enriched with nano clay were obtained using the nano clay enrichment method, it was determined that these products had higher compressive and flexural strength than required by the regulations. Additionally, it was stated that the breathability and capillary water absorption properties of adobe were preserved in the final product [11].

Table 1. Scientific research on adobe material development.

Publication		**Additive material**	**Researched Features**
Adobe Material Development	[2]	Use of fiber, wheat straw, styrofoam, pumice, and clay.	Cost and energy efficiency, mechanical properties
	[3]	Addition of fiber, polyester, and straw to different clays in various proportions.	Mechanical Properties
	[4]	Use of plastic fiber and textile fibers as reinforcement materials; use of pumice, gypsum, and cement as binders.	Mechanical properties and earthquake resistance
	[5]	Use of pine needles in adobe materials.	Physical and thermal properties
	[6]	Addition of polypropylene fiber.	Physical and mechanical properties
	[7]	Use of different stabilizers such as lime, gypsum, cement, lime with cement, lime with pozzolan, and cement in soil block production.	Physical and mechanical properties
	[8]	Addition of additives such as waste glass powder, pumice, marble powder, gypsum, slaked lime, and volcanic tuff.	Water dispersibility, compressive strength, ultrasonic sound wave speed, density, and thermal conductivity
	[9]	Use of recycled paper waste.	Pressure analysis
	[10]	Addition of sunflower stalks.	Physical and mechanical properties
	[11]	Use of nano-clay enrichment method.	Compressive and flexural strength, breathability, and capillary water absorption

Mortar mixtures are being researched in terms of material content and the addition of additives to the mortar. A mortar prepared by mixing gypsum-based ready-mixed mortar with soil for use in the repair of damaged adobe structures has been experimentally researched, and it has been stated that the mortar obtained is easy to apply to walls and exhibits good adhesion [12]. Mortar mixtures

prepared using additives such as lime, gypsum, cement, and wool in clay mortar for use in the restoration of registered adobe structures were experimentally analyzed, and it was concluded that wool-added adobe mortar performed well [13].

Figure 1. Image of adobe bricks and plaster belonging to an adobe structure located in the village of Danaburan, Mazgirt district, Tunceli province (Source: Lizge Deniz Çakmaz Archive).

The contents of plaster used in adobe structures (Figure 1) are being investigated. The process of protecting the surface of structures with plaster, which is one of the methods of protecting adobe structures and their surfaces from possible damage, has been examined, and traditional and industrial plasters have been analyzed [14]. In the study, it is stated that the plaster layer, which is in contact with environmental factors, may be damaged over time due to the negative effects of these factors. As a result of this situation, it is stated that the wall layer may lose its defense against environmental factors or become defenseless. Therefore, the possibilities of developing clay-based plasters and the additives that can be incorporated into them were investigated, and it was stated that the performance of the samples obtained depending on the additive may vary, and an experimental study was conducted [15]. In the study, where samples obtained by mixing natural pozzolan-containing lime mortar with soil were experimentally investigated for use as exterior plaster material in adobe structures, samples with vapor permeability compatible with adobe material were obtained. It was stated that the pozzolan-containing material exhibited better strength and water resistance compared to normal lime mortar [16].

Gypsum-reinforced adobe material is discussed in many contexts. In studies aimed at presenting the possibilities of using adobe as a building material in one- or two-story buildings in rural areas, issues such as improving the durability, water and moisture sensitivity, and ease of manufacture of adobe have been addressed. Given the high availability of gypsum in Turkey and the possibility of stabilizing soil with gypsum, gypsum-reinforced adobe material has been examined [17], [18]. The applicability of sprayed concrete technology as an alternative method to the technique of obtaining this material by tamping it in a mold has been investigated [19], [20]. The study results indicated that the technique could increase efficiency in practice. Additionally, the results indicate that the compressive strength of the product needs to be increased and its sensitivity to water absorption reduced [19]. The effects of labor on construction quality during the use of sprayed concrete technology were examined, and it was suggested that designing an automation system to regulate these effects would be beneficial [20].

The sustainability of adobe materials and components is being researched. As a natural building material, adobe is being studied in terms of its advantages and disadvantages, production, construction rules, and application examples [21]. In a study evaluating the compliance of adobe with the criteria listed in national and international certifications, the possibility of including it in the green material category was investigated. According to the study results, adobe meets the

requirements for being a green material due to its characteristics such as being a local material, having almost no harmful environmental effects, being easily accessible, cost-effective, having thermal performance, having minimal carbon emissions, being harmless to human health, being recyclable, and being reusable [22].

2.2 Scientific Research on Adobe Building Elements

Traditional adobe construction practices have been researched. Regional differences in practices seen in adobe buildings in Anatolia have been examined, and the structural characteristics of masonry adobe buildings, adobe dwellings with adobe infill between wooden frames, and mixed-system adobe dwellings have been analyzed [23]. The applications of architectural elements such as foundations, walls, plaster, windows, doors, and roofs in adobe buildings were examined [24].

The potential for improving adobe building elements with additives has been investigated. The possibilities for use as panel walls have been examined, and it has been stated that adding fiber to soil reinforced with binders and chemical additives enables the strengthening of the samples obtained [25].

Adobe structures were analyzed structurally. Experimental work was carried out to determine the pore structures and mineral sizes of samples taken from the structures, and damage to the load-bearing elements was observed and various solutions were proposed [26], [27]. Adobe structures were investigated in terms of their load-bearing systems, including openings in the structure, wall stability and thickness, structural elements, flooring, and roofing systems [28].

Figure 2. Image of an adobe brick wall belonging to an adobe structure in the village of Danaburan, Mazgirt district, Tunceli province (Source: Lizge Deniz Çakmaz Archive).

The study, which examined the effects of adobe walls (Figure 2) on energy conservation, investigated the use of contemporary construction techniques. According to the results of the study, adobe walls support energy conservation by providing thermal insulation and natural ventilation [29].

2.3 Scientific Research on Adobe Building

The comfort characteristics, thermal properties, cost, durability, and damage status of adobe buildings are being investigated. In addition, their architectural characteristics are being examined, protection issues at the settlement or building scale are being identified, and solutions to the identified problems are being proposed. Adobe buildings are structurally analyzed to assess damage, and examined in terms of sustainability, energy conservation, reuse, recycling, and environmental impact.

Figure 3. View of adobe buildings in Kayseri/Develi/Zile (a and b), Aydan Özkan's adobe house in Kayseri/Develi/Zile (c) (Source: Lizge Deniz Çakmaz Archive).

Buildings constructed with gypsum-added adobe material and their characteristics have been investigated. In the study, which explains the mechanical and physical properties of gypsum-added adobe material, research conducted on the development of adobe and the preservation of adobe heritage has been presented, and the experimental buildings constructed within this scope have been examined in detail [30]. A comparative analysis was made between experimental houses made of gypsum-adobe and brick-walled structures built as part of a housing project. According to the results of the study, it was stated that adobe buildings have a higher heat storage capacity, require less transport energy, can be built at a lower cost, and provide more efficient use of resources [31]. In a study investigating the effects of traditional adobe and gypsum-adobe materials on durability, damage analysis was performed on a gypsum-adobe building [32].

Traditional adobe buildings located in district and village settlements have been researched in terms of their architectural features, conservation issues, and the development of proposed solutions. The architectural features of the structures, such as their plans, facades, construction techniques, construction systems, structural elements, materials, and decorative features, were examined [33], [34], [35], [36], [37], [38]. The studies identified conservation issues at the structure and settlement scales. It has been stated that adobe buildings cannot meet the needs of users due to changes in social life and socio-economic conditions. It has been revealed that this situation has led to the replacement of original road pavements in settlement areas with incompatible paving materials, repairs that are incompatible with the traditional architectural fabric, and the construction of additional buildings. Due to the decrease in population and abandonment, the structures have been left vacant and neglected, and the maintenance required by the nature of the material has not been provided. As a result, issues such as sensitivity to water and moisture, softening, cracking, and fragmentation caused by moisture entering the structure have been identified as conservation problems. The loss of skilled craftsmen and deficiencies in legal regulations are among the problems addressed in the context of protecting traditional adobe houses from damage and destruction caused by natural disasters [39], [40], [41], [42], [43], [44], [45]. In order to solve conservation issues, solutions have been developed at the settlement fabric, material, and building scale, as well as in relation to socio-economic conditions and legal regulations [46], [47]. In addition, the reuse of buildings that have lost their original function is being investigated [48]. In a study emphasizing the value of ongoing maintenance, renovation, and decoration practices in adobe buildings in rural settlements as intangible cultural heritage, adobe buildings constructed in the Hüyük district of Konya were examined [49].

There are also studies on earthquake-induced damage and the detection of such damage. In a study examining adobe buildings damaged by earthquakes, the following were identified as causes of damage: lack of use of bonding timber, weak corner connections, excessive weight of earthen roofs, use of simple nailing methods at the connection points of wooden elements, lack of sub-base elevation, and damage caused by water and moisture [50]. According to the results of the study, which examined the use of plastic fibers and textile fibers as reinforcing materials and pumice,

gypsum, and cement as binders in the production of adobe materials and the gains that could be achieved, it was stated that the compressive strength of the adobe produced was higher than the limit value required by the standards [51]. In a study examining the effect of the physical properties of adobe walls on their seismic behavior, damaged and undamaged buildings affected by the 2006 Silakhoor earthquake in Iran were investigated [52]. In a study linking the preservation of architectural heritage with earthquake disasters and addressing earthquake effects as a preservation issue, recommendations were made for reducing earthquake effects [53].

Adobe buildings are being researched in many areas in the context of sustainability. In a study addressing energy requirements in the production of building materials needed for the construction of adobe and reinforced concrete houses, it was stated that adobe buildings have lower rates than reinforced concrete buildings [54]. In a study presenting contemporary adobe construction techniques and building examples, the relationship between environmental approaches in architecture and adobe was examined [55]. In addition, adobe buildings are evaluated in the context of sustainability [56], [57] and researched in terms of their effects on human health and the environment [58]. The transition from a linear economy to a circular economy in rural settlements with a high concentration of adobe buildings and the advantages it can provide have been examined. It has been demonstrated that while the linear economy follows a "take-make-dispose" approach, the circular economy is based on the reuse or recycling of waste. This approach is said to support efficient resource use, the production of building materials with low embodied energy, and the reduction of environmental impacts [59].

User opinions on adobe buildings were examined. Based on user opinions, reinforced concrete building users were surveyed in a study aimed at determining the reasons for not preferring and abandoning adobe buildings. In addition, the aim was to determine users' knowledge of natural building materials and adobe [60].

It was researched in the context of quality control. In the context of the total quality method, which aims to meet all expectations and needs in the most economical way, quality control is provided so that problems can be identified at their source and solved before they grow. The applicability of the total quality method in adobe buildings was examined, and its application to traditional and plaster-added adobe construction was evaluated [61].

Proposed models for the development of new adobe settlements have been prepared. The study, which revealed that planned and unplanned adobe house communities were being built to solve the housing problem of internally displaced persons in Syria, emphasized the need to build planned housing for these areas, taking into account the location, topography, and climate data of the area, as well as technical and social infrastructure needs. In addition, proposed models were prepared and presented [62].

4 DISCUSSION

Adobe is a composite building material. The infinite variations in its composite components provide design flexibility and give the designer freedom during the structural design phase [63]. In the literature, adobe materials and components have been experimentally investigated in terms of cost and energy efficiency, physical, mechanical, and thermal properties by adding additives. When the results of the study were evaluated, it was stated that 'the use of pine needles in adobe material has potential' [5], 'pressure resistance increases with the increase in the polypropylene fiber additive ratio and length' [6], and 'lighter samples are obtained with the use of recycled paper waste' [9]. Additionally, it was noted that 'the addition of sunflower stalks increases compressive and flexural strength' [10] and 'the use of a nanoclay enrichment method results in flexural and compressive strength higher than required by regulations' [11]. Mortar and plaster contents were examined; it was stated that 'gypsum-based ready-mixed mortar and soil mixture is easy to apply and shows good adhesion' [12], 'adobe mortar with wool additive performs well' [13], and

'compared to lime mortar, lime mortar with natural pozzolan additive exhibits better strength and water resistance as an exterior plaster material' [16]. It has been observed that experimental studies conducted on the development of adobe materials focus on specific properties of the materials. In this context, the material contents that have yielded positive results can be analyzed in terms of different properties and examined in greater detail. In addition to material contents, the feasibility of an alternative production method was evaluated by considering adobe production. As an alternative to the standard production method based on preparing adobe mixtures, pouring them into molds, and drying them, the feasibility of applying gypsum-added adobe material with sprayed concrete technology was examined, and it was stated that this method could increase the speed of application. It was stated that the compressive strength of adobe applied with sprayed concrete technology should be increased and its sensitivity to water absorption should be reduced. In this context, the compressive strength and water absorption properties of adobe applied with this method can be examined [19].

Adobe building elements have been examined in terms of their application characteristics [23], [24] and structurally analyzed [26], [27]. The usability of adobe as panel walls has been examined; it has been stated that it is possible to reinforce soil samples with binders, chemical additives, and fibers [25]. In this context, the material contents of adobe panels based on different combinations of binders, chemical additives, and fiber additives can be investigated, and the applicability of these panels can be examined. In addition, it has been stated that adobe walls can provide thermal insulation and natural ventilation, thereby supporting energy conservation [29]. Globally, energy conservation measures are needed in view of the problems caused by the high energy demand in the construction sector. In this context, adobe, a natural building material with the potential to contribute to energy conservation, stands out.

Adobe buildings have been extensively researched in the context of traditional adobe architecture, conservation issues, and the development of proposed solutions. It is very important to develop solutions for the documentation and conservation of original adobe buildings in order to prevent their disappearance. The durability and sensitivity to water and moisture of adobe mixed with gypsum has been researched [17], [18]. Test structures built using adobe material with gypsum added were examined [30] and compared with brick-walled structures [31] and structures built with traditional adobe material [32]. In addition, earthquake-induced damage and its causes were examined. It was stated that the lack of use of lintels in adobe buildings, the weakness of corner connections, the weight of the earthen roof, the use of simple nailing methods at the connection points of wooden elements, the lack of a sub-base level, and damage caused by water and moisture caused damage after the earthquake [50].

5 CONCLUSION AND EVALUATION

The scientific studies examined in this paper are divided into three categories based on their focus: "Adobe material and components," "Adobe building elements," and "Adobe buildings" (Table 2). An evaluation of the studies in the literature reveals that most of them examine the architecture of traditional adobe buildings, conservation issues, and proposed solutions. Another topic that has been widely examined in research is the "evaluation of the potential contributions to the development of adobe and the improvement of its disadvantages." The sustainability of adobe in terms of its natural building material properties and positive relationship with the environment has also been examined in many studies. The load-bearing system and damage conditions have been examined, and structural analysis studies have been carried out in this context.

Table 2. Distribution of scientific research on adobe materials and components, building elements, and construction.

	Focused Topic	Number	Total
Adobe Material and	Adobe Material Development.	10	21
	Adobe Mortar Development.	2	
	Adobe Plaster Development.	3	
	Adobe material with gypsum additive.	4	
	Sustainability of adobe materials and components.	2	
Adobe Building Element	Adobe building application characteristics.	2	7
	Adobe building elements obtained by adding additives.	1	
	Structural analysis (load-bearing system and damage conditions).	3	
	Effects of adobe walls on energy conservation.	1	
Adobe Buildings	Buildings constructed with gypsum-added adobe material.	3	33
	Architectural characteristics of traditional adobe buildings in district and village settlements, conservation problems, and development of proposed solutions.	17	
	Earthquake-induced damage and detection of such damage.	4	
	Sustainability of adobe buildings.	6	
	User opinions on adobe buildings.	1	
	Quality control.	1	
	Development of new adobe settlement areas.	1	
			61

Adobe has been examined in many studies due to its advantageous properties as an economical, ecological, and sustainable building material. However, its sensitivity to water and moisture and its vulnerability to earthquakes have been addressed in many studies, and efforts are being made to improve these properties.

Adobe is a composite material that has been used as a building material since ancient times. Composites are based on the concept of combining one or more components to obtain a final product with properties superior to those of the components themselves. Composites allow for many different combinations and enable the production of many different end products because they are obtained by combining different component materials. From this perspective, adobe brick, plaster, and mortar production can be highly diversified in terms of the components that make them up and the additives that can be added. In the literature, there are many studies that examine adobe at different scales, such as adobe brick, adobe plaster, adobe mortar, gypsum-added adobe materials and structures, and adobe building elements containing additives, in terms of material/component, building element, and building. These studies have focused on the development of adobe or the elimination of its disadvantages. Considering that the composite concept allows for many different adobe material contents, many different combinations can be developed and researched in the context of adding additives. More research can be conducted on the development of adobe as a building element. In addition, there are several studies investigating the usability of different technologies as alternatives to the existing adobe production method, and possibilities can be explored in this context.

Structural analyses of adobe building elements and structures, as well as the identification and analysis of earthquake-induced damage, have been carried out. These studies are of great importance in evaluating the structural condition and earthquake resistance of adobe structures. Considering that our country is located in an earthquake zone, further research can be conducted to improve the earthquake resistance of building elements and structures and minimize damage.

Traditional adobe buildings have been addressed in many studies in the context of their architectural features, conservation problems, and the development of solutions to conservation issues. It is very important to document existing adobe buildings and add them to the literature in

order to prevent their disappearance. In this regard, unique adobe buildings in rural settlements that have not yet been researched can be investigated.

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Characteristics of Tunceli Danaburan Village Earthen Architecture

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ABSTRACT

Buildings that reflect the local behavior, culture, social life, and economic status of their users establish a connection between the past and the future. Adobe has been used as a building material since ancient times and is still in use today. These unique structures, built using traditional construction techniques, are an important part of cultural heritage. This article examines the architectural features of the original adobe buildings in the village of Danaburan in Tunceli. The original adobe buildings in Danaburan are in danger of collapsing and disappearing over time due to users' unwillingness to protect them, migration, or neglect. The protection and preservation of these buildings is a very important focus. There is no study examining the architectural features of the original adobe buildings in the village of Danaburan. The aim is to research and document the original adobe buildings in the village. In addition, it is intended to reveal the architectural features of the adobe buildings in the village and add them to the literature. To this end, the earthen architecture of Danaburan village forms the scope of the study. In this context, the literature will be analyzed. Fieldwork will be conducted in Danaburan village, adobe buildings will be photographed and visually analyzed.

Keywords: Adobe material, adobe construction, earth architecture, Tunceli rural architecture, Danaburan village.

1 INTRODUCTION

Each settlement has its own unique characteristics. In this respect, buildings are a concrete reflection of the daily lives, local behaviors, cultural structures, social life characteristics, and economic structures of their users. In addition, buildings that convey local knowledge and experience in construction techniques are part of our cultural heritage. In order to preserve, maintain, and ensure the sustainability of these structures, it is necessary to carry out their maintenance and repairs.

Adobe structures are concentrated in the districts of Pertek and Mazgirt in the province of Tunceli. Some of the adobe structures in this region have been lost due to their low resistance to earthquakes over time, their sensitivity to water and moisture, the failure to provide the necessary maintenance, and the reluctance of their users to protect them. A review of the literature reveals that scientific research on adobe structures in Tunceli Province is very limited and that the structures in the region need to be researched and documented. In this context, it is believed that this study will contribute to the literature by providing original field documentation of the adobe structures located in the village of Danaburan, which is part of the Mazgirt district.

There are many adobe buildings in the village of Danaburan. There are also reinforced concrete, masonry stone, and masonry brick buildings. The original adobe buildings in the village are in danger of collapsing and disappearing over time due to the reluctance of their users to protect them, migration, or neglect. This study aims to investigate and document these structures, which are part of our cultural heritage, in order to prevent their disappearance. The objective is to examine the architectural features of these structures and contribute them to the literature. The scope of the study includes a literature review on the earthen architecture of Danaburan village, fieldwork conducted in the village, and visual analysis through photographing the structures. The selection of the structures presented as examples was determined by the observability of their original architectural features. Three different structural examples were selected, and the photographs obtained as a result of the fieldwork were categorized for the purpose of analyzing the different architectural features of each structure.

2 DANABURAN VILLAGE

2.1 Geographical and Topographical Features of Danaburan Village

Figure 1. Location of Danaburan village [1].

Tunceli Province has high mountainous areas, plateau areas with varying elevations, tectonic plains, and a rugged topography. The topographical conditions of the province have had a significant impact on settlement and population distribution. Mazgirt District is located in the southern part of the province, with its district center established at the foot of a mountainous area [2]. The hills and mountains forming the district exhibit a continuous increase in elevation from south to north. The district's elevation is 1,400 meters, and there are no plains [3]. Danaburan Village (Figure 1) is affiliated with Mazgirt district. It is approximately 50-60 minutes away from the Tunceli provincial center and approximately 20-30 minutes away from the district center (Figure 1).

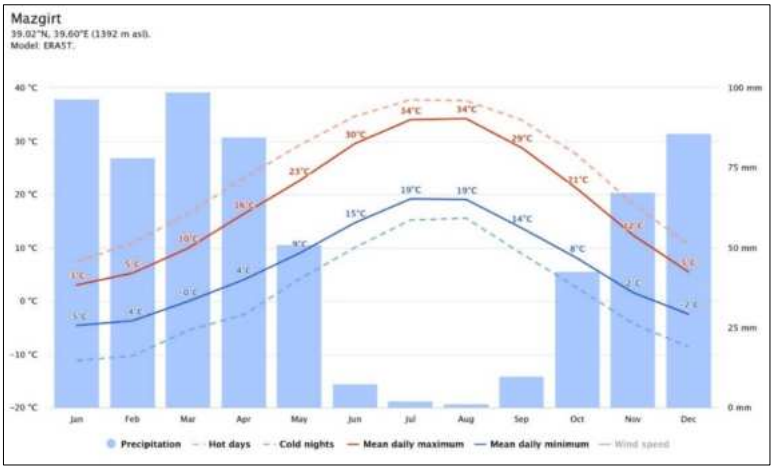


Figure 2. Average temperatures and precipitation in Mazgirt [4].

In the northern part of Tunceli province, where the continental climate prevails, winters are harsh and summers are cool. In contrast, winters in the southern part of Tunceli are milder, while summers are hotter and drier [2].

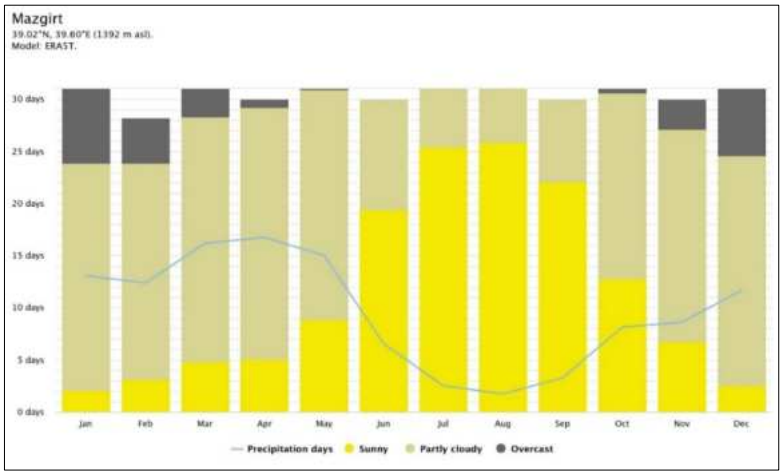


Figure 3. Cloudy, sunny, and precipitation days in Mazgirt [4].

In the Mazgirt region, the average daily maximum temperature is 34 °C, while the minimum temperature is 19 °C (Figure 2). The month with the highest number of sunny days is August (Figure 3) [4].

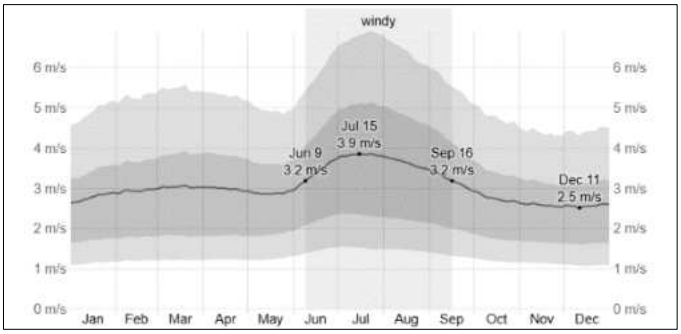
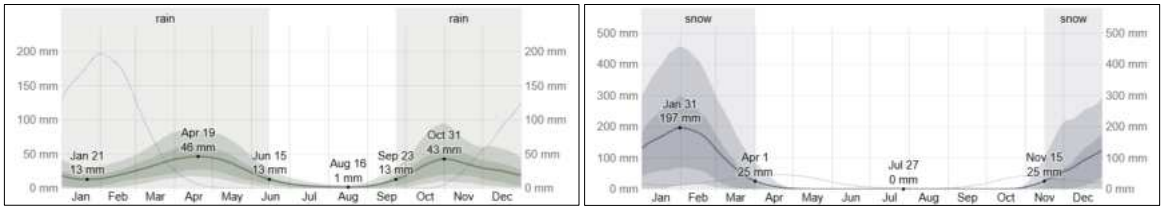


Figure 4. Average Wind Speed in Mazgirt [5].

According to the average wind speed diagram in Mazgirt, the windiest times of the year are from June to September (Figure 4). When examining the monthly average precipitation amount diagram, it can be stated that April is the rainiest time in Mazgirt (Figure 5a). When examining the monthly average snowfall diagram, it can be stated that February is the snowiest time (Figure 5b) [5].



a b

Figure 5. Average Monthly Rainfall in Mazgirt (a), Average Monthly Snowfall in Mazgirt (b) [5].

2.2 Socioeconomic Structure of Danaburan Village

When examining the population data for Danaburan village [6], it can be seen that the population has gradually decreased over the last 10 years (Figure 6). During interviews conducted in the village, it was learned that the owners of some houses that could not be reached by users come and go from the village seasonally. It was learned that the elderly population continues to live in the village, but their children do not choose to live there. However, there are also families who continue to live in the village as a whole.

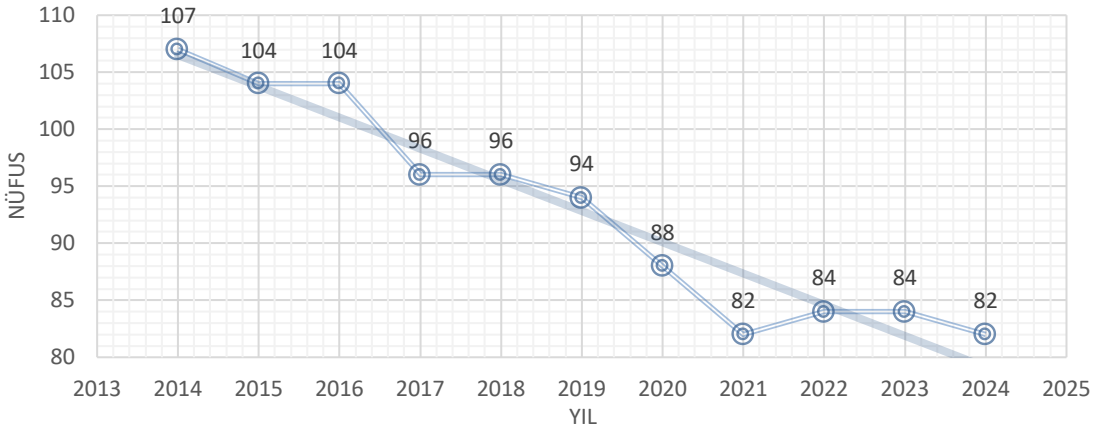


Figure 6. Changes in the population of Danaburan village over the years [6].

In southern parts of the province, winters are milder and summers are hotter and drier, which has facilitated the development of agricultural activities and livestock farming [7]. The main sources of income in Danaburan village are agriculture and animal husbandry.

2.3 Danaburan Village Settlement Characteristics

The Danaburan village settlement is located along the Danaburan Village road, which runs along the southwest-northeast axis, and the side roads connected to this road (Figure 7a). Continuing along this road, one can reach the village of Ağaçardı to the northeast and the village of Yazeli to the east. The main road connecting the village to other villages is in poor condition with substandard asphalt paving, while the side roads extending into the village settlement are made of earth.

Figure 7. Danaburan village settlement (a), 3D view of the village taken from Google Earth (b)[8].

The village settlement is concentrated particularly at the northeastern end of the southwest-northeast axis. Parallel to the village settlement axis and to the southeast of the village is a riverbed (Figure 7a). The elevation increases from the riverbed toward the village settlement. Again, the elevation increases from the riverbed toward the southeast (Figure 7b).

Figure 8. View of Danaburan village (Source: Lizge Deniz Çakmaz Archive).

In the settlement area concentrated at the northeastern end of the road axis (Figure 8), most of the houses are two-story buildings. In addition, there are also single-story buildings constructed for use as residences or storage facilities. In the settlement area, it has been observed that some residential buildings are surrounded by a garden area, with garden boundaries enclosed by various materials such as wire fences or tree branches. However, it has also been observed that some buildings are located immediately adjacent to the road and are not surrounded by any garden area.

2.4 Architectural Features of Buildings

Compared to the northern parts of Tunceli, where winter conditions are relatively harsher, it can be said that Danaburan village and the surrounding villages have a climate that allows for the construction and use of mudbrick houses. In this section, three unique examples of adobe buildings in the village will be examined in terms of their planning features, use of materials, maintenance, and repairs. A general view of adobe building example 1 with a courtyard is presented in Figure 9a, and a general view of adobe building example 2 with an entrance directly connected to the road is presented in Figure 9b.

Figure 9. Danaburan village courtyard adobe building example 1 (a), entrance facade opening onto the road adobe building example 2 (b) (Source: Lizge Deniz Çakmaz Archive).

In adobe building example 1, a reinforced concrete extension has been added to the adobe building and an entrance independent of the adobe building has been constructed (Figure 9a). In this construction, there is an adobe building used as a warehouse and a roof attached to this building with metal sheets. This family, which engages in livestock farming, has created a courtyard that is enclosed on two sides by structures and on two sides by wire fences. The animals are kept within the courtyard and the semi-open area created by the metal sheets.

Figure 10. The barn belonging to adobe building example 1 (a), storage area belonging to adobe building example 2 (b) and adobe building example 3 (c). (Source: Lizge Deniz Çakmaz Archive).

In the village where agricultural and livestock activities are carried out, the need for spaces such as barns and storage areas has been met on the ground floor of the buildings. In adobe building example 1, this area is still used as a barn because livestock farming activities are still carried out. In contrast, in adobe building examples 2 and 3, these areas are used as storage areas because livestock farming activities are no longer carried out (Figure 10).

Figure 11. Entrance facade view. Adobe building example 1 (a), adobe building example 2 (b) and adobe building example 3 (c) (Source: Lizge Deniz Çakmaz Archive).

The semi-open area constructed with a wooden projection on the first floor is accessed from the outside via stairs. In adobe buildings that have been preserved in their original state, this projection was found to be constructed of wood and adobe. However, when adobe building example 3 was examined, it was observed that metal stairs extending to a metal platform were used (Figure 11).

Figure 12. Adobe building example 1 (a) and 2 (b) (Source: Lizge Deniz Çakmaz Archive).

When you enter the first floor from the wooden ledge, you pass to an interior hall that opens to other spaces (Figure 12). In adobe building example 1, this area is used for circulation as well as for sitting, gathering, and resting. In adobe building examples 1 and 2, one passes into a large space directly opposite the entrance door. In adobe building example 1, the space reached is used as a kitchen, and there is a pantry room accessible from inside the kitchen. In adobe building example 2, the space reached does not have an upper slab, is used as a gathering area for sitting and resting, and the wet area can be accessed from inside this space. This wet area is used as a toilet and bathroom.

Figure 13. Adobe building example 1. Interior staircase (a and b) and exterior staircase (c and d) (Source: Lizge Deniz Çakmaz Archive).

Adobe building examples 1 and 2 have an internal staircase leading down to the ground floor. In adobe building example 1, this internal staircase is constructed of wood and stone (Figure 13a and Figure 13b). In adobe building example 2, a wooden staircase has been constructed (Figure 14a and Figure 14b). When the exterior staircase detail in adobe building example 1 is examined, it is seen that the staircase is constructed using stone material and the railings are constructed using wood material (Figure 13c and Figure 13d). In adobe building example 2, the exterior staircase and railings are constructed using wood material (Figure 14c).

Figure 14. Adobe building example 2. Interior staircase (a and b) and exterior staircase (c) (Source: Lizge Deniz Çakmaz Archive).

Considering that adobe is not resistant to water and moisture, it can be said that its use at ground and foundation level is inefficient. For this reason, adobe is generally used on top of stone foundations and plinths. In adobe building examples 1 and 2, it can be seen that adobe material is used from the stone foundation and plinth level, taking into account this disadvantage of adobe material. It has been observed that bond timbers are used in adobe brick masonry. The bond timbers distribute the weight horizontally and increase the durability of the wall. They prevent cracks that may occur vertically. Bond timbers were used at certain intervals in the adobe brickwork to connect the walls. In addition, horizontal and vertical bond timbers were used to create window and door openings. (Figure 15).

Figure 15. Appearance of the foundation, adobe brick wall, and wooden beams. Adobe Building Example 1 (a and b) and Adobe Building Example 2 (c) (Source: Lizge Deniz Çakmaz Archive).

In addition to load-bearing walls, these structures also feature wooden columns and beams. Wooden beams called "Keran" are placed at regular intervals parallel to the short side of the space on top of wooden columns called "Cısir" located on the ground floor (Figure 16a and Figure 16b). The gaps between the beams are covered by thinner wooden elements arranged at closer intervals, also parallel to the short side of the gap, and peeled tree branches are arranged very densely on top (Figure 16c). On the first-floor ceiling, wooden planks are arranged on top of the beams. The craftsmanship is of a higher standard compared to the ground floor (Figure 16d).

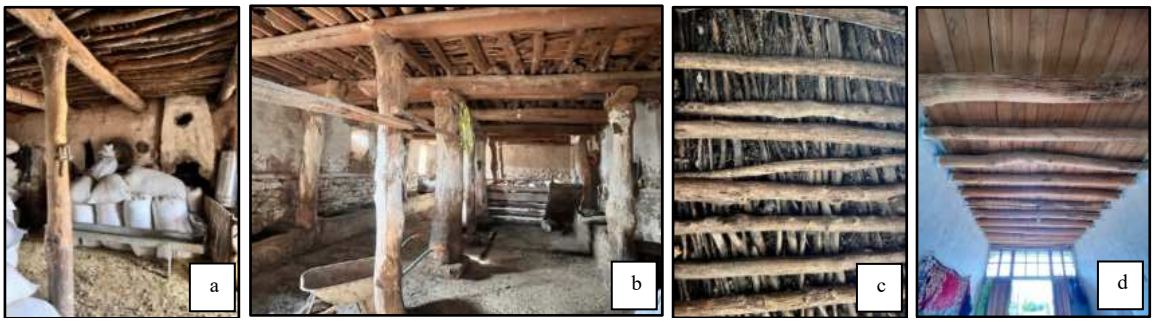


Figure 16. "Cisir" and "keran" views of adobe building example 1 (a ve b). Ground floor flooring of adobe building example 1 (c). First floor flooring. (d) (Source: Lizge Deniz Çakmaz Archive).

In adobe houses, the original doors and windows are made of wood (Figure 17). In adobe building example 1, there is an original wooden key belonging to the door on the ground floor (Figure 17c and Figure 17d).

Figure 17. Adobe building example 1. Room door (a), entrance door (b), storage door (c), and key (d) (Source: Lizge Deniz Çakmaz Archive).

The small windows on the ground floor are made of wood. In order to allow more light into the interior, the wall below the window has been built at an angle (Figures 18a and 18b). In some buildings in the village, the original wooden windows have been replaced with PVC windows (Figures 18c and 18d).

Figure 18. Original (a and b) and modified (c and d) window views of adobe building example 1 (Source: Lizge Deniz Çakmaz Archive).

Figure 19. Roof view (a) and roof system view (b) of adobe building example 1 (Source: Lizge Deniz Çakmaz Archive).

When the adobe houses in the village were examined, it was observed that the adobe flooring was covered with metal sheets placed on a wooden system (Figure 19b and Figure 20b). Upon examination of these applications, it was seen that the front walls of some houses were built with adobe bricks, while in some houses they were covered with metal sheets (Figure 19a and Figure 20a).

Figure 20. Roof view (a) and roof system view (b) of adobe building example 2 (Source: Lizge Deniz Çakmaz Archive).

3 CONCLUSION

Rural architectural settlements are areas where traces of regional life can be read. It can be said that daily life, social life, economic activities and cultural structure determine the planning features, material choices and construction techniques of settlements and buildings. In this respect, when this network of relationships is taken into consideration, it can be stated that the social, economic and cultural traces of the settlements can be read in the architectural structures. In addition, rural architectural construction includes knowledge of local construction techniques and materials. In this context, the unique adobe structures found in the village of Danaburan were examined to evaluate this network of relationships and to examine the settlement and architectural characteristics of the region.

The rural settlements of Mazgirt and Pertek, where winter conditions are milder than in the northern parts of Tunceli province, utilize adobe materials. Examples of adobe buildings from the village of Danaburan were selected and their architectural features were examined. In Danaburan, where agriculture and animal husbandry are the primary sources of income, it was observed that the ground floors of two-story adobe buildings were generally used as barns and storage. The living space in these structures was designed to be on the first floor. Wooden or stone stairs leading to the wooden projection on the facade access the first floor, which serves as an interior hall for seating, gathering, and recreation. This area provides access to other rooms and the kitchen. Wooden or stone stairs provide access between floors within the residences. The structures, built with adobe bricks on stone foundations and basements, were constructed with wooden beams. An examination of the structural features of the structures revealed that, in addition to load-bearing walls, columns called cısir and beams called keran were used. The column-connecting ribs were observed to be covered with thinner wooden elements, parallel to the short side of the opening, and this layer was covered with a dense layer of peeled tree branches. The original doors and windows of the original adobe buildings were wooden, and some users have been observed replacing them with PVC joinery. In addition, the roof structure was constructed over the floor of the structures originally constructed as flat roofs and covered with metal sheets. With this practice, the users aimed to minimize the constant maintenance and repair required for flat roofs.

Documenting the adobe structures of Danaburan village, whose architectural features are presented through visual analyses, is a key focus to prevent their disappearance. In addition, strategies must be developed to preserve these unique adobe structures. At this point, cooperation with local authorities is crucial to ensuring the continuity of the process. The current state of the structures must be carefully analyzed, and appropriate materials and techniques must be determined for maintenance and repair. One of the most decisive actors in this process is the local community, i.e., the users of the structures. Significant progress can be made by informing and raising awareness among users about the preservation of structures with unique value. Concrete measures against abandonment can be taken by developing strategies for agriculture and livestock farming, which are the main sources of livelihood for users. In conclusion, it is believed that this study will contribute to the literature by documenting and presenting the architectural features of the unique adobe structures in Danaburan village as an example of rural architectural development.

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Learning from Al Yanfa to Revive Tamnyah: A Pedagogical Journey through Asir's Vernacular Legacy

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ABSTRACT

This study explores a pedagogic approach applied in the "National Architectural Heritage - Asir Region" course at King Khalid University, Fall 2024. Students participated in an experiential project to study and rejuvenate Tamnyah Village, drawing on lessons from the adjacent Al Yanfa Archaeological Village found both within Asir region. The study investigated the infusion of traditional construction and intangible cultural practices into sustainable, socially informed interventions. By linking tangible heritage to intangible, the study exemplifies vernacular architecture as a living laboratory for the contemporary conservation and adaptive re-use. Project goals involved the documentation of Tamnyah's tangible heritage (e.g., Raqf stone walls, juniper roofs, rainwater harvesting systems), the integration of intangible practices (e.g., gendered knocking on the doors, Al-Qatt Al-Aseeri paintings) into the strategies, and the formulation of design intervention respecting historical integrity while responding to contemporary needs. Students used fieldwork, creative outputs, and the engagement of communities, undertaking the survey on the sites to detect visual distortions and making propositions to align the contemporary utilities to the traditional aesthetics. Conclusions emphasize vernacular architecture's pedagogical potential to instill sustainable design and cultural continuity. The correction of the visual distortions and the unifying the building elements reinforced the "spirit of place" of Tamnyah. Adaptive re-use propositions align with Al Yanfa propositions, revealing that the heritage sites may be re-used to encourage tourism while avoiding any loss of authenticity. This approach sustains the built environment and safeguards the community identity. The study points to the role of education to bring the conservation of the heritage closer to the contemporary issues, providing a climate responsive and culturally relevant template for the sustainable practices worldwide.

Keywords: Vernacular Architecture, Heritage Conservation, Adaptive Reuse, Sustainable Design, Cultural Heritage

1 INTRODUCTION

The Asir region in Saudi Arabia is known with a rich and special vernacular built heritage, marked by distinctive construction techniques, building materials, as well as strong associations with local culture and climatic conditions (Oliver, 2006). The traditional built fabric, known as "earthen architecture," is the result of centuries of accumulative learning in sustainable construction and climatically responsive design (Eizenberg and Eyal, 2016). However, like many regions experiencing rapid modernization, Asir is left facing serious challenges to conserve its priceless heritage (Askari, 2014). Rapid development tends to impose unsuitable alien building materials, construction, and utilities that alter the traditional appearance and cause loss of design coherence(Norberg-Schulz,

1980). Figure 1 illustrates the study's geographical context, covering the Asir region and the villages of Al Yanfa and Tamnyah.

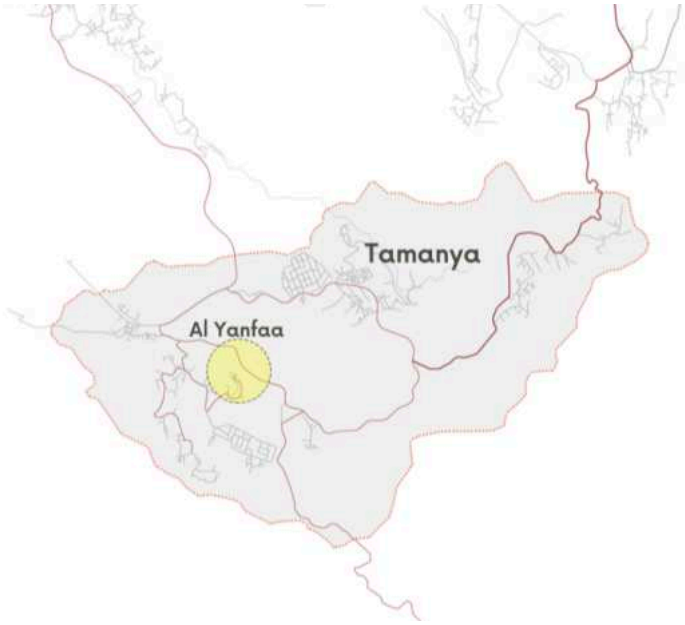

Figure 1. Map of Asir region locating Al Yanfa and Tamnyah villages. (Source : Students projects)

This study examines a teaching strategy devised for the course "National Architectural Heritage - Asir Region" which was delivered by the first author of this paper in the Fall semester 2024 at the College of Architecture and Planning, King Khalid University, Saudi Arabia. The foundation of this strategy lay in putting students in a practical project aiming at the study of Tamnyah Village, learning vital lessons from the nearby, more preserved, Al Yanfa Archaeological Village. These teaching objectives were threefold: first, to enable students to chart and critically analyze Tamnyah's physical legacy, with its urban characteristics and architectural features. Second, to integrate the village's intangible culture into proposed revitalization strategies. And third, to educate students to craft design interventions that contribute positively to meet present demands while not forgetting Tamnyah's historical integrity and distinct character. Ultimately, this study highlights the profound pedagogical value of vernacular architecture, positively using them as living laboratory material for cultivating sustainable design ideals and championing cultural endurance in architecture teaching and practice.

2 THEORETICAL AND CONTEXTUAL FRAMEWORK

2.1 Vernacular Architecture

Famously known by "architecture without architect", vernacular architecture is mainly driven by local climate, available materials, and local culture. It offers useful insights into sustainable buildings and human accommodation across diverse environments. Scholars like Oliver (2006) suggest theoretical foundations for considering vernacular formations as more than historical vestiges but as adaptive manifestations of cultural identity and practical solutions for human needs, namely locals. Such studies place heavy emphasis on the inherent climatic responsive design fundamentals present in traditional buildings, often predating modern environmental consciousness. Strong interpenetration between constructed environment and cultural identity is a recurring theme, referencing that vernacular buildings enshrine community values, social structure, and intangibles (Norberg-Schulz, 1980). Vernacular architecture serves as a living record of environmental adaptation, exchange of cultures, and local identity in Saudi Arabia's diverse scapes. Previous studies of Saudi Arabian heritage villages have examined both the architectural qualities and the threats of modernization and abandonment, calling for effective conservation strategies (Askari, 2014; Al-

Naim, 2013). Recognition of these local attributes is vital for the generation of interventions that are both suitable at a cultural level and significant in terms of architectural style and solutions.

2.2 Pedagogical Approaches in Heritage Conservation

There is growing recognition of pedagogical approaches that offer endeavours of bridging the gap between theory and practice in heritage conservation education. Contemporary education directions more often involves experiential learning at heritage locations and local community engagement, in order to grasp more effectively the nuances of the conservation challenges and management responses (ICOMOS, 2013). Local community engagement in heritage initiatives is now broadly accepted as key to successful and sustainable outcomes. This theory-to-practice bridging is vital in equipping future architects and conservers with the practical abilities needed to address difficult heritage challenges. The course named "National Architectural Heritage - Asir Region" taught in the Fall semester 2024 at the College of Architecture and Planning, King Khalid University, Saudi Arabia employed Kolb's experiential learning model (Fig. 2), progressing from theoretical foundations through hands-on documentation to design intervention (Kolb, 1984; Al-Salloum and Al-Shuaibi, 2020). The approach prioritized local knowledge integration, recognizing community members as heritage custodians rather than passive recipients of professional expertise. Student methodology included comprehensive site surveys, condition assessments, photographic documentation, and ethnographic observation of social custom and patterns.

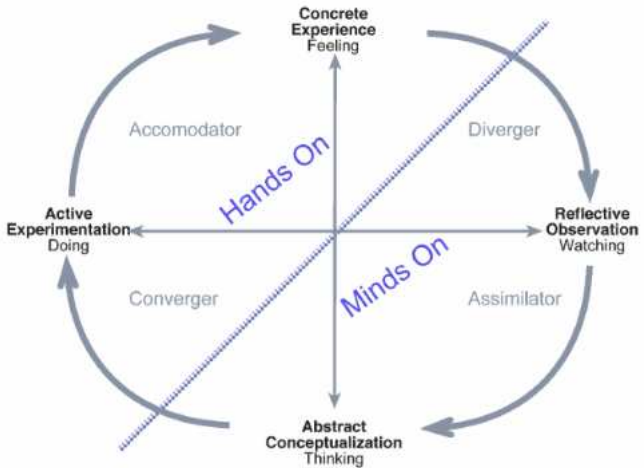

Figure 2. Kolb's experiential learning model. (Source : Kolb, 1984)

2.3 Saudi Arabian Heritage: The Asir Context

The Asir region is known for its distinctive earthen and stone buildings suitable for the mountainous landscape and climate of the region. Documentations have recorded traditional construction methods like the Raqf stone construction and structural systems using juniper wood that exhibit advanced local expertise in material knowledge and structural stability (Facey, 1997; Al-Hariri, 2016). Student documentation revealed specific technical details previously under-documented in academic literature. Raqf stone construction utilizes selected local limestones with clay mortar, producing walls that achieve thermal mass for temperature stability control. Juniper wood structural systems, cut in winter to avoid rot, carry traditional flat roofs topped with stone slabs and by clay finish for weatherproofing. Instances of these traditional building materials and construction methods in the Asir region are reviewed by course students and displayed in Fig. 3.

Figure 3. Traditional building materials and techniques in Asir region. (Source : Students projects)

In Asir region, the integration of intangible heritage elements, such as Al-Qatt Al-Aseeri patterns with symbolic significance (Al-Banna for femininity and mountains, Al-Aryash for vegetation, Al-Mahrab for religious themes), shows how cultural practice fosters "spirit of place" (Bortolotto, 2015). This theoretical framework recognizes that effective heritage conservation must address both tangible architectural elements and the cultural practices that give them meaning.

Figure 4. Al-Qatt Al-Aseeri patterns and color palettes. (Source : Students projects)

3 PEDAGOGICAL APPROACH AND PROJECT IMPLEMENTATION

3.1 Course Framework and Learning Architecture

The pedagogic model for National Architectural Heritage – Asir Region (ARC 413) at King Khalid University was a 16-week intensive course combining theoretical foundations with hands-on heritage documentation and design projects with pproximately participated 20 students who were divided into 5 research groups progressed from general conservation principles to regional applications, culminating in a revitalization project for Tamnyah village based on lessons from Al Yanfa Archaeological Village. The program unfolded in four systematic phases: the foundation phase (Weeks 1–4) introduced heritage conservation theory, situating global documents like the Venice and Burra Charters within Saudi vernacular contexts, and comparing American and European schools of thought to highlight how cultural contexts shape conservation strategies. Students also examined the historical development of traditional Asir buildings. The regional specialization phase (Weeks 5–8) focused on the architectural character of southern Saudi Arabia where students analyzed how landscape and climate shaped distinct typologies across Najran, the Abha-Sirat Abidah highlands, Rijal Alma, Al Baha's Zi Ain, the Faifa mountains, and Red Sea coastal zones. Emphasis was placed on traditional materials and construction, particularly Raqf stone, juniper wood roofing, and traditional strategies. The course learning objectivess focused on developing analytical, documentation, and vernacular architecture design skills, while focusing on community engagement. The course balanced theoretical grounding in conservation philosophy with hands-on projects, while assessments combined individual and group performance, fostering group work and critical thinking.

3.2 Experiential Learning Integration

The course applied Kolb's model of experiential learning to integrate theoretical knowledge with practice. The practical application phase (Weeks 10–13) after the midterm exam (Week 9) enabled learning about conservation methodology by direct practice in heritage sites. It comprised construction practice as well as restoration practice in traditional stone buildings.

Students were trained in the use of three basic principles for assessing heritage: historic significance, historic integrity, and historic context. The course reinforced the integration of both tangible and intangible facets of heritage, so that students had to record not just physical buildings, but also the culture practiced, traditional crafts, and social traditions that impart meaning to constructed places.

Experiential learning culmination took place in the field study component (Week 14) where students inducted thorough site observations at heritage sites across the Asir region, putting into practice documentation techniques that they had acquired in preceding weeks while developing skills in condition survey and heritage evaluation. The practical exercise served to make students appreciate the interface between theoretical foundations of conservation and practical challenges of execution.

3.3 Project-Based Learning Implementation

The Tamnyah village revitalization project was implemented as the course's capstone learning experience, extending beyond the formal 16-week structure to allow for deeper engagement with community stakeholders and more comprehensive design development. This project-based approach required students to work in multidisciplinary teams, combining architectural analysis, cultural documentation, and community consultation skills.

Students took up a comparative strategy, using Al Yanfa Archaeological Village as a comparative case study. This strategy allowed the students to draw transferable learnings while accounting for the unique nature and challenges that are specific to Tamnyah. Students were required to survey existing conditions, examine visual distortions as a consequence of inappropriate modern interventions, and propose other appropriate design interventions. Students utilised systematic documentation methods encompassing architectural analysis by means of measured drawings, photographic surveys, and construction technique documentation. Urban morphology studies investigated settlement patterns and spatial organisation, with condition assessment analysing material deterioration and structural stability. Cultural documentation captured traditional customs,

crafts, and social behaviour. The holistic approach generated informative datasets informing evidence-based design interventions while ensuring cultural sensitivity and historical accuracy.

3.4 Community Engagement and Cultural Sensitivity

The pedagogical approach recognized that heritage conservation cannot be effectively taught or practiced without meaningful community engagement. Students were required to interact with local knowledge holders, traditional craftspeople, and community members throughout their project. Such engagement had different outcomes: the development of cultural consciousness, an understanding of social aspects of heritage conservation, and learning to navigate the complex relatioships between professional conservation practice and community values. Students learned to document traditional activities such as gendered door-knocking customs, Al-Qatt Al-Aseeri decorative arts traditions, and seasonal community rituals that animate physical spaces and give them cultural meaning. Through this holistic teaching approach, students acquired technical knowledge in heritage documentation and analysis, as well as in cultural community-centered skills necessary for effective conservation.

4 SITE CONTEXT: AL YANFA AND TAMNYAH VILLAGES

4.1 Al Yanfa Archaeological Village Success Model

Al Yanfa Archaeological Village is a remarkable case study in successful heritage conservation and adaptive reuse in the Asir region. Traditionally, this village exemplifies local building forms and construction patterns representative of the region. Its present condition is the result of proactive conservation and adaptive reuse that have infused life into ancient buildings. The conversion of knedadeesh, an old subterranean spaces, into culture galleries and exhibition spaces illustrates how ancient infrastructure can be adapted for present-day cultural programming. Integration of infrastructure has been done by sensitive installation of utilities that does not detract from visual harmony with the ancient fabric. Community outreach assured local craftspeople's involvement in restoration and tourism activities, providing sustainable economic models that directly benefit residents. Best learning from Al Yanfa interventions is that heritage places can be restored without loss of authenticity, usually by adapting local spaces to culture or tourism uses. Such interventions provide evidence on how traditional spaces can be adapted for present-day usage while preserving architectural integrity and cultural significance. A visual representation of these restoration interventions is provided in Fig. 5.

Figure 5. Photos of Al Yanfa before and after restoration projects. (Source : Students projects)

4.2 Tamnyah Village Profile

Tamnyah Village, in the same geographical and climatic context of Asir, is another contrasting, but equally informative, case study whose historical development and architectural values are a reflection of Al Yanfa in many ways, including distinctive Raqf stone construction and juniper wood roofs and roofing systems. Nonetheless, Tamnyah is now dealing with serious challenges related to the conservation of tangible and intangible heritage as a consequence of the effects from modernization and different levels of abandonment. Student analysis revealed Tamnyah Village's architectural and cultural assets alongside conservation challenges. Architectural heritage include

well-maintained Raqf stone construction with walls that are up to 40–50cm thick, exhibiting superior thermal mass for temperature control, as well as ancient juniper wood roofing systems with stone slab and clay covering, demonstrating advanced local materials knowledge and climatic awareness. The intact urban morphology consists of narrow alleyways and courtyards providing comfortable microclimates, while the combined rainwater drainage systems with building design showcases advanced water management strategies. Architectural typologies and urban morphology of the village yield a rich pool of conventional building practices. Beyond the physical buildings, Tamnyah accommodates diverse socio-cultural practices and intangible heritage elements that form part of the identity of the village. Cultural heritage includes Al-Qatt Al-Aseeri decorative arts traditions with symbolic pattern systems, as well as gendered door-knocking conventions (Fig. 6) that exhibit social protocols and concepts of privacy, while conventional crafts, such as basketry, textile production, and metalworks continue alongside seasonal community rituals and agricultural practices.

Figure 6. Gendered door-knocking traditions : High door handle for men and low one for women. (Source : Students projects)

However, several challenges threaten this valuable heritage; visual distortions from inappropriate modern materials include metal roofing sheets creating visual discord and poor thermal performance, concrete block additions inconsistent with stone construction, and modern paint colors conflicting with traditional earth tones. Exposed electrical infrastructure and utility installations create visual pollution, and disrupt the traditional skyline. Limited accessibility for elderly residents and people with disabilities presents contemporary functional challenges that require sensitive intervention.

5 STUDENT ANALYSIS AND KEY FINDINGS

5.1 Detailed Technical Documentation

Student documentation revealed the intricate building construction techniques of Tamnyah Village's cultural heritage. It provided unprecedented technical detail into Asir vernacular building construction like building construction of walls by Raqf stone which prioritizes durability and thermal properties, while often utilizing harder stone varieties for enhanced structural stability.
This encompassed close examination of the stone construction techniques of Raqf, which constitute the characteristic village building walls (Al-Hariri, 2016). Detailed drawings and cross-sections shed light on the advanced juniper wood roof structures wherein juniper wood beams bear stone slab coverings with clay finishing. The construction offers natural insulation and facilitates thermal expansion, and the classical guttering of palm frond or wood orients the rainfall toward rainwater

capture structures. The natural rainwater drainage mechanisms demonstrate the historical inhabitants' deep understanding of sustainable building adapted to the local climate.
Ventilation strategies utilize strategic window placement to achieve cross-ventilation, and traditional wood frames facilitate changeable airflow control. Small high windows allow the air circulation while ensuring privacy, demonstrating refined climate control and social consideration. Detailed urban morphology examination revealed the distinctive settlement and street network characterizing the village's spatial organization, showing the formation of comfortable living conditions designed in response to local topography and climate through the application of traditional planning principles.

5.2 Comprehensive Visual Distortion Analysis

A critical part of the analysis involved identifying and categorizing visual distortions resulting from modern interventions. Students systematically documented modern interventions compromising village character through material incompatibilities, infrastructure problems, and urban design issues (Fig. 7). Inappropriate material choices and construction methods used in recent repairs or additions were also identified, leading to material degradation and a disconnect from the original architectural language. These new colors conflict with the old earth ones lead to dissonant visual contrasts harming the village's visual coherency. Plastic and metal elements disrupt material harmony, introducing alien textures and colors into the traditional palette. Infrastructural issues exacerbate these visual concerns. Visible electrical wires and power boxes contribute visual pollution as they pose a hazard to people's safety. Satellite dishes and telecommunication equipments are prominent rooflines which used to have simple, graceful profiles. Contemporary lighting installation is not suited to heritage environment, overwhelming the scale and nature of the traditional spaces in most instances. The water tanks become evident from public areas, interrupting the traditional views and sightlines.
Urban design issues further compromise village character. The lack of pedestrian accessibility provisions creates functional barriers while potentially requiring insensitive modifications to historic fabric. These interventions result in a great deal of loss of architectural cohesiveness, thus the importance of sensitive design proposals capable of meeting the realities of contemporary requirements while maintaining traditional characteristics.

Figure 7. Examples for visual distortion in Tamnyah Village. (Source : Students projects)

5.3 Intangible Cultural Heritage Integration

Apart from the physical built environment, students examination also covered Tamnyah's rich intangible cultural heritage. Student reports showed advanced cultural practices underpinning design decisions that reveal the embedding of social customs and cultural knowledge systems into the built environment. The students recorded particular social etiquettes, like the gendered door-knocking traditions, which govern relationships inside the community and mirror traditional ideas of privacy and social structures. The customs entail particular spatial relationships and circulation routes which need to be addressed by all renovation or adaptive reuse schemes. The dynamic Al-Qatt Al-Aseeri decorative art scenes, which are, in many instances, decorating interior walls, were catalogued, showing their motifs and cultural interpretations. These are the traditional crafts which include palm frond basketry demonstrating sustainable use of local material, textile production by the use of local fibers and traditional technology, metalwork of implements and decorative items, and pottery used in water conservation and cooling and demonstrating climatic control through the property of the material used. This intertwining of the intangible highlighted the way that construction knowledge and traditional crafts are embedded in the daily routine and communal rites, and thus effective conservation of the heritage must pay equal attention to the tangible physical structures and the cultural practices that give them meaning and continued relevance in contemporary life.

6 DESIGN INTERVENTIONS AND PROPOSALS

6.1 Visual Harmony Restoration Strategies

Responding to the visual distortions identified, restoring visual harmony to the village was a central aspect of the proposed interventions. Students applied integrated comprehensive strategies in the aim of responding to identified distortions via material guidelines, infrastructural solutions, and landscaping incorporation. Part of the course deliverables resulted in developed guidelines for discreet utility integration, suggesting solutions to cover or integrate modern infrastructure such as power lines and television dishes. Special material palettes and construction norms were suggested, favoring the use of local building material such as Raqf stone and juniper wood. Material guidelines emphasize polyurethane cladding systems mimicking traditional stone appearance for infrastructure concealment, allowing modern utilities to be hidden within traditional-looking enclosures. Heritage-appropriate colors using earth tones including browns, whites, and ochres maintain visual continuity with traditional buildings. Traditional material prioritization with acceptable modern substitutes when necessary ensures both authenticity and functionality. Standardized details for window frames, doors, and architectural elements create consistent visual language throughout the village.

In relation to infrastructure solutions, functional applications were considered while maintaining heritage character. Underground routing of cables wherever possible to avoid visual pollution of overhead cables. Local stone and traditional construction are applied to heritage-designed electrical equipment enclosures so the infrastructure blends into historic fabric. Modern-efficient traditional-style lighting fixtures provide adequate lighting while retaining visual character. Concealed water storage tanks are incorporated into building design to mitigate visual impact.

Proposals also considered upgrading the landscape and streetscape. Landscape integration involves the choice of native vegetation species favoring traditional farming and integrating buildings into natural environment. Restoring and adapting the traditional irrigation system shows sustainable water management practices. The pedestrian route design employs local stone and traditional motifs to ensure visual continuity. Appropriate signage systems reflect regional design vocabulary while providing necessary wayfinding information.

6.2 Adaptive Reuse Strategies

Inspired by successful initiatives in Al Yanfa, the student proposals for Tamnyah Village emphasized sensitive adaptive reuse strategies. Drawing from Al Yanfa's success, students proposed specific interventions that could transform underutilized spaces into community and cultural resources. Knedadeesh cultural corridors might be repurposed to accommodate a variety of uses. Students suggested art galleries featuring Al-Qatt Al-Aseeri and regional crafts might honor traditional artistic practices while accommodating exhibition of the latest interpretations. Art galleries displaying Al-Qatt Al-Aseeri and local crafts would celebrate artistic traditions while providing exhibition space for contemporary interpretations. Cultural education centers with traditional craft workshops could facilitate skills transfer between generations while generating economic opportunities. Climate-controlled storage for archaeological artifacts would preserve important cultural materials while making them accessible for study and display. Community spaces maintaining traditional functions could accommodate contemporary community needs while respecting historical usage patterns.

Development of tourism infrastructure upholds the village vernacular environment, keeping intact the traditional authenticity while providing glorified visitor experience. Heritage-centered construction visitor centers support the need for facilities while keeping intact the architectural integrity. Integrated interpretation and guided walking pathways allow visitors to experience and appreciate traditional culture and architecture. Traditional craftsmanship demonstration spaces allow the display of living heritage while creating economic opportunities for local artisans. Local traditional food cousine and farming experience are connected to visitors through authentic dining experiences using local ingredients and traditional recipes.

The strategy plans also explored larger economic development potentials benefiting local communities. Local craftsman workshops, including retail, developing sustainable economic models that preserve traditional skills while generating income. Heritage accommodation through building renovation offers authentic visitor experiences while illustrating the appropriate renovation techniques. Event spaces facilitate community traditions while enticing cultural tourism benefiting the community.

6.3 Accessibility and Infrastructure Improvements

Improvements to universal accessibility encompass delicately designed ramps from traditional material and construction techniques which provide access while not losing historic character. Altered doorway widths when structurally possible balance modern accessibility requirements with traditional proportions. Accessible parking spaces having traditional screening blend modern transportation requirements and historic visual necessities. Altered bathroom facilities adhere to privacy traditions while satisfying modern standards and requirements of accessibility. The latest utility integration caters to practical infrastructural requirements through sensitive solutions to heritage. Solar installation along heritage-sensitive concealment allows sustainable power while being respectful of visual integrity. Contemporary plumbing installations through traditional spaces allow for contemporary requirements of sanitation while not compromising historic fabric. WiFi and communication infrastructure through low visual impact facilitates latest connectivity requirements. Emergency access routes allow traditional street character while assuring safety compliancy. The initiatives also encouraged youth involvement, cultivating a feeling of responsibility and pride in their cultural identity and creating academic opportunities to connect the youth with their cultural and architectural identity. The overall strategy looked to empower local community, engaging them as active agents of the revitalization process and not mere recipients of external intervention.

7 CONCLUSIONS AND FUTURE DIRECTIONS

7.1 Key Contributions

This experiential educational journey through Asir vernacular heritage presents a number of central contributions to professional education in the areas of heritage conservation which reveal the benefit of experiential education strategies in professional training. Firstly, the contribution presents a reproducible conservation education pedagogical model which exemplifies the effectiveness of hands-on, community-based projects in conveying key critical skills and cultural awareness to students while adding value to practical conservation initiatives.

The detailed field recording of the traditional building techniques by the comprehensive technical documentations forms the basis of future conservation works, keeping alive the knowledge of complex building systems exhibiting that demonstrate centuries of environmental adaptation. The visual distortion analysis presents the systematic detection of unfit interventions along with the corresponding solution strategies, giving site management and restoration plans practical directions.

7.2 Recommendations

Based on the project's findings, various recommendations become clear to support effective conservation of the heritage and shape future policy formulation and conservation practice. There is a clear need for robust policy frameworks that support heritage protection while allowing for sensitive modernization and adaptive reuse, creating regulatory environment that enables rather than hinders appropriate conservation work. Furthermore, the encouragement of community-centered conservation strategies is essential, so as to empower local people as the custodians and beneficiaries of the revival of their heritage, and not mere recipients of alien conservation actions. This requires development of governance structures and capacity-building programs that support community leadership in heritage conservation.

On going development of training programs and courses like the "National Architectural Heritage - Asir Region" is also suggested to train future generations of heritage practitioners who are aware of both the technical conservation needs and the cultural sensitivity required by successful practice. Such programs need to prioritize experiential learning, community involvement, and the blending of traditional knowledge and modern conservation science.

7.3 Future Research Directions

The outcomes of this study open several avenues for future research that can advance understanding and practice of heritage conservation education. Long-term impact assessment of implemented design interventions and pedagogical models would provide valuable insights into their sustainability and effectiveness over time, helping to refine and improve conservation approaches based on

empirical evidence. Comparative studies with other regional contexts facing similar challenges could further refine the universality and adaptability of the developed methodologies, identifying which elements are applicable elsewhere and which require cultural or contextual adaptation. Such studies could contribute to the development of global best practices for heritage conservation education while respecting local specificities. Lastly, advanced technology application in heritage documentation, like the use of photogrammetry by drones and 3D modeling, may be beneficial in increasing the accuracy and accessibility of heritage data, leading to better-informed conservation practices. Technologies of digital documentation may also allow greater dissemination of heritage knowledge and conservation processes among diverse contexts.

Through prolonged social interaction and technical accuracy, vernacular architecture continues to act as dynamic laboratory of sustainable and cultural design. The project underscores education's crucial role in bridging heritage conservation with contemporary challenges, offering a climate-responsive and culturally resonant model for sustainable practice globally that demonstrates how traditional knowledge and contemporary needs can be harmoniously integrated.

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Exploring Endangered Cultural Landscapes in Asir: Bridging Anthropological Gaps Through Documentation & Field work

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ABSTRACT

The economic integration and transformation processes caused in our modern world are changing the traditional cultural landscapes, a phenomenon that is deeply affecting the life of the inhabitants in the Arab countries. Being one of them, the region of Asir in South-West Arabia holds a rich cultural and historical heritage, yet a noticeable lack of anthropological research documenting and preserving its landscapes and traditions is observed. This is mainly due to the lack of cultural knowledge about the traditional vernacular architecture of the area as well as the higher appreciation of living in large western style villas on concrete block construction. The result of this phenomenon led to the abandonment of approximately 400 traditional settlements of stone and mud architecture. This study aims to address this gap by conducting fieldwork, engaging with local communities, and developing a methodological framework for understanding Endangered Cultural Landscapes in the region. Motivated by an ongoing PhD thesis on Asir and a broader scientific interest, this research leverages recent improvements in accessibility to conduct firsthand investigations. Key areas of focus include documenting cultural landscapes, mapping intangible traditions, and integrating local knowledge through interviews and participatory research. By combining theoretical and practical approaches, this study seeks to contribute to the preservation and understanding of Asir's unique cultural identity while establishing a foundation for future research in similar regions.

Keywords: Cultural heritage, survey documentation, intangible and tangible heritage, earthen architecture

1 INTRODUCTION

In recent years, new types of housing have been introduced in Saudi Arabia. Often, modern homes are built quickly because of fast city growth and economic changes. These homes usually follow the "International style" instead of using traditional design ideas from local architecture. Because of this, there is a need for better advice on designing homes that fit the needs of the people [1].

It is important that today, despite all the modern changes, tribal customs still find a place in Saudi culture and architecture, where the family is the most valued social group. For any contemporary architectural or community planning project to be successful, these elements must be taken into consideration.

In this paper, therefore, the following questions arises as to whether traditional settlements as examples of past practices and current conditions could and would guide future planning efforts:

Will urban patterns in south-west Arabia, more specifically in the region of Asir 'Fig.1', nearly eradicated in the 21st century, find a place in new urban planning's in the region? Will it allow modern architects to study the complex interaction between the social, territorial, and architectural environments in order to apply valuable principles to the modern design of cities, towns, and residential communities, while rethinking how to design the tower house typology, the most common in this area?

Figure 1. Location of the Asir region along the Red Sea at different scales.

2 BRIDGING LOCAL ARCHITECTURAL IDENTITY THROUGH SPECIFIC METHODOLOGICAL FRAMEWORKS

2.1 Mapping intangible traditions

2.1.1 Territory and Architecture viability

The southwestern part of Saudi Arabia has always been shaped by its land features and different kinds of social groups. Unlike most areas in the country, Asir is a particular region where there is a big difference between the lowlands and highlands, between places with lots of rain and dry areas, and between places where people live in settled farming communities and others where Bedouins live as nomads. This variety has influenced the traditional buildings made of earth in the region in many ways [2]. This paper will look at the highland areas, which have unique types of stone and mud-brick buildings, also known for their verticality, as if they were rising from the land and are in strong contrast with the verticality of the mountains and the horizontality if the terraced fields [3]. It will also consider this geographical area because these settlements are unlike any other Arab settlements, in which a city wall is built to protect the village. In fact, the only efficient way to defend their town was by choosing the correct geographical position in relation to the surrounding natural resources. As stated by Ebn Saleh, the historic cities of Asir possess their own rational, even rigorous, spatial organization, especially if one takes into account how urban structures are also the product of a process of transformation of tribal customs and conventions [4]. By merging this affirmation with the different statements stated above, a better understanding on the chosen case study will be done. A series of photographs, schematic and architectural drawings were the main outcomes of the field surveys organized in the Al-Khalaf village in Asir. They are presented in this research trying to explain how significant it is to become aware of the importance in understanding the forming process of these settlements, the degradation of the traditional expression of old settlements and the effect of casual and pragmatic modernization on them.

2.1.2 Community engagement

As most of the villages in Asir are completely abandoned since more than 50 years, it was essential to include in the investigation comprehensive interviewing with locals, who sometimes lived for a couple of years in these structures before moving out. Through extensive discussions with settlement elders 'Fig.2' about the way they were living in these houses, the built environment and their dynamics in the village, a lot of information about the shape and arrangement of the settlement was collected. According to the locals, the village itself is very much related to the genealogy of the families. The only way to understand and date back a settlement is to recompose the genealogical tree of the different families that have lived there for many decades. In the case of Al-Khalaf, 12 generations have lived in this area, meaning that the settlement dates back to 350-400 years back. Two main families were living in this village, the Al-Mubarak and the Al-Mattar. The first family consisted of seven clans whereas the second one consisted of five clans. This subdivision was directly observed on the settlement's layout after the field surveys which will be elaborated and described in the following section.
By talking to the local community, then, the necessary measures to ensure the safeguarding of the intangible cultural heritage present in this village were followed carefully. They are relevant in order to ensure, maintain and transmit heritage intangibility for a place like Al-Khalaf, in which the involvement of communities, groups and individuals directly response to the UNESCO convention dedicated to the Involvement of communities, groups and individuals.

Figure 2. Interviews with elders who lived in Al-Khalaf village. Locals agreed on meeting directly in the village in order to talk and visit the settlement together.

2.2 Documenting cultural landscapes

2.2.1 Field surveys

Throughout three successive trips between 2023 and 2025, an architectural field investigation was conducted to establish technical drawings and map the entire settlement (houses, roads, agricultural fields, defense towers, natural sources) 'Fig.3'.

Figure 3. Aerial view of Al-Khalaf village. We clearly observe the main square with the main Mosque and the souk adjacent to it. A central street axis separated the northern part of the settlement from the southern one.

Together with a group of architectural students at King Khaled university in Abha, a method was established in order to be able to map the village of Al-Khalaf from scratch. Several lectures were given to the apprentices before the first field trip. First, a general description on the land use in Asir was elaborated, in which it was clarified that the settlement was managed and organized so that each one maintained a Friday mosque and multiple daily mosques, residential areas and necessary defense facilities and agricultural fields. The land subdivision depended on the kinship and the different families within the same tribe. Then, using what has been shared by the locals about the layout organization of the settlement in respect to the kinship and the families, we could identify two moieties within the settlement. Combining both these elements with the direct observations on site 'Fig.4', a methodological framework was developed explaining how one can produce geometrical and architectural drawings applying old school methods while at the same time using the different elements already shared by the locals as reference points.

Figure 4. Group of students participating to the field survey of Al-Khalaf village. Each student had a base map that he/she completed and enhanced while on site.

2.2.2 Drawing elaboration and direct observations

The process then consisted in producing a base map. This refers to geometrical drawing outlined from a top view google image, in which all the visible elements were traced with almost no accuracy in the sizes and proportions. However, this exercise allowed to locate the important buildings such as the mosques, the defense towers and some storage towers, the cemetery and the public spaces. It allowed also having a sense of scale of the place. Using this base map, the team did a second visit to the site to collect, measure and correct the drawing they had. Once the survey was done, a first drawing correction was done from which, then, a third field survey was organized. It allowed enhancing the level of detailing of the drawing, showing the thickness of the walls, positioning and placing the different housing entrances as well as the location of the staircase. By merging and crossing the elements gathered from the interviews as well as the results of the field surveys, we can say that the layout of Al-Khalaf's settlement has an overall uniformity in construction. In fact, the village is arranged in a way that makes it safe and comfortable for people to walk around. The urban layout and architectural style are unique, even though the shapes of the buildings, the materials used, and the methods of construction are the same. Clear street hierarchy from public, to semi-public, to private are observed. Productive landscapes surrounding the build settlement are part of the urban layout and are directly connected to the settlement. Buildings of medium size and mass composed with facades breaks and clustered together 'Fig.7'. Also, the level of agreement in the whole settlement shows a use of limited technology and building materials, which helped shape the architectural identity of Al-Khalaf. In fact, the scarcity of materials and the knowledge available during the time of building and expansion probably led to a uniform and sustainable way of construction. Different material such as gypsum paint and stone wall were used for highlighting the base. The middle part of the wall was then built with repetitive equal intervals of rammed earth and stone slates that protected the walls from the heavy rains 'Fig.5 & 6'. These techniques allowed the settlement to blend within its context.

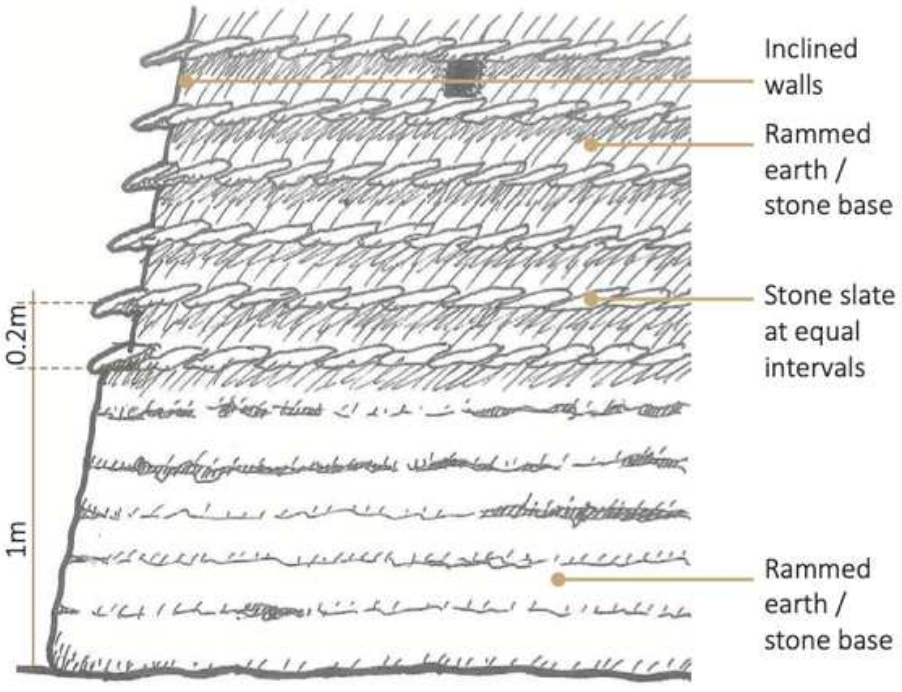

Figure 5. Traditional architectural elements & construction techniques in Asir's highlands: Typical architectural elements in middle and base

Figure 6. Homogeneous construction technique of the house in Al-Khalaf with stone base, inclined walls with rows of slate inserted into walls at equal intervals.

Figure 7. Final ground floor plan survey drawing of Al-Khalaf village. This drawing clearly shows the different paths, clusters and the relationship of the settlement with the context around.

3 CONCLUSION

This study looks at how the land shape and city structure affect vernacular human habitation, which is a research area that hasn't been fully explored before. It focuses on earth-built structures that were used for both farming and daily life. These spaces are shaped by traditions developed over more than three hundred fifty years of village building. The way the community has shaped and changed the design of their houses over time reflects their values, social rules, and the need for protection in their Islamic way of life.

Due to the implementation of new constructions in the traditional urban settlement of Al-Khalaf, it is our role to preserve these abandoned villages as they are at risk of disappearing with no immediate consolidation and preservation action. In order to do that, is it essential to learn more about the different environments in Saudi Arabia and how local people have designed their homes and communities using local yet sustainable construction techniques. In this way, designers can better understand the old building practices that are more responsive to regional context. This knowledge can help reduce problems that come from the modern way of building and living compared to the traditional methods. That's why it's important to look at the standards again, considering the goals and technology we have today. When we work with local communities, we can find ways to create spaces that feel real and meaningful while using local and sustainable materials (mud and stone) that could be the solution for rebuilding abandoned cultural landscapes and possibly be a key example for the architecture of tomorrow.

4 ACKNOWLEDGMENTS

I would like to thank many people for their advice, information, discussions, administrative and financial help.
To begin with, I must express my deep thanks to the local people whom I met, interviewed and travelled with. They were very generous and helpful.
I would like to thank my co-tutor, Prof. Dr. Ahmad Bin Dajam, for the continuous help and advice he gave me. He spent much time and effort, and even travelled in the research area to help and organize my field work.
I would also like to thank the architecture students at King Khalid University who helped and supported the different field works.

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Deterioration Risk of Earthen Heritage Sites in Hot-Dry Climate Regions Under the Impact of Climate Change

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ABSTRACT

According to the reports published by the Intergovernmental Panel on Climate Change (IPCC), prolonged droughts and an increase in dry days are projected for the Mediterranean Basin—of which Turkey is a part—in the coming period. In this context, the Southeastern Anatolia Region, characterized by diverse traditional material uses and a substantial stock of vernacular housing, holds significant potential in the fight against climate change. Extreme temperatures are perceived as a major threat to transmitting earthen-based historic structures to future generations. Rising temperatures jeopardize the long-term preservation of these structures and compel local material users to adopt more effective protection strategies. Within the scope of this study, earthen-based cultural heritage sites in the cities of Şanlıurfa and Diyarbakır—identified as vulnerable to climate change—were examined. A qualitative research method was employed, including on-site investigations. The findings revealed that earthen construction materials such as adobe face several challenges due to extreme temperatures during production and use phases. Specifically, rapid drying, cracking, thermal expansion, and shrinkage during production lead to various mechanical degradations. Throughout the structure's life cycle, fluctuations in humidity and temperature reduce the material's mechanical strength over time and also cause deterioration in the physical integrity and chemical structure of its organic components. As a result of the study, it is recommended that climate-responsive methods be developed to protect local building material use patterns against extreme temperatures, considering future climate scenarios. Accordingly, future research should establish contextual and holistic approaches based on climate-oriented risk analyses to preserve earthen-based cultural heritage. These approaches should contribute at a conceptual level and lay the groundwork for the development of practical conservation strategies.

Keywords: adobe; earthen architecture, climate change, heritage preservation, hot-dry climate

1 INTRODUCTION

In the present day, the impact of climate change on cultural heritage has become a significant topic on the international agenda. This global crisis, which extends beyond being a physical problem threatening natural ecosystems, also poses a serious risk to the preservation of cultural heritage—an essential carrier of intangible values such as identity, belonging, and collective memory, from past to present. Although the effects of climate change vary among countries depending on geographical and climatic conditions, the shared threat lies in its reduction of the preservability of cultural heritage, thereby jeopardizing the transmission of these values to future generations [1]. Within this framework, numerous interdisciplinary studies have been initiated in the 21st century to assess the impact of climate change on cultural heritage, focusing particularly on disaster risk and resilience [2, 3]. The climate crisis is regarded as a comprehensive, multi-component problem. As such, addressing this global issue solely through scientific means is not considered a viable solution. In

this context, the traditional knowledge approach—developed through trial and error based on past experiences and reflected in the "architecture without architects" solutions in response to historical urban fabric and the built environment—is of great significance [4, 5]. However, today, the threats to the survival of cultural heritage and the disruption of this knowledge transfer, along with the scarcity of skilled and qualified labor, are considered serious problems that may lead to the loss of this vital experience and accumulated knowledge [6, 7]. In this respect, the transmission of earth-based cultural heritage to future generations constitutes a critical issue. It has been reported that 14% of cultural heritage sites listed as World Heritage in Danger are composed of adobe architecture [8]. In particular, cultural heritage assets composed of compressed earth materials should be highlighted in future scientific studies within the framework of adaptation to climate change [9]. In this context, materials such as adobe face significant threats from extreme weather events induced by the climate crisis—such as high temperature extremes, alterations in precipitation patterns, frost, and severe winds [10]. In other words, adobe building materials are more vulnerable to extreme weather events compared to other types of building materials [11]. Accordingly, academic research focusing on how to construct climate-resilient structures using earth-based materials like adobe should be increased in studies that address the preservation of cultural heritage. In this direction, reports published by the Intergovernmental Panel on Climate Change (IPCC) foresee that, in the coming period, the Mediterranean Basin—which includes Turkey—will experience prolonged droughts and an increase in the number of dry days [12]. Given its distinctive spatial fabric in the context of cultural heritage and historical environment, the Southeastern Anatolia Region is required to take effective and holistic measures to combat climate change in order to ensure the transmission of historical heritage to future generations. Within the scope of this study, the traditional domed houses in the Harran district of Şanlıurfa province and the adobe structures located in Erimli Village in the Sur district of Diyarbakır province were selected as sample cases. The physical and structural deteriorations observed in these structures due to climate change were examined. Specifically, damage types such as cracking, material erosion, moisture-induced deformations, and surface abrasion caused by climatic variables including rising extreme temperatures, prolonged droughts, and sudden precipitation events were documented; the threats these damages pose to structural integrity and cultural sustainability were evaluated.

2 EARTHEN ARCHITECTURE AND CLIMATE CHANGE: A LITERATURE REVIEW ON THE PRESERVATION OF CULTURAL HERITAGE

Culture is the most significant non-written source that carries the traces of the past into the present. However, within the development indicators formulated following the publication of the "Our Common Future" report in 1987, culture was not assessed as a part of the indicator framework. Moreover, among the 17 goals defined by the United Nations in the Sustainable Development Goals (SDGs), there is no theme directly linked to culture. This omission has recently become a focal point of discussions and criticisms. In this context, emphasizing that cultural continuity should be considered a vital component of sustainable development, the British Council published a report in 2020 titled "The Missing Pillar: Culture's Contribution to the UN Sustainable Development Goals", advocating for the essential role of culture [13].Similarly, in 2021, ICOMOS (International Council on Monuments and Sites) addressed this issue in its report "Heritage and the Sustainable Development Goals: Policy Guidance for Heritage and Development", underlining the importance of cultural heritage in achieving the Sustainable Development Goals [14]. Within this framework, strengthening the link between the past and the future by transmitting both tangible and intangible cultural heritage into the present and future is a critical concern. The transmission of cultural heritage values to future generations has become increasingly significant, especially in light of the adverse effects of extreme weather events caused by climate change. Consequently, tangible and intangible heritage embedded in the collective memory and associated with local architectural traditions is under threat. Put differently, the transfer of traditional knowledge through vernacular architecture significantly contributes to strengthening the adaptive capacity of local communities against climate-related hazards [15]. In alignment with the goal of promoting international cooperation, the principal mission of CIAV (International Scientific Committee on

Vernacular Architecture), established by ICOMOS, is to provide global guidance for the preservation of local tangible and intangible heritage [16]. CIAV, therefore, represents a holistic cooperation model that supports not only the conservation of structures but also the protection of memory and traditional construction techniques. It is not only tangible cultural heritage structures that are at the brink of extinction due to the climate crisis. The locally sourced earth-based materials that constitute the fundamental components of these structures are highly vulnerable to climatic events such as extreme heat, wind, and flooding. In this context, it is noted that approximately 20% of World Heritage sites consist of earthen architecture [17]. In order to safeguard and transmit these earth-based structures to future generations, ICOMOS established the ISCEAH (International Scientific Committee on Earthen Architectural Heritage) in 1987, with the mission of protecting earthen heritage sites [18]. Formed to document, preserve, and adapt earthen architectural products, this committee considers traditional knowledge as a resilient tool against the risks posed by climate change. Therefore, the conservation of adobe-based building materials has also been recognized at the international level as a significant issue, leading to the initiation of specialized committees and organizational efforts aligned with this objective.

Characteristics and Degradation Causes of Earthen Structures

Adobe (mudbrick) is believed to have historical origins as ancient as human civilization itself. Prior to the development of advanced building materials, human communities transitioned from living in caves to constructing basic shelters using stone and earth materials to meet their fundamental need for habitation. The technique of producing adobe building materials has traditionally been applied in arid or semi-arid regions [19]. In 1890, the Centre for the Study of Earthen Architecture (CRAterre) identified 12 basic techniques for earth construction globally. These techniques are illustrated in Figure 1 and include: digging, covering, filling, cutting, compressing, shaping, stacking, molding, extruding, casting, forming, and applying [20]

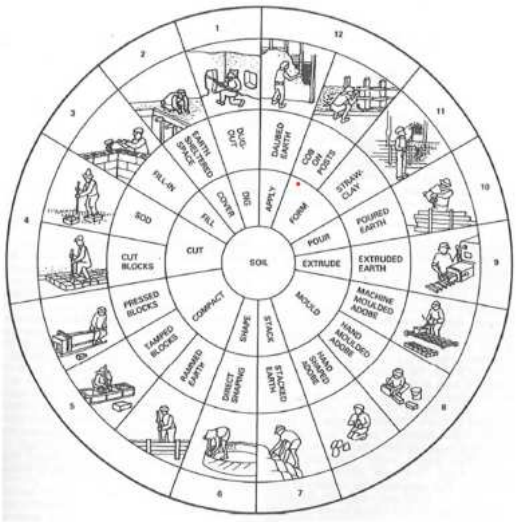

Figure 1. CRAterre's Twelve Traditional Earth Construction Techniques

By the late 20th century, a number of guides and research efforts focusing on earthen construction materials had begun to emerge. However, after the mid-20th century, the mechanical performance of earthen materials began to be viewed negatively, and it was only after the 2000s that experimental studies on these materials gained momentum. Notably, the global push toward sustainable development and the energy crisis have acted as important incentives for the renewed use of these materials. Although interest in earthen materials has increased, research addressing their mechanical and structural characteristics is still relatively scarce. Their tendency to exhibit brittle responses under low levels of tension, compression, and shear has reinforced the view that such materials are inherently weak. Moreover, these materials often have inadequate foundations

and weak connections between walls and roofing systems. These characteristics increase inertial forces during seismic events, leading to poor and limited performance in earthquakes [21, 22]. Additionally, the mechanical behavior of earthen materials varies according to the soil properties of the geographic region in which they are located. This variability has presented challenges in establishing a unified characterization approach. Accordingly, Silveira et al. (2021) compiled existing standards to support both national and international material characterization efforts [23].

Earthen-based materials are not only vulnerable to seismic effects but also highly sensitive to extreme weather events. Climate change, one of the most pressing environmental challenges of the The 21st century has witnessed a rise in both the occurrence and severity of weather-related phenomena, including shifts in atmospheric humidity, temperature instability, abrupt heavy rainfall, and high-intensity winds [24]. These climatic events pose significant risks to earthen heritage structures. Different weather conditions lead to different types of structural deterioration. For instance, rain and wind contribute to erosion-induced surface wear, cracking, and material loss in load-bearing elements, all of which adversely affect structural integrity [25]. Another critical issue is the moisture sensitivity of earthen materials. In areas prone to high water tables or flood risks, frequent moisture exposure leads to cracking and staining. Not only elevated temperatures but also phase changes such as freezing and thawing contribute to material degradation. High winds cause erosion and surface abrasion. The inclusion of organic additives like straw, grass, or wood—commonly used to improve thermal performance—also increases the fire risk. In certain climate zones, the incorporation of palm wood into adobe mixtures has been observed to be vulnerable to prolonged heat exposure and combustion [26].

According to future climate scenarios, projected increases in temperature will likely lead to severe material degradation in earthen structures. Specifically, high temperatures cause thermal expansion in the soil and rapid evaporation of moisture, resulting in deformation, shrinkage, and cracking. Irregular temperature fluctuations generate thermal stresses that accelerate deterioration. Laboratory tests have identified rainfall as a major contributor to degradation and indicate that multiple deterioration mechanisms often operate simultaneously [27, 28, 29, 30]. In laboratory conditions, degradation typically manifests as mass loss in small samples. However, in situ observations have shown that degradation also includes erosion, stratification, and cracking, not just weight reduction [31]. Determining the causes of deterioration in earthen materials is inherently complex. Field studies have shown that the same type of degradation can result from different processes, raising the issue of equifinality [32]. Therefore, field investigations alone cannot always provide definitive explanations for deterioration mechanisms. Most studies on earthen materials have been conducted at accessible heritage sites such as Çatalhöyük. This has narrowed the range of sample areas and limited the generalizability of findings, particularly for less accessible regions [33]. In order to establish efficient preservation strategies for historical structures made of earthen materials facing climate change impacts, a precise understanding of both the material properties and the specific climatic conditions of the region is crucial. The selection of reinforcement methods should be grounded in a thorough assessment of various factors that influence the long-term performance of the material.

3 MATERIAL AND METHODS

Within the scope of this study, the deterioration mechanisms of adobe structures located in a hot-dry climate region have been examined in relation to extreme weather conditions induced by climate change. Accordingly, the research was conducted within a mixed methodological framework encompassing field surveys, on-site observations, photographic documentation, and literature-based evaluation criteria. The case study areas include the Harran houses—recognized for their conical domes and listed on the UNESCO World Heritage Tentative List, where climate change-related risks have become increasingly significant in recent years—and Erimli Village, a rural settlement where the tradition of adobe construction is still preserved. Through fieldwork and on-site inspections, photographic surveys of individual buildings were carried out. The deterioration patterns of adobe structures were assessed based on the main indicators defined in the

literature, namely erosion, surface flaking, cracking, salt efflorescence, and biological growth. In addition, it is well established that wetting–drying cycles accelerate deterioration under climatic stress factors [27, 28, 31]. In this context, deterioration patterns were documented through visual grading and systematically evaluated with photographic evidence, thereby ensuring a transparent assessment process.

Case Study: Climatic Characteristics of Diyarbakir and Şanliurfa

Located in the Southeastern Anatolia Region of Turkey, the cities of Diyarbakır and Şanlıurfa exhibit similar characteristics in terms of their ancient historical backgrounds and climatic conditions. The urban fabric of Diyarbakır is established on a vast basalt plateau [34], while the city of Şanlıurfa is situated on the Balıklıgöl Plateau and features a historically layered urban structure. Both cities possess deep-rooted cultural heritages and have successfully preserved and transmitted numerous cultural heritage assets from past to present. The cities of Diyarbakır and Şanlıurfa fall under the Mediterranean climate classification (Csa) according to the Köppen–Geiger climate categorization, characterized by hot and dry summers and mild, relatively wet winters. The annual temperature values and monthly temperature distributions of both cities exhibit notable similarities (Figure 3). For both cities, the highest average temperatures are recorded in July and August. However, when evaluating the temperature averages and their increases, it has been observed that the summer seasons in Şanlıurfa are more severe compared to Diyarbakır. In both cities, the hot period—namely, the summer season—lasts longer than the winter season.

Figure 2: The Location of Sanlıurfa and Diyarbakır in Turkey [35]

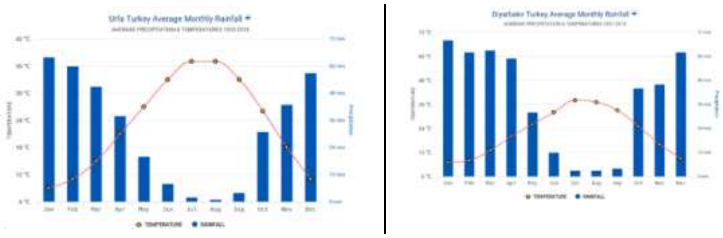

Figure 3: The climatic conditions specific to the cities of Diyarbakır and Şanlıurfa [36]

The average precipitation levels also show similar patterns. The months with the highest precipitation for both cities are December, January, and February. In this context, the expected climate change scenarios and disaster risks in these cities, which share similar climatic characteristics, also demonstrate parallel and comparable tendencies. In other words, for these two cities located in a hot and dry climatic zone, extreme temperatures are projected to become a major issue in the future.

Assessment of Deterioration Risks to Earthen Cultural Heritage

Within the scope of this study, the domed adobe houses (kümbet evler) in Harran and the adobe structures in Erimli Village, located within the boundaries of Diyarbakır province, were examined in terms of structural deteriorations caused by increased extreme temperatures associated with climate change. The assessments were conducted based on fieldwork and in-situ observations rather than experimental data. In the initial phase of the study, the domed houses located on the Harran Plain, to the east of the Suruç Plain—considered a significant cultural heritage site both nationally and internationally—were selected for examination. The archaeological excavations carried out in Harran, a settlement with an approximate history of 8,000 years, have revealed the area's considerable historical depth [37]. The domed houses in Harran were constructed using the corbelling technique and feature dome systems covered with adobe material. Harran's domed houses were officially registered as an archaeological and urban conservation site in 1979 [38].

Figure 4: Architectural Characteristics and Dome Construction of the Harran Domed Houses

In the Harran region, due to the limited availability of timber-based wooden materials and the distant location of stone quarries, the domes of the Harran houses were constructed using stone material [39]. The domes, built by successively corbelling stones in a stepped arrangement, are internally connected by arches. In the past, as thermal comfort could not be achieved through active systems, the upper part of the dome was left open to allow hot air to escape from the interior. This design enabled air circulation, thereby facilitating thermal comfort within the living spaces [40]. The walls of the Harran domed houses were constructed using adobe material with a thickness of 40–50 cm. The local availability of adobe, its low thermal conductivity coefficient, and its capacity to regulate air transfer seasonally contribute to the material's high sustainability [39, 41]. However, the adobe houses of Harran are currently facing challenges caused by climate change, including extreme increases in temperature and shifts in precipitation patterns. In particular, temperatures rising above seasonal norms in the Harran region have led to deterioration such as cracking, thermal expansion, and surface erosion. These masonry structures, constructed with a load-bearing system, have experienced thermal stresses due to heat, which have compromised the static stability of the stones in the domes, thus affecting the structural integrity of the buildings.

Figure 5: Wall Damage and Degradation Patterns Observed in the Traditional Domed Houses of Harran

An analysis of the precipitation regime reveals that rainfall extending into the month of April causes several forms of deterioration in adobe walls, including loss of adhesion, material disintegration, and increased moisture content. Although the traditional Harran domed houses use stone rather than adobe as the primary roofing material—allowing for more efficient water drainage compared to flat-roofed structures—the accumulation of water at connection points can still lead to localized structural degradation. According to findings from literature reviews, adobe materials exhibit weak performance under both tensile and compressive forces, resulting in limited resistance to seismic loads. In this context, during the earthquake centered in Kahramanmaraş on February 6, 2023, some of the Harran domed houses sustained damage, and 28 domed units were completely destroyed [38]. However, through restoration efforts, all damaged domed houses have since been repaired.

Figure 6: Domed Houses Collapsed as a Result of the Kahramanmaraş-Center Earthquake on February 6, 2023 [42]

Erimli Village, located in the city of Diyarbakır, is a rural settlement where adobe houses are still actively used. It is situated 21 kilometers from the city center, within the Sur district of Diyarbakır, and was historically known as Simaki Village [43]. Erimli Village contains roughly 40 buildings constructed with adobe. Structurally, the prevalent adobe brick dimensions used in the area are 30 by 30 by 8 centimeters. When adobe plaster is applied to both sides of the walls, the exterior wall thickness extends to about 80–85 centimeters, whereas the interior walls typically measure between 55 and 60 centimeters [44]. The roofing system is composed of flat earthen roofs supported by wooden beams. Initially, the structural system involves placing brushwood and timber over the beams, followed by a covering layer made of soil mixed with straw to complete the roof assembly [45]. Climate change, along with the increase in extreme temperatures and alterations in average precipitation patterns, has led over time to the deterioration of adobe structures in Erimli Village as well. In particular, the flow of rainwater along wall surfaces following precipitation events has caused erosion and the loss of material layers on adobe surfaces.

Figure 7: Observed Wall Damage and Degradation in the Erimli Village

Vegetation growth on the roofs indicates that the soil retains moisture for extended periods. Furthermore, the accumulation of such vegetation increases water permeability, which in turn leads to erosion at the base of the walls and compromises the integrity of the load-bearing system. As shown in Figure 7, cracks have formed primarily due to shrinkage stresses caused by thermal fluctuations and the effects of rainfall. Deformations have been observed around the alignment of the clerestory windows, where the load distribution is uneven. Discoloration and material spalling have been identified, leading to localized surface erosion in affected areas.

Figure 8: Deterioration in Roof Coverings and Windows in Erimli Village

4.CONCLUSION AND RECOMMENDATIONS

Climate change is considered one of the greatest and irreversible challenges of the 21st century. It is particularly anticipated that the construction sector and built environment components will be significantly affected by this crisis. In this context, the key to adaptation strategies lies in the continued use of vernacular architectural elements developed through past experiences. In other words, historical building typologies, material types, and construction techniques—originating from locally available resources and developed without detachment from environmental sustainability—tend to cause fewer ecological disruptions. However, over time, the changing patterns of climate-induced weather events have begun to negatively impact vernacular architectural components and construction practices. Within the scope of this study, the physical and structural deteriorations caused by extreme weather events in earthen-based cultural heritage structures were investigated. In adobe houses located in the cities of Şanlıurfa and Diyarbakır, which share similar climatic characteristics, climate-related degradation was assessed. In both the domed houses of Harran and the adobe houses of Erimli Village, irregular and intense rainfall, high temperature fluctuations, and associated impacts such as cracking, surface erosion, moisture-related deterioration, and thermal expansion have led to the weakening of structural integrity. In Erimli Village, it was found that water drainage is more problematic on flat earthen roofs compared to the domed roofs of Harran houses, leading to water accumulation and the formation of deep fissures in wall surfaces and junction points. Similar wall and surface deteriorations were also observed in the Harran domed houses. The adverse impacts of climate change have affected adobe as a building material, putting the original building stock at risk of degradation or complete loss. In this regard, for historical structures such as the Harran domed houses, future material optimization studies can be conducted under laboratory conditions using different material compositions, in alignment with climate change scenarios published by the IPCC. The preservation standards prepared by ICOMOS for earthen-based materials could be adapted to the context of adobe settlements in Turkey to achieve material standardization. Field studies specific to Turkey should be conducted to identify vulnerable regions and develop appropriate conservation strategies. In similar hot–dry climate regions, particularly in Algeria, Morocco, Tunisia, and Mexico, restoration techniques applied to earthen architecture—such as field tests in which rammed earth structures are exposed to long-term natural climatic conditions, and the use of protective plaster and drainage systems in adobe buildings—emerge as noteworthy practices. Accordingly, the conservation strategies to be developed in Erimli and Harran should be grounded in and substantiated by these international references, thereby enhancing the scientific validity and practical applicability of the proposed recommendations. Lastly, it is essential to recognize that vernacular knowledge represents an important component of cultural identity for future generations. Therefore, to prevent the disappearance of traditional building techniques formed through the master-apprentice tradition, documentation and educational programs should be organized with the participation of local communities. The preservation of earthen structures in the face of climate change holds critical importance not only for the physical environment but also for the sustainability of collective memory and regional cultural heritage.

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Natural and anthropogenic risks assessment for preservation and sustainable reuse of earthen architectures in Piedmont (Italy)

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ABSTRACT

This work is carried out within the framework of the EVER EARTH Project, which aims to deepen the knowledge of the earthen architectural heritage in the Piedmont region (Italy) and improve its resilience to natural and anthropogenic hazards. A multidisciplinary study will be carried out based on the analysis of data and information derived from previous investigations with respect to the current situation. A selection of earthen buildings serves as case studies for risk assessment and the development of an intervention methodology.
Meteorological risks will be assessed through the analysis of historical data and climate projections of meteorological conditions in the study area, as well as probability distributions and return periods of critical events.
Seismic vulnerability will be assessed by analysing the selected buildings, adapting the parameters and the relative score weights in the GNDT level 2 survey form and the FAMIVE method form to the peculiarities of the earthen architecture. Vulnerability indices will be defined to build priority lists for recovery interventions and efficiently direct public administrations' financial contributions. Based on the vulnerability indices, damage matrices will be identified to predict different damage scenarios depending on the intensity of the seismic event.
The analysis of the interventions carried out on the individual construction elements of the buildings taken as case studies will be used to assess the anthropogenic risk. Furthermore, to know people's perceptions, opinions, and evaluations of earthen buildings, a sociological survey will be carried out based on interviews addressed to appropriately selected local witnesses. The outcomes of the investigation and analysis will provide valuable information for identifying intervention strategies that will contribute to the effective conservation and redevelopment of the earthen-built heritage.

Keywords: Earthen architecture, risk analysis, conservation, reuse.

1 INTRODUCTION

As stated by ICOMOS in 1999, vernacular architecture is "an expression of the culture of a community, of its relationship with the territory and, at the same time, the expression of the world's cultural diversity"[1]. This architectural heritage is deeply rooted in the history and environment of many regions, influencing spatial identities, preserving collective memory and defining its *genius loci*. It manifests through dispersed and often modest settlements whose forms and materials are the product of long-standing interactions between communities and their local contexts. Yet, the homogenising effects of globalisation have gradually weakened these bonds, altering traditional

patterns of inhabitation and contributing to the marginalisation of peripheral territories. Even when partially depopulated, such settlements preserve embedded cultural meanings and material traces of past lifeways. As such, they constitute a valuable—though often overlooked—heritage, including not only tangible artefacts of historical or artistic significance, but also landscapes shaped by cumulative, place-specific interventions over time. The value of this heritage lies in being both a testimony to the past and a valuable resource for sustainable territorial development. When appropriately preserved and redeveloped, this built heritage can: (1) improve the quality of the rural landscape, returning an underused building heritage to the community, (2) reduce land consumption due to new construction, (3) reinforce local identities, and (4) promote the regeneration of territories and ancient knowledge. Widely spread in many countries all over the world, earthen constructions constitute a testimony of knowledge, skills, and human adaptation to a specific natural habitat. Nonetheless, this heritage is at risk today worldwide. Often viewed as incompatible with modern standards of comfort, safety, and efficiency, earthen buildings have been widely abandoned. Furthermore, the development of industrial construction techniques has disrupted traditional know-how, leading to a gradual loss of craftsmanship, thus causing a lack of maintenance and incompatible interventions. The paper focuses on the Enhance VERnacular EARThen Heritage (EVER EARTH) research project, which aims to conserve and enhance the earthen built heritage located in the Piedmont region (Italy).

2 The EVER EARTH project: research aims

The EVER EARTH project proposal intends to use a multidisciplinary approach to propose an intervention methodology that can be replicated in other contexts, aimed at safeguarding and promoting the re-use and redevelopment of vernacular earthen architecture, starting from the Italian Piedmont region case study. Characterised by the presence of a widespread earthen heritage (Figs. 1-3), Piedmont region has implemented specific interventions for its protection and recovery, thanks to the work of cultural associations and through the promulgation of regional law 2/2006 'Norme per la valorizzazione delle costruzioni in terra cruda' [2-4]. More than 15 years after the law's enactment, it is considered important and useful not only to evaluate the results of the implemented measures and to capitalise on the results, but also to study in-depth the risks to which the earthen heritage is exposed and to outline strategies that, applicable in other contexts and for similar heritages, could contribute to the effective protection and enhancement of the vernacular architecture and rural landscape.
The EVER EARTH project's macro objective is to outline strategies to promote conservation, reuse, and new development of the earthen heritage.
In particular, the project aims to:

- deepen knowledge of the earthen architecture heritage and improve its resilience against natural and anthropogenic risks through a multi-disciplinary study pivoted on data and information analysis derived from previous and preliminary investigations, compared to the current situation;
- foster compatible interventions in conservation, restoration, and reuse of the built earthen heritage through theoretical and practical teaching/educational/training activities aimed at professionals, practitioners, and stakeholders;
- set up a methodological tool useful for public administrations and cultural associations to design and plan interventions for the conservation and reuse of earthen vernacular buildings.

The developed methodology could be easily replicated and applied in different sites, promoting the preservation of the vernacular built heritage.

Figs. 1-2. Vernacular earthen buildings in the provinces of Cuneo (Piedmont) on the left and Asti (Piedmont) on the right.

Fig. 3. Vernacular earthen buildings in the province of Alessandria (Piedmont).

3 The EVER EARTH project: research methodology

The EVER EARTH project promotes the conservation, adaptive reuse, and sustainable development of earthen architectural heritage through a series of integrated actions, including (Fig. 4):

- a critical review of previous experiences related to the conservation, reuse, and enhancement of earthen architecture;
- analysis of the state of conservation of the earthen heritage and risk assessment;
- development of strategies to support the effective protection and enhancement of the vernacular architecture and rural landscape.

Focusing on Piedmont earthen heritage, a collection of data about the conservation and recovery activities undertaken following the enactment of the 2006 regional law (L.R. 2/2006) has been implemented. Furthermore, about 50 buildings (among those surveyed between 2006 and 2010) distributed throughout the Piedmont area have been selected based on their representativeness of the earthen heritage (in terms of typologies and construction techniques) as case studies for the risk assessment and the development of an intervention methodology. The analysis of the current state, together with the analysis of the results obtained from the actions implemented by the regional administrations or cultural associations in terms of perception, opinions, and assessments on the buildings, will allow the development of strategies to increase their resilience and define protection policies and projects aimed at the recovery of earthen buildings.

3.1 Analysis of the state of conservation and risk assessment

A survey and in-depth study of the natural and anthropogenic risks to which the earthen heritage is subjected is being carried out to favour the development of adequate preservation and recovery interventions.

As far as the survey of the natural risks is concerned, the following topics are being examined:

- Meteorological risks: the analysis will use historical data and climate projections of meteorological variables in the study area and the probability distributions and return periods of critical events. The goal of the analysis will be (i) to highlight the critical events that occurred in the last 3 to 5 decades, (ii) to identify climate-related trends in the local meteorological variables, and (iii) to quantify the current and future risk associated with the most impacting events. In addition, site surveys will identify the effects of historical meteorological events on the current state of conservation of the buildings. A qualitative and quantitative assessment of these effects will be performed over the time period of the project on the building selected as a case study. This information, complemented with a literature survey, will support the quantification of risk and the definition of appropriate adaptation strategies to limit the effects of adverse events; the impact of climate variables modification on buildings' hygrothermal balance will also be investigated through dynamic hygrothermal modelling, highlighting risks and compatible interventions.
- Seismic vulnerability: the analysis at the territorial scale of the selected sample of buildings, adapting to the earthen architecture peculiarity, the parameters and related weights of scores in the survey GNDT 2 level [5] and the FAMIVE method [6-7] forms will be done; adaptation of these forms have been successfully carried out in other contexts. After the on-site survey, vulnerability indexes to build prioritisation lists for retrofitting interventions and efficiently targeting public administrations' financial contributions will be defined. Based on vulnerability indexes, damage matrices will be identified to forecast different damage scenarios depending on the intensity of the seismic event.

Within the survey of the anthropogenic risks, the following activities will be undertaken:

- Analysis of the interventions carried out on the individual construction elements (masonry, roofs, facades, slabs, finishes, etc.) of the buildings taken as a case study. In particular, replacement interventions, materials, and techniques adopted will be evaluated. The buildings that have undergone recent retrofitting interventions will be surveyed according to the recently presented Intervention Quality Index method [8] to evaluate the compatibility of interventions with conservation principles. The acquired data will highlight the effects and any criticalities in relation to the intervention methodology adopted. This information will contribute to the development of recovery methodologies.
- Furthermore, in order to know people's perceptions, opinions, and evaluations of earthen buildings, a sociological survey will be carried out, based on interviews addressed to selected local witnesses such as local administrators (mayors, city planning and culture councilors of municipalities, unions of municipalities, etc.); companies and professionals operating in the field of architecture and construction; owners of earthen buildings; cultural associations engaged in the conservation and enhancement of earthen culture and landscapes [9].

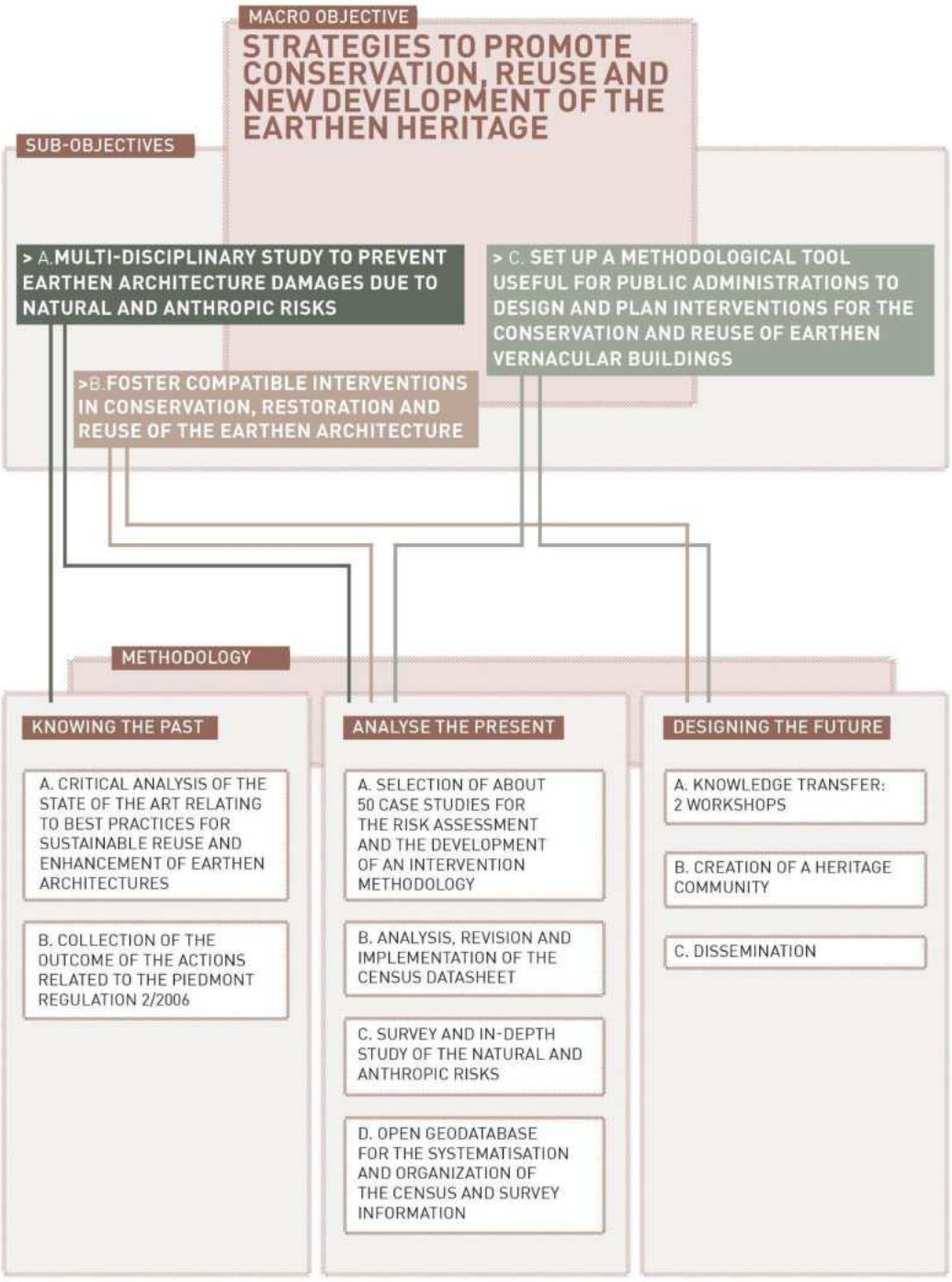

Fig. 4. Project objectives and methodology

3.2 Strategies for the protection and enhancement of the vernacular architecture and rural landscape
The preservation and enhancement of earthen vernacular architecture requires the acknowledgement of its historical and cultural value, as well as the identification and sharing of intervention methodologies that aim to strike a fair balance between conservation efforts and the needs of those who live, or will live, in and care for this heritage. Since the continuity of use is an essential condition for preserving the built heritage, it is important to identify solutions that can promote the continuity of the social fabric. With this in mind, the research

project will experiment with actions to foster the creation of a heritage community, as defined by the Faro Convention (2005)[10], and to promote the transfer of knowledge to mitigate natural and anthropogenic risks.

In order to raise awareness of the cultural and architectural value of earthen heritage and to strengthen a shared sense of identity, the project incorporates participatory strategies addressed at local communities and a wider audience. Therefore, thematic cultural walks and public events will be organised with the contribution of professional figures and experts who will enable local communities to explore the characteristics of the landscape and the culture of the earth. These activities, accessible to a wide audience, are intended to foster direct engagement with the material and immaterial dimensions of earthen heritage, offering accessible experiential modes of interaction that deepen public understanding of the interconnections between place, culture, and memory.
Moreover, the project foresees the organisation of 2 workshops for the training of professionals able to analyse, design, and intervene in an appropriate way on the earthen heritage (Fig. 5). These workshops will cover both theoretical and practical aspects, including material characterisation, construction techniques, conservation principles, structural reinforcement, climate and seismic risk mitigation, and the fundamentals of Life Cycle Assessment (LCA).

Fig. 5. Activities carried out during the workshop held in May 2025 (Piedmont): analysis of building characteristics, structural resistance, meetings and interviews with residents and local experts.

4 CONCLUSIONS

The EVER EARTH project intends to develop a multidisciplinary methodology of analysis and intervention on the vernacular earthen heritage. Capitalising and systematising both the data acquired during the census carried out following the enactment of L.R. 2/2006 and those deriving from the updating and integration campaign carried out within the research activities, the EVER EARTH ongoing project intends to assess the natural and anthropogenic risks affecting the earthen heritage. Furthermore, involving institutions, associations and citizens, it aims at promoting both the spread of knowledge about earthen architecture, its characteristics, and conservation issues, and the development of heritage communities wishing, within the framework of public action, to sustain and transmit earthen heritage to future generations [10].

In particular, the expected results of the project can be summarised as follows:

- systematisation of data derived from the updating and integration campaign carried out within the project, containing specific information on the building and its state of preservation;
- quali-quantitative assessment of the anthropic risk affecting the examined earthen assets as well as meteorological risk analysis and assessment of climate change scenarios, in order to identify adaptation strategies relating to the design details, materials, and specific solutions;
- set-up of damage matrices and vulnerability indexes of the surveyed buildings, useful in the identification of priorities in structural retrofitting interventions;
- spread of knowledge and promotion of the sense of care for the earthen heritage by owners and administrations;
- training of skilled people able to intervene on the earthen heritage;
- development of a multidisciplinary methodology of analysis and intervention on the vernacular earthen heritage.

This methodology, which could also be applied in other contexts and for similar heritages, will be conceived as a toolkit to help plan policies and projects for the conservation and reuse of earthen buildings.

5 ACKNOWLEDGMENTS

We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 104 published on 2.2.2022 (and No. 1401 published on 18-09-2024) by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU– Project Title EverEarth – CUP E53C24003350006- Grant Assignment Decree No. 20442 adopted on 06 November 2024 by the Italian Ministry of University and Research (MUR).

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Natural Materials Aesthetics in Türkiye: The Adobe Residential Architecture of Safranbolu

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ABSTRACT

Recognized for its distinctive architecture, Safranbolu is a UNESCO World Heritage site that showcases notable and well-preserved examples of traditional Turkish residential architecture. The use of adobe in these dwellings is closely linked to the region's climate and the availability of local resources. Its ability to keep interiors cool in summer and warm in winter significantly enhanced the comfort of these residences. Furthermore, adobe's straightforward application and low cost made it a preferred building material.

The two- and three-story Safranbolu houses, which are arranged along narrow, winding streets, typically feature thick stone walls on the ground floors. On the upper floors, some examples incorporate adobe blocks between wooden structural elements, while other walls are constructed directly from adobe. These adobe walls are usually protected externally by either wooden siding or plaster. This architectural style prioritizes family life and privacy, often incorporating inner courtyards or gardens.

The objective of this study is to elucidate the unique characteristics of traditional Turkish residential architecture in Safranbolu and the specific application of adobe within these structures. The methodology begins by presenting the geographical context and a concise history of Safranbolu, followed by an outline of the general principles of traditional Turkish residential architecture. Subsequently, the specific manifestations in Safranbolu houses and the function of adobe in this architectural context are detailed.

In conclusion, the well-maintained historical fabric of Safranbolu's houses clearly demonstrates the value of its adobe architectural heritage. The sustainable preservation and transmission of these structures to future generations are of considerable importance.

Keywords: residential architecture, adobe, Safranbolu, natural materials

1 INTRODUCTION

Traditional Anatolian Turkish residential architecture has been profoundly shaped by a synergy of geographical, climatic, and material conditions. For millennia, natural building materials such as wood, stone, and adobe have been widely utilized across Anatolia. This architectural style is characterized by its emphasis on privacy and family life, evident in the neighborhood settlement patterns and house plans featuring inner courtyards or gardens. The most distinctive features of this architecture include wide eaves, facade overhangs, bay windows, and shuttered windows, all complemented by meticulous woodwork and the use of natural materials. These elements collectively define the unique character of traditional Turkish residential architecture.

Situated in Turkey's Western Black Sea region, Safranbolu stands as one of the best-preserved historical settlements in the country, earning its place on the UNESCO World Heritage List in 1994. As a historical hub on Anatolia's Silk Road, Safranbolu has been a melting pot of cultures for centuries. This rich history has cemented its status as a settlement with an exceptionally significant historical and cultural heritage. The town's rich architectural heritage is underscored by its impressive inventory: 1,466 houses, 48 mosques, 131 fountains, 31 bridges, numerous inns, and several Turkish baths. This extensive collection, which also includes 47 archaeological sites and 5 urban sites, has significantly boosted the region's tourism appeal in recent years, largely due to the successful restoration of its traditional houses [1]. These historic structures are far more than just buildings; they represent a vibrant cultural heritage that preserves the past and embodies a distinct cultural identity.

2 SAFRANBOLU ADOBE RESIDENTIAL ARCHITECTURE: A LEGACY OF AESTHETICS AND SUSTAINABILITY

As an integral part of Anatolia's ancient building tradition, adobe played a key role in the construction of Safranbolu houses, contributing to their unique aesthetic identity while also providing climatic comfort and a sustainable living philosophy. Situated in a region with a history dating back to 4000 BC, Safranbolu and its surrounding areas are rich with historical structures and sites spanning hundreds, and in some cases, thousands of years. This region, referred to as "Paphlagonia" by Homer in the 1st century BC, has been continuously inhabited throughout the Persian, Lydian, Hellenistic, Roman, Byzantine, Ottoman, and Republic of Turkey eras [2].

The architectural plan typology of Safranbolu's residential buildings reflects a structure that prioritizes family life and privacy, directly mirroring traditional Turkish lifestyles. Almost all of these houses feature inner courtyards or gardens, and their high surrounding walls ensure the interiors are not visible from the street, reinforcing the introverted nature of family life. From a distance, the settlement appears to vanish within its lush natural surroundings, as the houses are built in perfect harmony with nature (Fig. 1).

Figure 1. The adobe houses of Safranbolu, Türkiye (author's archive, 2023)

The architectural design of the houses prioritizes functionality, material usage, climatic adaptation, and spatial reflections of social life. The primary elements of this formation are as follows:

2.1 Structural Composition

- The houses typically rise two or three stories high. This vertical density serves both to maximize the use of narrow plot areas and to ensure privacy. Functionally, service spaces are located on the ground floor, while the rooms and main living areas occupy the upper floors.
- Ground floors are generally constructed with solid, thick stone walls. These lower levels provide crucial resistance against ground moisture and often house storage, cellars, or stables. Consequently, these floors are mostly closed off from the street, creating a silhouette that appears massive and solid.

- The upper floors feature adobe infill walls built within a wooden framework, a technique known as *hımış* which means timber-framed structure with adobe/brick infill. These floors result in a lighter and more flexible structure compared to the stone-built ground floor. The use of adobe lends a more delicate appearance to the upper stories and effectively reduces the load on the building's structural system.

2.2 Harmony with Topography and Social Life:

- The houses are typically positioned to harmonize with the land's topography. Streets, shaped by the slope of the terrain, offer pleasant perspectives and vantage points. On steep streets, wide stone steps, often embedded with flowers and grasses in the spring, make for comfortable navigation while adding a richer visual texture. This organic planning allows the houses to form a cohesive unity with their surroundings.
- Inner courtyards and gardens are crucial for providing natural light and ventilation, while also ensuring a private, introverted lifestyle. The high garden walls offer protection from cold air and wind during the winter months. These courtyards are central to daily life, serving as spaces for preparing seasonal food, caring for animals, and entertaining guests. The street-facing facades are generally kept simple, but the use of bay windows and rhythmic window rows adds dynamic movement to the overall silhouette (Fig. 2). When viewed from a distance, the house and its adjoining garden wall can create the illusion of a longer, more profound streetscape, adding depth to the urban fabric.

Figure 2. The houses in the Çeşme neighborhood of Safranbolu, Türkiye, were designed to be in harmony with the local geography and topography. The houses and their adjacent garden walls are the most significant structural elements that define the street boundaries (author's archive, 2023)

2.3 Interior Organization and Privacy

- The houses are typically introverted, turning away from the street towards an inner courtyard or garden. This design reflects a traditional lifestyle that prioritizes family privacy and security.
- In some larger mansions, a clear spatial division exists between women's (harem) and men's (selamlık) living areas. Both sections are fully equipped with spaces designed to meet all essential needs [3].
- The sofa (communal living space) and eyvans (three-sided open spaces) are central to the design of traditional Safranbolu houses. These areas not only facilitate natural ventilation and provide cooling during the summer but also serve as primary communal gathering spots for the residents. The architectural layout typically features a central sofa, which acts as a passage to the rooms and houses the staircase connecting the floors. In larger homes, the eyvan is often located between rooms and functions as an extension of the living space. The placement of room doors—frequently set in the eyvan or in a beveled corner rather than opening directly into the hall—is a notable architectural detail that preserves privacy. This strategic door placement is a tangible reflection of the intimate and private nature of the traditional lifestyle [4].

2.4 Multifunctional Rooms

- Each room is designed to be multifunctional, meeting all the needs of a nuclear family. They are organized to serve various purposes, including sleeping, daily living, dining, and entertaining guests. These rooms are outfitted with fixed furniture, such as ottomans and built-in storage, to maximize efficiency. The use of adobe contributes to the serene and peaceful atmosphere of these introverted living spaces. The material's breathable quality naturally regulates indoor air quality and maintains moisture balance, creating a healthy environment (Fig. 3)

Figure 3. Interior examples of traditional Safranbolu houses, Türkiye (author's archive, 2023)

2.5 Scale and Proportions:

- Safranbolu houses are notable for their human-scaled proportions, which creates an effect that is both modest and monumental. A careful balance exists between the height of the buildings, the width of the streets, the height of the garden walls, and the spacing of the bay windows and windows, all of which emphasize the aesthetic of the facade. This harmony makes both residents and visitors feel secure and welcomed within the area. The aesthetic unity between the built environment and its surroundings creates an inviting atmosphere, encouraging people to return. This architectural sensibility is also evident in the longevity of these houses, as their manageable size allows them to be easily repaired, remodeled, and renovated as needed, thus extending their lifespan for centuries.
- The natural colors of adobe and wood create an aesthetic harmony, integrating seamlessly with the geographical texture. The adobe architecture in Safranbolu and its villages offers a timeless and unique language, combining a rational relationship with natural materials, adaptation to the climate, the needs of social life, and aesthetic concerns. These buildings are more than just physical spaces; they are living monuments that carry the knowledge and philosophy of the past into the present.

3 THE RELATIONSHIP BETWEEN CLIMATIC PERFORMANCE AND FACADE DESIGN IN SAFRANBOLU'S ADOBE DWELLINGS

The thermal performance of adobe is a decisive factor in the form of these dwellings. The thick adobe walls provide a form of passive climate control, effectively keeping the interiors cool in summer and warm in winter. This natural insulation reduces the need for large openings in the facades, contributing to the buildings' overall energy efficiency.

3.1 Climatic Adaptation and Façade Design

- Windows, typically found on the upper floors, are vertical rectangles framed by wooden jambs. Their size is carefully balanced to ensure privacy while preventing excessive solar gain. Street-facing windows are often covered with wooden lattices or shutters. For this reason, some traditional houses also feature skylights in their main rooms to enhance natural illumination. In Safranbolu houses, the strategic use of natural light reduces energy

consumption, improves indoor lighting quality, and provides psychological comfort by allowing ample daylight into the rooms and other spaces.

- Bay windows and overhangs are among the most prominent architectural features of Safranbolu houses. These projections, which extend over the street on the upper floors, provide both a wider view and increased interior space. They also allow for better control of natural light and fresh air circulation. Aesthetically, bay windows and overhangs contribute to the external appearance of the house by adding dynamic movement to the facade. The most spectacular examples of woodwork can be found in the wooden consoles that support these bay windows, showcasing the high level of craftsmanship in the region [5].
- The exterior surfaces of Safranbolu's adobe houses are finished with a stucco coating (adobe plaster), a practice that serves both an aesthetic purpose and a critical structural and climatic function (Fig. 4). In many dwellings, adobe blocks are placed within a wooden frame, while some single-story buildings feature solid adobe walls built directly on the foundation. These walls were then covered with a special adobe plaster to protect them from external elements. The white-colored exterior plaster provides aesthetic integrity to both the individual buildings and the neighborhood as a whole.

Figure 4. Bay windows and overhangs, wide eaves, and window rows on the houses in Safranbolu, Türkiye, are the most important architectural elements that define the street silhouette (author's archive, 2023)

3.2 Protection Against Water and Moisture

- Adobe is highly durable in dry climates; however, direct contact with water or constant exposure to moisture can cause it to erode, dissolve, and lose its structural integrity. Unplastered adobe walls are particularly vulnerable to serious damage from heavy rainfall, humid air, or rising ground moisture.
- A plaster coating, typically made from a lime or local clay-based mortar, forms a crucial water barrier on the adobe surface. This plaster prevents rainwater from directly penetrating the wall by allowing it to run off harmlessly.
- Many houses also feature wide eaves, a key architectural element that provides long-term protection for the hard-to-reach upper floor facades from rain and other weather elements.

3.3 Protection Against Wind and Dust Erosion

- Unplastered adobe surfaces are susceptible to erosion from wind and can become dusty over time. Plaster acts as a crucial protective layer against this mechanical degradation (Fig. 5).

3.4 Insect and Pest Control

- The stucco coating seals small gaps and cracks in the adobe walls, effectively preventing insects and other pests from entering the structure. This is an important hygiene and safety factor, particularly for dwellings located in rural areas.

3.5 Aesthetics and Surface Smoothness

- The application of stucco gives the wall a smoother, more finished, and aesthetically pleasing appearance. It also provides a surface that can be painted, allowing the house to be easily maintained. The use of white lime plaster in Safranbolu is a key practice for understanding the town's holistic identity. The plastering of these adobe houses is not just an aesthetic choice; it's a structural necessity born from the nature of the material and local building traditions. This method extends the life of the wooden frames and adobe infill, protects the structure from external elements, and increases the overall comfort of the house. It's a prime example of how traditional architecture efficiently and sustainably uses natural materials.

3.6 Supporting Thermal Performance

- While plaster doesn't significantly add to the thermal insulation of an adobe wall, it's crucial for airtightness. By sealing cracks, it helps maintain a more stable indoor temperature, contributing to the overall comfort of the house.

3.7 Fire Resistance

- Lime or earth-based plasters can increase a wall's fire resistance. It acts as a protective layer, delaying direct flame contact with the adobe. This is a crucial safety feature, and in some family histories, this experience has led to a preference for adobe plaster, even on facades that were previously timber-clad.

3.8 Protection from Precipitation

- Plaster is vital for protecting the wooden frame and adobe infill from precipitation. It efficiently directs rainwater away from the facade, preventing the adobe from getting wet and eroding. In some cases, thicker plaster applications were used, particularly on facades that received heavy rainfall, to provide an extra layer of protection.

Figure 5. Examples of houses in Safranbolu, Türkiye, with deteriorated exterior plaster exposed to the elements (author's archive, 2023)

4 STRUCTURAL PERFORMANCE OF SAFRANBOLU ADOBE HOUSES

In Safranbolu and its surrounding areas, local materials like wood, adobe, and stone were the primary building materials. The preferred construction systems were skeleton and masonry. Typically, ground floors were built with solid stone masonry walls, while the upper floors used a wooden frame with block adobe filling.

The walls, known as "*hımış* structure," were made by fitting locally sourced and dried adobe blocks into a precisely ordered wooden skeleton. This system, with its intermittent struts and buttresses,

served a load-bearing function. The earthquake resistance of *hımış* buildings, like all other structures, depended on the quality of the materials and craftsmanship.

In rural areas, local builders constructed these buildings using regional materials to meet the users' needs. Despite potential assembly errors, the system's flexibility and lightness, along with numerous secondary supports and nodal points in the frame, especially on the lateral wall, helped compensate. The structure's resilience came from the ductility of the timber frame and the energy-absorbing properties of the adobe blocks. For instance, the devastating 1999 earthquakes and their aftershocks caused no damage to Safranbolu and its surroundings.

4.1 Structural Design

- In timber-framed buildings, a key feature is the abundance of uprights and joints within the load-bearing walls. Secondary uprights placed between main ones, along with diagonal bracing and horizontal belts around windows and doors, enhance the system's ductility and absorb a significant portion of earthquake energy.
- Special attention was given to the joints between floor beams and the main and intermediate uprights, especially around window openings. Interlocking techniques, used in addition to nails, created stronger connections. The use of fitting techniques for the connections of buttresses with uprights and floor beams also helped prevent ruptures and fractures. Furthermore, the structures' symmetrical and square or rectangular plans were designed to prevent torsion when subjected to earthquake forces.

4.2 Earthquake Resistance

- The mudbrick blocks within the *hımış* structure, which are placed between wooden poles spaced 20-35 cm apart, provide significant resistance to the horizontal shear forces of an earthquake (Fig. 6). The friction between the blocks and the timber frame allows the building to absorb seismic energy, resulting in little to no damage during seismic events. In some examples, the mudbricks were placed horizontally, while in others they were placed diagonally, each method contributing to the structure's resilience.
- Since the timber frame of these *hımış* buildings rests on a masonry ground floor, the center of gravity is kept as low as possible. This design ensures the building is stable and prevents it from toppling during an earthquake, provided the foundation and the upper frame are properly connected [6].

4.3 Renewability in Materials

- Repairing and renovating timber frame systems damaged by earthquakes or other events is a straightforward, affordable, and simple process. Replacing a few posts, braces, or sections of the adobe wall is a practical task. Adobe has long been a favored building material because it is readily available, easy to work with, provides a smooth finish, and offers a good barrier against moisture. An adobe wall holds plaster well and is cheap to construct, which significantly reduces the amount of timber needed for the structure.

Figure 6. Examples of adobe infill in timber-framed houses from Safranbolu, Türkiye (author's archive, 2023)

5 CONCLUSION

The Economic, Environmental, and Social Imperatives of Sustainable Housing

- Current housing trends, which favor very large floor plans, present significant challenges in terms of economic, environmental, and social sustainability. Such large houses are difficult and costly to maintain, leading to a diminished lifespan for modern homes. This highlights a pressing need for national conservation policies. Yet, historical structures, which can be seen as "Turkey's adobe houses," are not merely architectural artifacts; they are a tangible expression of a dynamic connection to the past and a cultural richness that enriches global heritage.

The Legacy of Adobe in Safranbolu Architecture

- The traditional use of natural materials like wood, stone, and adobe has been a hallmark of Anatolian architecture for centuries. In Safranbolu, the preference for adobe was directly tied to the region's unique climate and the accessibility of local materials. Adobe's thermal mass properties were crucial, enabling the houses to stay cool in the summer and warm in the winter, effectively serving as a natural air conditioning system. Furthermore, its ease of use and low cost made construction both accessible and affordable, demonstrating how architecture can integrate aesthetic principles with economic and practical sustainability.

Preserving a Cultural and Architectural Heritage

- The adobe dwellings of Safranbolu and its villages are more than just buildings; they are a vibrant reflection of the region's local identity and its profound connection to natural resources. The well-preserved historical fabric of the town clearly illustrates the immense cultural value of this architectural heritage. The sustainable preservation of these unique structures is therefore of great importance for future generations [7]. These buildings, which can be rightfully called "Turkey's adobe houses," serve as a living link to the past, a testament to the respect for natural materials, and a source of architectural richness that contributes to global culture. Ultimately, Safranbolu's adobe houses continue to offer valuable lessons for contemporary architecture and urban planning, urging us to reconsider the human-space-nature relationship and develop more sustainable settlement models

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The Architectural Features of Beehive Corbelled Dome Houses

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ABSTRACT

In the context of biomimicry, designs inspired by nature appear in vernacular architecture in the evolution of traditional architecture. It is seen that the beehive-shaped corbelled domes, of which there are examples until today, are designed with inspiration from biomimicry.

Beehive corbelled domes, arches and vaults' constructive knowledge is spread all around the world, either in vernacular or in monumental buildings, from dwellings to infrastructures and palaces. Its origin is still uncertain, being the megalithic times and the Mesopotamian civilizations (around 6000 years) pointed out by several authors as its most probable origin.

In the ancient Hellenic world, beehive corbelled domes reached a notable level of technical evolution very early on and created not only brilliant monumental forms, such as the Late Minoan tombs in Crete and the famous Thesaurus of the Mycenaean kings in Peloponnesus, but also simple adobe or stone habitats widely spread over the historical Hellenic world from Macedonia to Cyprus. Beehive corbelled domes can be seen examples around the Mediterranean.

In this context, the beehive corbelled domes are seen to have applied the technique of learning/adaptation and/or application "inspired by nature" in the past. Beehive corbelled domes can be described as structures built by overlapping layers of masonry (stone or adobe), jutting toward the center, built in horizontal rings or in a spiral movement until meeting at the top. It is usual to see cylindrical, cone, half-spherical or combined solutions for the corbelled dome such as the beehive corbelled domes buildings in which the interior of the dome is part of the wall, starting from the floor or part of the wall, or domes start from the top of the walls.

In this study, it is aimed to examine architectural features of the beehive corbelled domes in the Mediterranean region, which were built using stone and adobe materials, where the local architecture continues to exist despite the changes of design principles and construction methods

Keywords: Adobe, Beehive Corbelled Domes, Vernacular Architecture, Biomimicry Design

1 INTRODUCTION

The field of natural inspiration is very important and useful for designers today, and nature provides many designers with creative ideas and limitless inspiration to develop a new design [1]. Biomimicry is a common knowledge that should be learned and used in every field of science, including architecture. Since the beginning of human civilization, humans have tried to take ideas from nature; this was mainly based on structural and formal ideas. In the context of biomimicry, designs inspired by nature appear in vernacular architecture in the evolution of traditional architecture [2]. The adobe brick beehive domes, examples of which can still be found today, appear to have been built using a technique of vernacular architecture for learning/adaptation and/or application that was "inspired by nature".

There are three levels of mimicry; the organism, behaviour and ecosystem. The organism level refers to a specific organism like a plant or animal and may involve mimicking part of or the whole organism. The second level refers to mimicking behaviour, and may include translating an aspect of how an organism behaves, or relates to a larger context. The third level is the mimicking of whole ecosystems and the common principles that allow them to successfully function. Ecosysytem however is what could be studied to look for specific aspects to mimic [3].

Within each of these levels, a further five possible dimensions to the mimicry exist. The design may be biomimetic for example in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function). The differences between each kind of biomimicry are described in Table 1 and are exemplified by looking at how different aspects ecosystem a termite is part of could be mimicked [3].

Table 1. A Framework for the Application of Biomimicry of Ecosystem Level[3].

Level of Biomimicry		*Example - A building that mimics termites*
Ecosystem level (Mimicry of an ecosystem)	*form*	The building looks like an ecosystem (a termite would live in).
	material	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example.
	construction	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example.
	process	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water for example.
	function	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilising the relationships between processes; it is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

Vernacular architecture is a form of building that is distinctive to the region where it is practiced, based on local needs and preferences. It is an aspect of cultural expression rooted to a particular place. Vernacular architecture brings with it enormous artistic, functional and cultural wealth. This architecture is produced not by specialists, but by the spontaneous and continuing activity of whole people with a common heritage, bringing new values to the community experience [4]. Many of the design and construction practices in vernacular architecture are the core of sustainable design principles, which are environmentally friendly and less energy intensive than their modern counterparts [5].

Nearly all vernacular structures can be abstracted to primary geometrical forms, the cone, dome, cylinder, and cube, or sometimes a combination of them (Picture 1). The cone consists of a circular plan and inwardly inclined surfaces which terminate in a single point on top, like an upside-down ice-cream cornet. The cone is one of the widest used vernacular forms, found both as roof shape and as undifferentiated structure, where there is no visual difference between wall and roof, which is also called as "rooftecture" recently [6].

Picture 1 Earthen vernacular architecture examples, Harran, Şanlıurfa (Photo by authors) and Taos Pueblo, New Mexico [6]

Vernacular architecture has been helped largely by nature: fertile soil must be cleared of stones. Construction is the result of need, since stones thrown in a heap gradually disappear. Construction is necessary: and corbelling is the simplest method. And if an object is going to be constructed, it should at least be functional. Corbelling has been known as a constructional principle in classical architecture for several thousand years: a little less than three thousand years ago it was supplemented by the arch, which defined a vault and subsequently a cupola [7].

In the Mediterranean region, beehive corbelled domes were widespread and varied in local architecture. Today, only traces of lost structures can be found, and there are very few historical remains made of clay, especially dried clay, but there are many stone compositions in vernacular architecture. In some cases, adobe corbelled domes are found in which have a long-standing tradition of earth constructions in the world of vernacular architecture.

2 HISTORY OF BEEHIVE CORBELLED DOMES

Beehive corbelled domes, arches and vaults' constructive knowledge is spread all around the world, either in vernacular or in monumental buildings, from dwellings to infrastructures and palaces. Its origin is still uncertain, being the megalithic times and the Mesopotamian civilizations (around 6000 years) pointed out by several authors as its most probable origin [8].

Corbelling has been known as a construction principle in architecture for several thousand years: a little less than three thousand years ago, it was supplemented with the arch, which defined a vault and subsequently a cupola. The first cupola, the Roman Pantheon, is also the first modem architecture of our time. However, this was made by masters, who were acquainted with the achievements of high culture and had learnt there. On the other hand, unschooled but not unlearned masters built smaller constructions in the simple method of overlapping much, much later, right up to today [7].

In the ancient Hellenic world, beehive corbelled domes reached a notable level of technical evolution very early on and created not only brilliant monumental forms, but also simple adobe or stone habitats widely spread over the historical Hellenic world from Macedonia to Cyprus. This tradition survived in the following centuries with no significant innovations from then on, though the relation to ancient forms was not always clear. In the case of dry-stone corbelled buildings, in particular, the precise

date of construction is usually uncertain, since, though their age understandably cannot exceed two or three centuries, they maintain the unchanged primordial forms [9].

In the archaeological record, the earliest constructions for which scholars have proposed a reconstruction with a dome-shaped roof date to the Halaf period, which corresponds to one of the latest phases of the Neolithic in the Near East (c. 5900-5300 BC). It concerns houses with a circular ground plan of which the diameter can reach up to six meters and which are sometimes attached to a structure displaying a quadrangular plan. Structures of this type were identified for the first time with certainty at Arpachiyah in Northern Iraq [10].

The technology of the vault appears to have been quickly mastered in the ancient Near East. Corbelled domes and barrel vaults were used in the construction of subterranean tombs in Ur in Southern Mesopotamia dating to the third millennium. From this moment on, the building technique is applied rather frequently in ancient Mesopotamian architecture as it avoids the use of wood, a rare commodity in that region, in the roof structure [11]. Although descended from a longer tradition, the examples of clay brick beehive domes of Harran houses in Türkiye, have been dated to the 19th century AD, as are the dry stone of Trulli houses in Italy (Picture 2), [12].

Picture 2. Harran houses in Türkiye and Trulli houses in Italy (Photos by authors)

The architecture that developed in the Aegean islands and on the Greek mainland from earliest times and prevailed throughout the prehistoric era was based on a rectangular plan and a post-and-beam system. Stone was the most popular building material in the rocky islands, but mud bricks were also used in certain regions where clay deposits were available. Timber, finally, played an important role in reinforcing the walls, especially in the later Bronze Age periods [13].

3 THE ARCHITECTURAL FEATURES OF BEEHIVE CORBELLED DOME HOUSES

Corbelling is the drystone walling system means building with no mortar or cement, just putting together pieces of stone: natural, uncut with irregular shapes, or dressed stones with regular surfaces. Longer stones are used for lintels only, and larger elements are built into the comers. The comers are the most problematic elements, vernacular architecture, as an 'indigenous building technique',8 uses groundplans without them. The majority of stone shelters are circular. Corbelling as a principle is circle or square at ground level, circle after the first courses, overlapping in cross section and with a frame as counterweight and for leading off rainwater. (Figure 1), [14]. Corbelling is gradual overlapping that is repeated from layer to layer, in height all the way to the capstone. Experience suggests that the ideal height of a construction is 3/2 of the diameter of the base plus the thickness of the wall [7].

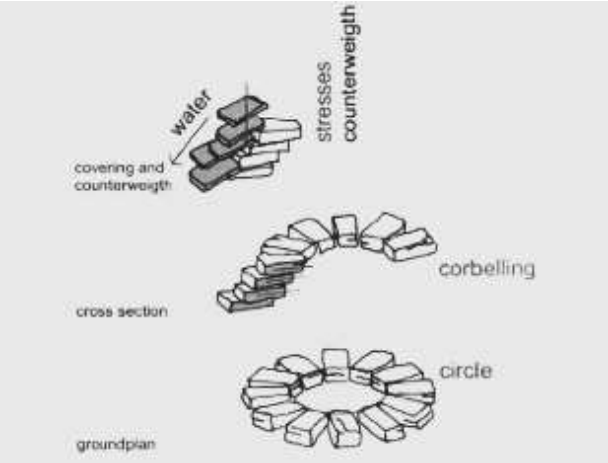

Figure 1. Corbelling as a principle [14]

Beehive corbelled domes can be described as structures built by overlapping layers of masonry (stone or adobe), jutting toward the centre, built in horizontal rings or in a spiral movement until meeting at the top. It is usual to see cylindrical, cone, half-spherical or combined solutions for the corbelled dome such as the beehive corbelled domes buildings in which the interior of the dome is part of the wall, starting from the floor or part of the wall, or domes start from the top of the walls [15].

Corbelled dome architecture is a culture and construction technique common to both East and West. In particular, the corbelled domes or "tholos domes" are an ancient construction technique that produced remarkable urban and rural architectural habitats, from an aesthetic and anthropological point of view: thousands of examples of habitats are found all over the Mediterranean region. In the Mediterranean region, the architectural culture of corbelled domes is an expression of dry-stone building culture mostly connected to sheep rearing and the related nomadism of shepherds, with only a few exceptions, most notably in Alberobello, Apulia [16].

The character of the cell may at first sight justify the isolation and free-standing nature of most corbelled domes existing in the Mediterranean zone. While in other places the construction of corbelled domes usually answers occasional, sporadic or seasonal needs and depends on the availability of stone, in this case the absence of stone, the absence of mortars like gypsum, lime, etc., and the absence of wood, determines the creation of dwellings, hamlets and villages built exclusively in earth [17].

Stone shelters are in principle corbelled and this construction defines the interior space, which is the same in all compositions. In contrast, the external form has heritage, local characteristics and natural possibilities, above all material and location. Corbelling is the principle of overhanging. The rule that the alternation may not extend over the center of gravity is crucial for not just the element immediately below, but all lower elements [18].

The shape of clay dwellings also appears on the outside of the construction, in contrast to stone, which has a double wall (constructional and coating). The shape of a false cupola is a spindle, an object in clay is essentially higher than stone, so these compositions are also called beehive houses, after beehives of straw or husking. The best known are in Lebanon, along the Turkish border, on both sides (Harran), but they also exist in Syria, and in Greek and Italy. The architecture of the Mediterranean is stone; clay is almost never found, except in detail, since there is clearly too much humidity and rainfall (Figure 2) [18].

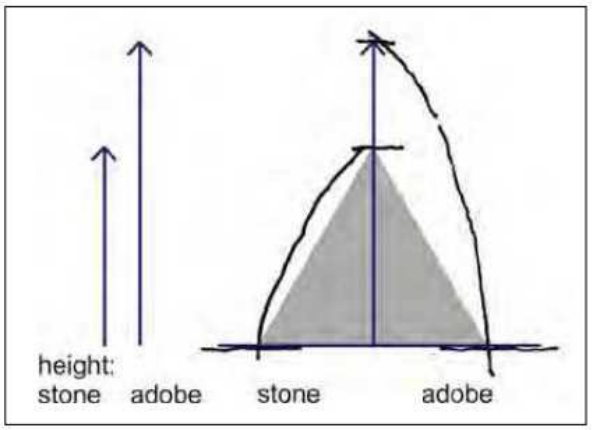

Figure 2. Corbelling in stone and in clay: due to lower hardness of adobe bricks, height difference [18].

The theoretical start is within a wall, and many shelters are precisely that then of course it stood in front of the wall, in it, behind it or outside the wall, completely independently. While the interior supporting part is always the same, the outside can be very different (Figure 3), [18].

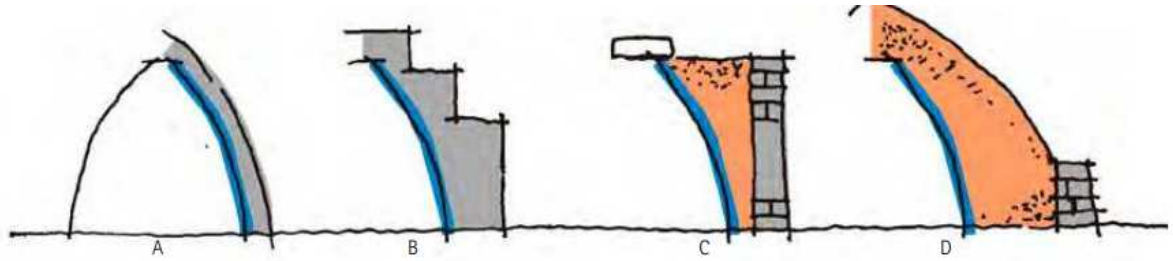

Figure 3. The interior supporting part and the outside [18]

Present traditional houses provided with domes, display a ground plan which is either square or circular. As a result, we can assume that ancient architectural units with a circular or square plan could have been covered with a dome [19].

Earthen architecture is realized with materials constituted by a prevailing mineral component and a possible organic fraction (original or addictive). The composition (proportion and type of clay minerals and proportion of coarse fraction) determines the behavior of the earth, in particular its plasticity, shrinkage, workability, mechanical characteristics and durability of the artefacts [20].

The character of the cell may at first sight justify the isolation and free-standing nature of most corbelled domes existing in the Mediterranean zone. While in other places the construction of corbelled domes usually answers occasional, sporadic or seasonal needs and depends on the availability of stone, in this case the absence of stone, the absence of mortars like gypsum, lime, etc., and the absence of wood, determines the creation of dwellings, hamlets and villages built exclusively in earth [17].

The structures are made using two different and compatible dry-stone techniques: the dry-stone walling system and the corbelled dome system. The walls, built either in limestone, granite or slate, are erected by bonding the stones without cement or mortar [21].

Corbelled dome vernacular constructions are made of stone, mostly dry stone and only occasionally employing the use of mortar. The raw material is usually abundant in the surroundings where only

the hewing of a rock to pieces is necessary. At high altitudes stone fragments are naturally produced by the disintegration of rocks by frost. Schist stones are ideal for corbelled constructions, since they can be gathered on site and used immediately, with hardly any need for further tools. Understandably, corbelled architecture is more frequent in regions where schist rocks are present. Though the constructions in question are often modest in structure, an examination of the techniques behind these forms reveals constructional skills that were far from primitive [9].

The separation of the vertical wall into two individual entities: on the outside, a thin vertical 'skin'; on the inside, a surface, close to a sector of sphere. This case represents clearly an intermediate typology between the ''modern'' cell and the old prototype (a simple cone-like structure, A). A more complex solution is to obtain the pendentive as the result of a progressive 'deformation' of the right angle in such a way as to avoid a too sudden passage between a square and a circular shape B. The pendentive is the ''transition'' between the box at the base and the dome above. Notwithstanding that, this choice relates to a certain degree of weakness; it avoids a sudden variation of shape at the corner, and allows larger heights of the vertical walls in shape C (Figure 4), [15].

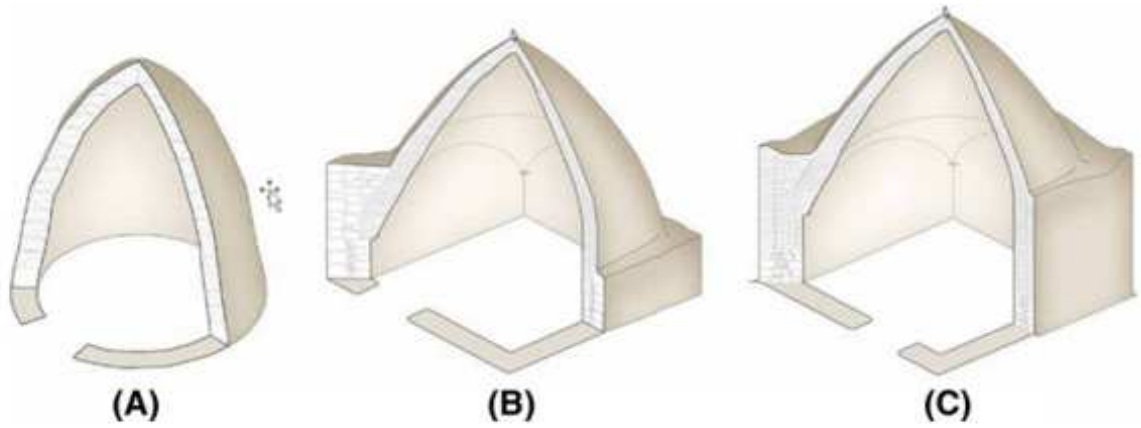

Figure 4. Sketches showing the three types of beehive corbelled dome building [14]

The horizontal laying bed dome, made of super imposed progressively jutting rings, is created with earthen bricks and earthen mortar. The thickness coincides with the largest dimension of a single brick (about 35–40 cm); thinner bricks are used (around 5–6 cm), if compared with the dimensions of the bricks used in the walls. The use of thinner bricks enables first a better control of the curvature by controlling the extension of the juts, and, in addition, as the work goes on, it ensures the achievement of a shape with a pleasant aesthetic character [15].

Synopsis of typology in Mediterranean civilizations throughout history, most types of corbelled domes have appeared, with the exception perhaps of the conspicuous conic examples, as the trulli type. Cylindrical and truncate-conical volumes enclosing beehive domes (mitato type) are the most frequent. There are also ellipsoid domes on elliptical or rectangular volumes (drakospito type), but in this case the dome is mostly truncated at the top and covered with a terrace (kypha type). 'Corbelled dome' is not the exact term here, but rather pseudocupola, corbelled side walls leaving a void at the top, then covered with stone slates or beams and a layer of earth (Figure 5), [9].

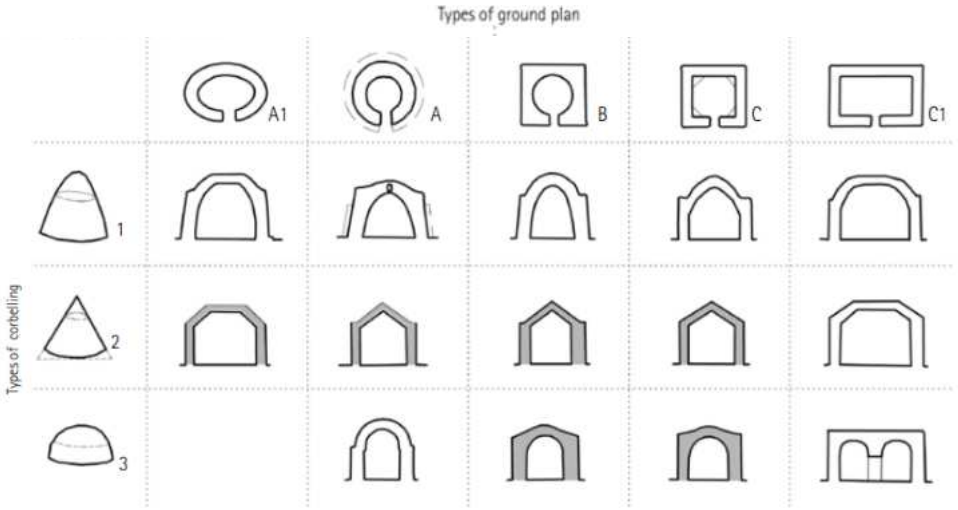

Figure 5. Corbelling dome forms, Synopsis of typology in the Mediterranean [9]

This form of architecture reaches its highest expression in the urban area of Alberobello, where the districts of Rioni Monti and Rione Aja Piccola comprise exclusively of Trulli. Each type presents many variations in size, number of steps, presence and shape of the outer stairs, shape of the internal plan (circular, pseudo circular, quadrangular), and shape of the base proile (circular, oval, quadrangular with rounded corners or square corners), [22].

Corbelled dome habitats of southern Greece are strongly related to dry and arid climatic conditions unfavorable to wood production; they can be found mostly in small, rocky islands and in barren, windy landscapes, often at high altitudes where the sole construction material remains stone. Stone is usually abundant in such harsh grounds anyway, in different types of rock, limestone, schist, etc. the corbelled dome architecture of southern Greece concerns mainly dry-stone structures. This also strongly influences morphology, since dry-stone masonry requires an outside escarpment for purposes of static. Naturally, the escarped forms are often applied even in constructions with mortar, giving corbelled buildings a unique character of their own. Sometimes the structure may be so modest that the result resembles little more than an irregular mass of stones. The external form does not always correspond to the internal structure; square or rectangular volumes can equally be covered with cruciform corbelled domes [9].

The selection of materials to produce sun-dried adobe bricks is carried out using clay soil fenestrated from the surrounding area. The mortar consists of the same type of earth. The sieving process, through which the mortar is obtained, ensures a higher cohesion to the clay, and consequently a higher degree of adhesion. The union between bricks and mortar because of the similar properties of the two materials are crucial for the assessment of the behavior of the whole structure (Figure 6), [15].

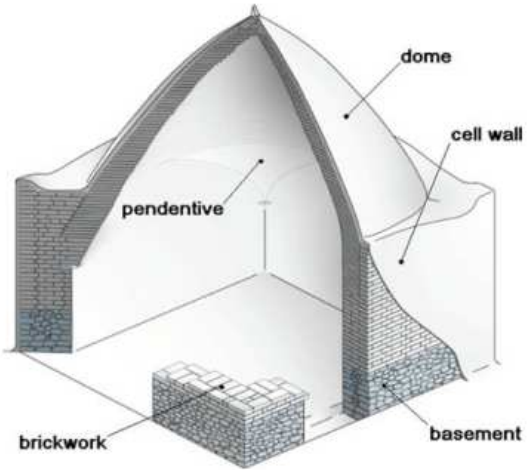

Figure 6. Axonometric view of the section of a beehive corbelled dome [15]

In examples of Greek corbelled dome architecture, no 'urban' character is discernible; these are usually desolate buildings scattered among fields and remote pastures. Occasionally, when several of them are grouped together in a region, they do present some kind of remote connection to each other, as happens in certain groups of mitata in Crete or in the voltoi "village" of Englouvi in Lefcada. Otherwise, the only connection of note concerns the grouping of 2-3 domed units together serving as habitation and as product storage (Figure 7), [9].

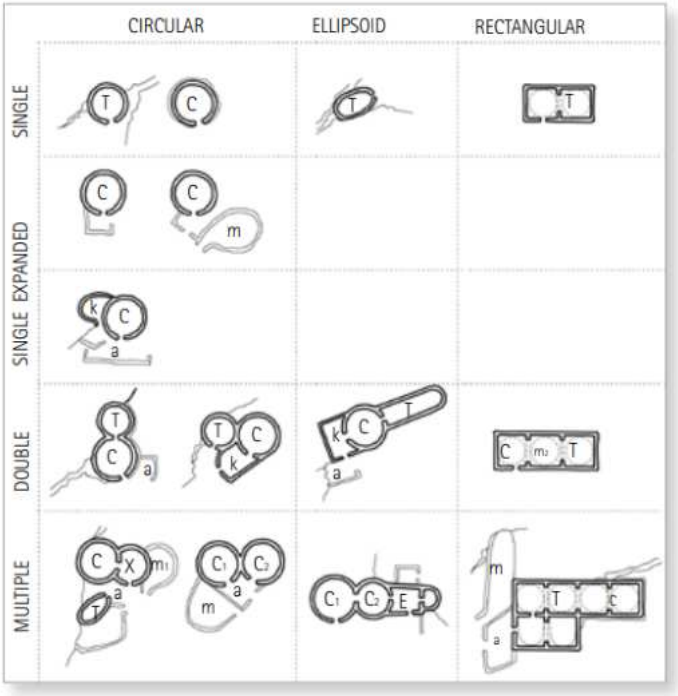

Figure 7. Grouping of beehive corbelled dome units [9]

Syrian beehive dome dwellings belong to the vernacular architecture group of ephemeral character, and this factor hinders their survival. Syrian dome dwellings are cell constructions marked by the notable presence of domed roofs that stand out characteristically in the desert landscape. This type of vernacular construction incorporating a corbelled dome is common in the Mediterranean area and is usually built in stone. Far less common is to find them gathering to form groups of dwellings or

even whole villages. Even considering the existence of other conflicting examples, the most distinguishing feature of these dome dwellings lies in their character and capacity to be grouped together, along with the use of adobe as a construction material [23].

Corbelled domes in Syria construction method we may distinguish two principal techniques depending on the type of dome: normal dome (circular or square basis) and Sultan dome (supported on walls). - The first type, which starts at ground level or above on a foundation wall, is the simple and the same in adobe or cob technique. There are two sub-types: circular basis or square basis - the circular normal dome is the basic dome type, there are not complicated details, nor specific structural elements because the builder begins to form the dome shape from the ground level with a circular plan and do not need transition from one shape to another. - the square normal dome is an evolution of the basic dome type, there are not complicated details, nor specific structural elements although the builder begins to form the dome shape from the ground level with a square plan and starts to lay the bricks smoothing the corners to get transition from square shape to circular shape with 8-15 layers. - The second type is the Sultan dome which is built on high or low square perimeter walls made of adobe, getting the transition from square to circle with the perimeter walls made of adobe, getting the transition from square to circle with the perimeter wall [24].

The architecture of Syria (Aleppo region) and southern Türkiye (Harran region) is characterized by construction techniques that use earth as a building material (Picture 3). The shape of clay dwellings also appears on the outside of the construction, in contrast to stone, which has a double wall (constructional and coating). The shape of a false cupola is a spindle, an object in clay is essentially higher than stone, so these compositions are also called beehive houses, after beehives of straw or husking [18].

Picture 3. Beehive corbelled domes of Harran houses (Photo by authors)

The different height of the perimeter wall may help to distinguish more clearly the two type of domes in the vernacular landscape of the domed villages of Syria: the so-called dome of the Sultan dome (Figure 8) with a perimeter base that rises up to the height of the lintel of the door to become a real wall of the facade, and the simple dome with a very low base. Between the two, there are other variants according to the height of the perimeter base. In the interior, this difference is shown in the respective dimension and height of the pendentives that allow the transition between the square-shaped layout and the circular dome. The material and constructive differences are minimal, since they are all built with adobe walls and corbelled domes. The profiles of the domes allow us another classification that would divide them into complete pointed domes and truncated domes, where the availability of wooden branches cuts short the construction of the dome into a flat roof. Normally,

these truncated domes have a medium-high perimeter base, approximately two-thirds the height of the entrance. Houses with corbelled domes have only a few small doors and windows, mainly from need to protect against the external climate, strong sunlight or winds [17].

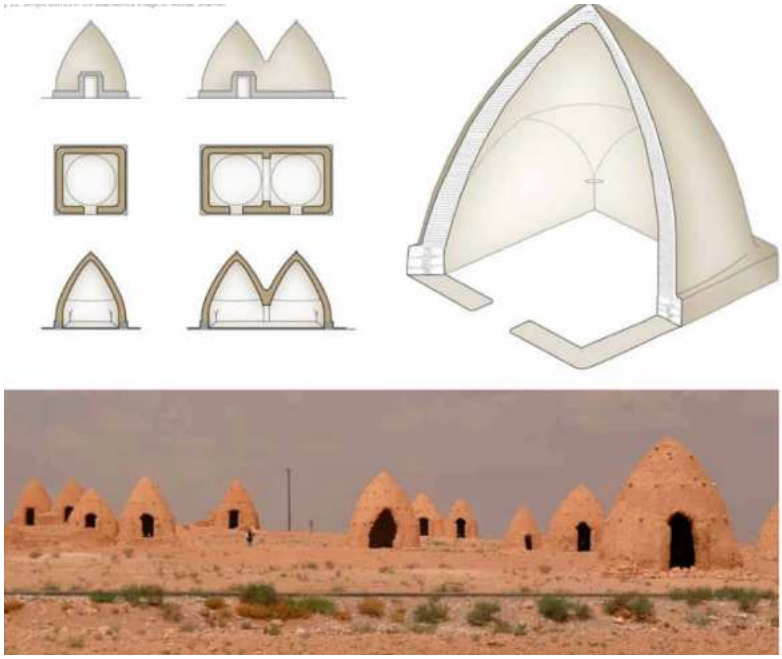

Figure 8. Beehive corbelled dome example, village of Meksar Shamlei, plan, elevation, section, axanometric view [17]

The building culture developed through thousands of years in Syria many ways to achieve the transition from square shape to circular one for realizing or supporting earthen corbelled dome. Although there are many differences of dome shapes in different areas the common character is that all of them, built with adobe technique, are corbelled domes, because their courses are set horizontally or better slightly tilted inwards, each course is laid out according to a spiral and cantilevered over the one before. Main forms of earthen corbelled domes in Syria are parabolic, catenary, conic or multi-conic and truncated [24].

The corbelled dome is realized by laying the earthen bricks according to a continuous helicoidal spiral, tapered and often tilted towards the centre. The main shapes of Syrian earthen corbelled domes are: - parabolic; catenary; conical or, better, multi-conical; truncated [25].

Most of the houses are rectangular and vaulted; a few of them follow a second, very interesting type: cubic outside, with a beehive corbelled dome over an interior circular ground plan of c. 2.5 x 2.5 meters. All these small dwellings, most of them with entrances protected by tiny vaulted porches, are dominated by a large edifice of the second type with a cylindrical external form which presents two grades towards the top (Figure 9), [9].

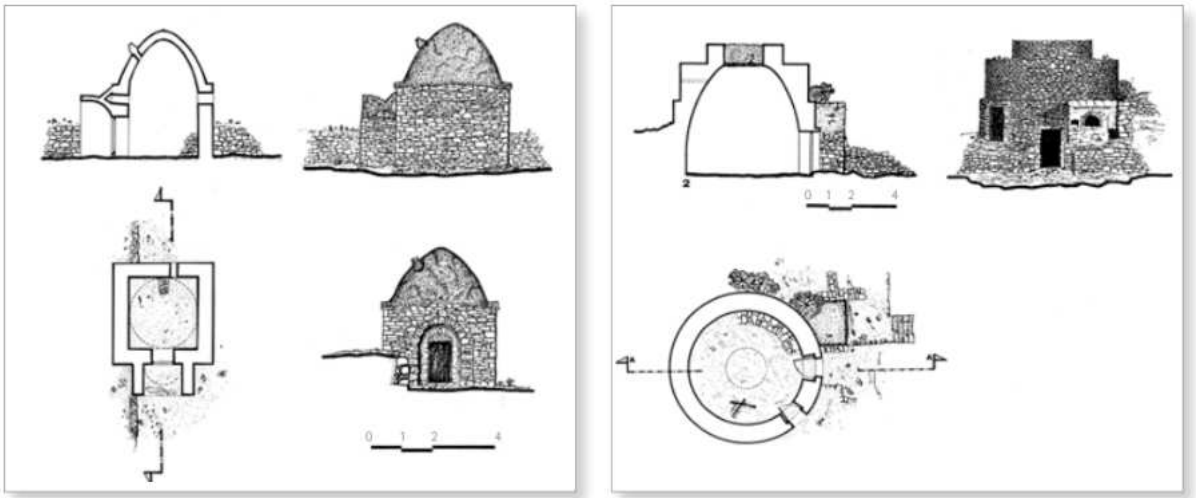

Figure 9. Corbelled domed types [9]

Beehive corbelled dome, besides offering a means of habitation that is practical in areas of scarce natural resources, can meet the demands of hygrothermal welfare in a semi-arid climate due to cooling abilities achieved using certain materials and the form of the construction. Earthen material has naturally elevated thermal inertia, resulting in damping and a lag of changes in internal temperature compared to those of the outside. The earthen walls also regulate the humidity of the environment through vapor permeability, contributing further to the conditions of hygrothermal and respiratory comfort. The dome structure, when correctly built, is an excellent solution, both in structure and function.

CONCLUSION

As vernacular architecture, beehive-shaped domed structures are the use of geometry inspired by nature and used instinctively without any additions. The beehive dome, which requires constant maintenance and depends on the temporary durability of mud plaster, is an example of preserved longevity.

As in other parts of the world, despite changes in the traditional economy, there are two options when it comes to beehive domes in places where local architecture still stands: to preserve and restore local architecture regardless of the disappearance of the social and economic context that once gave rise to it, or to allow change to take its course and take measures to prevent the gradual disappearance of this architecture.

Biomimicry is applied to architectural design in terms of both form and functionality. In nature, there are many solutions waiting to be discovered by architects in collaboration with biology and other scientific disciplines. Among the designs inspired by nature in architecture, examples of beehive-shaped domed houses made of stone and earth are also important in terms of cultural heritage. Since beehive domes are constructed using short-lived materials such as mud plaster, their preservation must be ensured. The beehive shape of these abodes allows them to withstand earthquakes, violent wind storms, and seasonal heavy rains, which explains why they are still in use these days, thousands of years later.

The vernacular architecture has developed largely with the help of nature, and examples of structures consisting of protruding domes shaped like beehives made of stone and adobe should be preserved

as cultural heritage and similar examples should be modernized and applied in eco-villages using new adobe techniques.

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Kerpic'25 – Earthen Architectural Heritage
13th International Conference
Rabat, Morocco, 25-27 September / 2025

The Dome of Heaven: A Holistic Journey of Using Sustainable Adobe Material

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ABSTRACT

The Dome of Heaven Mosque is located in one of the prettiest shore settlements of Istanbul, in Kumburgaz area, at about a bit more than one hour from the vibrant city center. It lodges in one of the most charming seashore districts of sandy beaches quite nearby to Istanbul. This location is itself a destination for the population of Istanbulian citizens that desire to spend a pleasant weekend on a relax and yet charmy point without being too far away from the dynamic city center of Istanbul. Kumburgaz could be thus defined as a compound point that intends, in this context, to be nearby to the city center dynamism for its visitors through a relax yet though a rich program it offers. Building up a strong link in between the natural material using local techniques and modernist architectural point of view is the basic concentration point of the Dome of Heaven Mosque project. Thus the very basic natural constructional material adobe is chosen as the main material of the project, yet planning in the dynamism of the modernist architecture has been solved. On an intellectual point of view, creating a kind of balance in between a naïve modernist space design and using of natural material can be defined as the most significant aspect of design criteria of the project. Adobe material is the traditional material of the Anatolia. It is natural material. It is easy to use. It is a cheap material to use. It is modest in its' nature. It naïve. It is to be as the earth is. Designer Architect Sule Erturk would like to work with a full group of women architects during this project to feel the sustainable feminen energy of the earth on a sustainable process based mosque design. Thus, the paper would express the conceptual journey of creating a modern mosque in Istanbul in the way of sustainable design of adobe material.

Keywords: Modern, Adobe, Mosque, Design, Sustainable

1 INTRODUCTION

"We came from the earth, and to the earth, we shall return".

Surah Taha (20:55), the Quran [1]

The Dome of Heaven project emerges from an ontological inquiry into the interconnectedness of existence and the search for an architectural language that resonates with the essence of life. At the heart of this conceptual framework lies a fundamental understanding: the interrelation of all beings through a singular Source, a notion that aligns with both the cosmological worldview of Islam and broader philosophical reflections on origin, unity, and continuity. This conceptualization draws inspiration from the Qur'anic narrative of creation, which repeatedly emphasizes humanity's emergence from the earth and its inevitable return to it: "From the earth We created you, and into it We shall return you, and from it We shall bring you forth once more" [1]. Thus, the cycle of existence—from genesis to dissolution and regeneration—constitutes the central metaphor upon which the architectural vision is constructed. In this interpretive framework, earth functions as both material and symbol. It signifies the primordial substratum of life, the ground of being upon which all terrestrial existence unfolds, and the medium through which the dialectic of permanence and impermanence is articulated. By situating earth as the principal material of the mosque, the design

invokes an ontological humility—echoing the simplicity and elemental character of the Masjid al-Nabawi, the Prophet's mosque in Medina—while fostering an aesthetic of modesty and authenticity that resists ornamental excess as not only the first mescid space of the Islam and also one of the most sacred mosques. This material strategy resonates with the Qur'anic worldview wherein earth is not only the physical origin of humanity, but also a reminder of its existential fragility and moral responsibility. The philosophical premise underpinning the project transcends mere material determinism; it embodies an aspiration to transform spirituality into architectural form, thus rendering visible the invisible bonds that connect humans to nature, to one another, and to the cosmos. This ambition is grounded in a prolonged intellectual engagement by the design team with diverse epistemologies—Islamic theology, Sufi metaphysics, existential philosophy, mathematical cosmology, and environmental ethics—which collectively inform the project's conceptual rigor. Within this integrative matrix of knowledge, the mosque is envisioned not solely as a liturgical container, but as a phenomenological landscape that facilitates an experiential encounter with the sacred. This approach positions the mosque as a space of spiritual nourishment and social inclusivity, where ritual and reflection converge with communal life and ecological consciousness. It seeks to reaffirm the mosque's historical role as a civic and cultural nucleus, while simultaneously projecting an architecture that transcends cultural particularism to embrace universal principles of peace, love, and harmony. By grounding its materiality in earth and its metaphysics in light, the design articulates a poetics of modesty and transcendence, inviting users to reimagine the sacred not as a fixed locus but as a dynamic process of return—return to origin, to essence, and ultimately, to the Divine. In its aspiration to harmonize form, matter, and meaning, the Dome of Heaven Mosque exemplifies the potential of contemporary Islamic architecture to function as a critical and creative medium, capable of negotiating the tensions between tradition and modernity, sacredness and functionality, individuality and collectivity. This paper situates the project within a broader theoretical discourse on sacred space, interrogating the ontological status of the mosque, the symbolic economy of materiality, and the phenomenological dimensions of architectural experience. It argues that the mosque, far from being a static typology, operates as an open system of symbolic relations, wherein ritual, nature, and architecture coalesce to enact a metaphysical narrative of unity-in-diversity.

2 EVALUATION OF MOSQUE PLANIMETRY IN TIME

The most enduring physical manifestation space of Islamic architecture is The Mosque. From its inception, Islam expanded rapidly, and with this geographical expansion, architectural and artistic works reflecting an increasingly distinct stylistic diversity began to emerge against the backdrop of powerful socio-cultural contexts developing across the territories it reached. In Islamic countries, mosques in particular, as well as a variety of other architectural products, were produced in ways that adhered to local traditions. Across almost every region of the Islamic world, considerable effort was devoted to ensuring that mosques—the most prominent type of religious structure—could be constructed as monumental and enduring works. In the fundamental planimetry of mosques, certain core elements remained constant, while new combinations were continuously added, resulting in ongoing evolution. This process ultimately culminated in the development of a canonical Islamic religious building typology, which reached its most mature form in the 16th-century Ottoman context through the work of Mimar Sinan. Leveraging the vast resources of the Ottoman imperial treasury, Sinan shaped monumental complexes in stone and marble that harmonized magnificently with the urban skyline while challenging the supremacy of the Byzantine imperial Hagia Sophia. Masterpieces such as the Süleymaniye Mosque, with its structural sophistication and symbolic dialogue with the city silhouette, and the Selimiye Mosque, with its unprecedented spatial and structural resolution, stand as the finest examples of this classical period. However, beyond such grand monuments, the Islamic world also contains countless smaller-scale mosques that embody strong local identities and demonstrate significant architectural quality. Among the most important and unique of these are undoubtedly the delicate and refined examples constructed in adobe, which exemplify a material sensitivity and craftsmanship distinctive to certain regions. On the other hand, despite this diversity of materials and scales in mosque architecture, there is also a common spatial tendency that can be observed. To understand that common tendency, the perception of manifestation space in Islam should be understood at first. The Arabic root based term *mosque* is derived from *cem*, originally appeared

as an abbreviation of the expression *al-masjid al-jāmi*, which referred to the large congregational structures designated for Friday prayer and literally signified "a place where the community gathers for worship" [2]. Notably, the word *mosque* does not appear in either the Qurʾān or the ḥadīth literature; rather, the Qurʾān consistently employs the term *masjid*. The Arabic term *masjid* itself originates from the root *sujūd*, meaning "prostration" or "the act of lowering the forehead as a sign of submission," and by extension denotes "a place for prostration" [3][2]. Historically, it was primarily Turkish and Ottoman communities that introduced the use of the term mosque to describe communal prayer spaces, whereas other Islamic societies adhered to the term *masjid* for such structures [3][2]. Given that Islam prescribes no liturgical system in the sense of formalized ritual architecture, the configuration of the sacred space in Islam is not anchored in rigid architectural prescriptions. Contrary to popular assumptions, the notion of sacredness in Islam is defined spatially rather than materially. Among the five obligatory acts of worship (ʿibādāt), prayer (ṣalāh) holds a central position, and while congregational prayer in a mosque is considered a meritorious practice (sunna) and a source of communal virtue, it is not exclusively tied to the mosque. Prayer may be performed in mosques, smaller *masājid*, private dwellings, or even open spaces, provided that the location is clean. This flexibility underscores the limited influence of doctrinal requirements on the architectural form of prayer spaces. At this juncture, an essential question arises: To what extent does religious prescription shape the construction of spaces dedicated to worship? Within the mosque, where prayer and spiritual practices occur, the sole indispensable architectural requirement pertains to orientation. The defining element of Islamic spatial organization is the qibla wall, oriented toward the Kaʿba in Mecca. Prayer rows are aligned parallel to this wall, reflecting the theological principle that the Kaʿba is the singular sacred locus in Islam. This orientation is explicitly mandated in Qurʾānic verse 2:144 (Sūrat al-Baqara), while verse 2:239 prescribes how prayer should be adapted under extraordinary circumstances [4][2]. These prescriptions indicate that Islamic ritual syntax is not predicated upon the sanctity of the physical site; rather, the mosque serves as an instrument that facilitates access to the sacred rather than embodying it. Within Islamic doctrine, physical structures such as mosques are not intrinsically sacred—the sanctity resides in the ritual act itself. Thus, the mosque functions as a representational locus, a space oriented toward and symbolically associated with the sacred [2]. In Turkish, the term *sacred* (kutsal) is defined as "divine" [5]. Sacredness constitutes an essential element in the interpretation of religious phenomena, as religion and sacredness form an inseparable whole. According to Mircea Eliade (1959), the sacred is defined as "the absence of the profane" (Eliade, 1959). Eliade asserts that "for a religious person, space is not homogeneous," indicating that sacredness occupies a central role in the life of the believer. In this context, the space and time defined by the sacred cannot be equated with ordinary, profane time-space; the distinction lies in what Eliade terms hierophany—the manifestation of the sacred [2]. Hierophany, understood as the repeated presence of the sacred, establishes an ontological order that sustains itself through ritual. Worship becomes the means by which the sacred is infinitely re-enacted, and this cyclical manifestation necessitates a place. Through symbolic differentiation, such a place is set apart from other spaces and thereby becomes appropriate for ritual practice. Eliade notes that this appropriateness emerges through a constellation of symbolic elements in which hierophanies converge with spatial configurations that signify the presence of the sacred [6]. Consequently, the sacred place is created as a locus for worship; through ritual, individuals inhabit sacred space and sacred time, thereby approaching the divine. The sacred place, thus, becomes both a framework for and an expression of the experience of the sacred. Durkheim similarly underscores the foundational role of this distinction, arguing that all religious systems—whether simple or complex—are structured upon a duality that divides the world into the sacred and the profane [7]. This binary opposition functions as a mechanism for preserving the absolute and immutable character of the sacred by establishing a radical discontinuity that prevents profane intrusion. As this duality frames the universe, it also informs spatial experience: a place is either sacred or profane. Building upon this understanding, Norberg-Schulz observes that religious, traditional, and even so-called "primitive" individuals can sustain their existence only within a system constituted by "meaningful places" [8]. Within this system, the "meaningful" or "qualified" place—distinguished from the amorphous and structureless expanse of the non-sacred—is identified as the sacred place [8]. However, Islamic architecture introduces a unique nuance to this dualistic framework. Mosques do not fit neatly within the sacred-profane dichotomy. While mosques are spaces designated for the performance of ritual—specifically, prayer—they do not, in themselves, embody intrinsic sacredness. Rather, they serve as intermediary spaces that facilitate the

experience of the sacred without being sacralized in their materiality [9]. Within the Islamic tradition, the mosque occupies an interstitial position between the transcendent and the profane: a spatial mediator that enables orientation toward the divine without itself becoming an object of worship [3]. In this context, neither the material, nor any other materialistic feature that is given importance in the general context of architecture is important in the construction mechanism in which the Islamic worship area is formed. However, what is necessary is to provide a place with a clean and hard surface suitable for the ritual of worship, which can protect the servant (kul) from external geographical conditions while performing the worship of the servant (kul) with his congregation. Yet though, there are still a number of habits regarding the use of space. And the planimetric organization of mosques reflects a complex synthesis of functional, liturgical, and symbolic requirements, which evolved over centuries in response to religious practices, climatic conditions, and cultural traditions. At its core, mosque planimetry is structured around the articulation of the prayer hall, the principal congregational space oriented toward the qibla, the direction of Mecca. This spatial configuration is defined by essential liturgical elements, including the mihrab—a niche marking the qibla wall—the minbar, designating the position for sermon delivery, and, in certain traditions, the dikka or elevated platform for recitation. Early Islamic architecture appropriated and transformed pre-existing typologies—such as the hypostyle hall derived from Arabian and Late Antique models—into a canonical form that enabled scalability for communal worship. The modular columnar grid of hypostyle mosques facilitated expansion along multiple axes, accommodating demographic growth while maintaining uninterrupted visual and spatial orientation toward the mihrab. In subsequent periods, particularly under Seljuk and Ottoman patronage, mosque design underwent significant formal innovation through the introduction of axial emphasis and centralized schemes. The adoption of the four-iwan plan and the development of the dome-covered prayer hall exemplify these shifts, reflecting an architectural ambition to integrate hierarchical spatial composition with a symbolic expression of unity and transcendence. Regional adaptations further underscore the typological flexibility of mosque planimetry. Iranian mosques emphasize axiality and monumental articulation of iwans, while Ottoman architecture privileges centralized, domed configurations, drawing upon Byzantine precedents to achieve spatial integration and visual coherence. The incorporation of ancillary spaces—such as open courtyards, ablution facilities, and educational complexes (madrasas)—illustrates a holistic architectural synthesis that negotiates ritual imperatives with social and pedagogical functions. Thus, the historical evolution of mosque planimetry exemplifies a dynamic architectural discourse that mediates between liturgical constraints, aesthetic aspirations, and contextual determinants. The resultant typology is both pragmatically responsive and symbolically resonant, establishing the mosque as a spatial and cultural paradigm within the Islamic built environment. The mosque form seen today has emerged over time due to religious needs and cultural habits. Although it seems to have preserved its function and form since its existence, the typology of mosques has also changed. The domed and square plan structure tradition used in mosques in our society since the 14th century has played an important role in shaping the mosque typology [10] [11] Without any doubt the classical Ottoman era is the period during which the classical design principles of a mosque have been put through. Here is the typological evoluation of the mosque architecture in time line since the beginning up till to the classical era of Ottoman architecture.

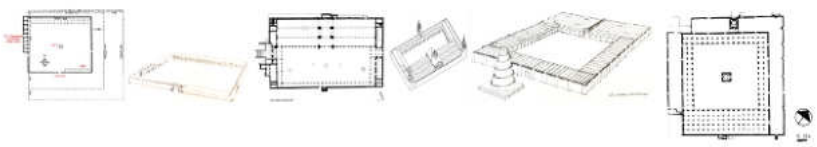

Fig.1. Plan typology of early islamic era mosques (**1.a** plan of Mescid-i Nebevi [12]; **1.b.** perspective of Mescid-i Nebevi [13]; **1.c.** The great Mosque of Damascus [14]; **1.d.** The Great Mosque of Samarra [13]; **1.e.** Tolunoğlu Ahmed Mosque [15]).

In the early examples of Islamic religious architecture, mosque planimetry reveals a clear formal and spatial response to the fundamental liturgical requirement of orientation toward the qibla—the direction of the Kaaba in Mecca. This directional imperative significantly influenced the spatial organization of the earliest mosques, which were typically articulated as longitudinal prayer halls

aligned with the mihrab wall located along the longest façade of the building. The mihrab, a recessed niche in the qibla wall, not only serves as a directional marker but also operates as a focal point for both spatial hierarchy and devotional alignment. In these early longitudinal plans, such as those evident in the Prophet's Mosque in Medina in its primitive form, the linearity of the prayer space facilitated the formation of parallel rows of worshippers facing the mihrab, thus enhancing communal cohesion during ritual prayer. Over time, as mosque architecture evolved in scale, function, and complexity, additional architectural elements were integrated into the basic typology. Among these, the most prominent addition was the courtyard, typically situated on the side opposite the mihrab wall, serving as both a transitional zone and a spatial buffer between the profane exterior and the sacred prayer hall. These open-air courtyards, or sahn, were often surrounded by porticoed galleries or colonnades, and in some regions, they were flanked by barracks-like service units or ancillary rooms, which supported the mosque's educational, administrative, and social functions. The inclusion of such forecourts introduced a degree of spatial layering and processional experience, emphasizing ritual progression from entrance to prayer space and reflecting broader cultural, climatic, and regional influences on mosque design. Thus, the evolution from a simple longitudinal plan to more complex, articulated spatial arrangements illustrates both the adaptability and the symbolic continuity of mosque architecture across Islamic history.

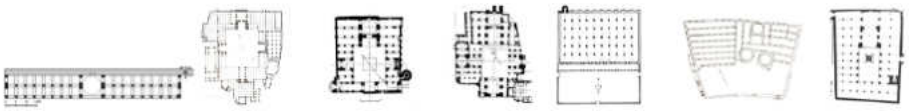

Fig.2. Plan typology of Turk-islam mosques (**2.a** The Great Leşker-i Bazaar Mosque **2.b**.Isfahan Mescid-i Cuma mosque **2.c**.Zevarre Mosque **2.d.**Ardistan Mosque **2.e**. Sivas Ulu Cami **2.f.** Konya Aleaddin Mosque **2.g.** The Great Mosque of Malatya [16])

Beginning with early examples such as the Great Mosque of Lashkari Bazar in present-day Afghanistan and extending to later developments such as the Great Mosque of Malatya, the architectural evolution of Turkic-Islamic mosque typologies—particularly those constructed under the Anatolian Beyliks and the Seljuk Empire—reveals a sustained engagement with and transformation of the longitudinal prayer hall plan. These mosques, which initially reflected a relatively simple and rectilinear spatial arrangement aligned along the qibla axis, gradually evolved into more complex spatial configurations through the incremental addition of structural and functional units, including side aisles, porticoes, and courtyards. This process of accretive growth was not merely an expansion of capacity but also a reflection of changing liturgical, climatic, and cultural conditions. A defining feature of these structures is the pinched wooden roof system, often supported by multiple rows of wooden columns, which became a signature element in many Anatolian mosque designs. This roofing technique, which utilized local timber and carpentry traditions, allowed for large, open interior spaces while maintaining structural lightness and flexibility. The use of wooden columns, arranged in tightly spaced rows, not only created a rhythmic internal order but also facilitated modular expansion over time. These hypostyle interiors—distinct from the monumental vaulted stone architecture of contemporaneous Persian or Arab mosques—exemplify the Anatolian synthesis of vernacular construction techniques with Islamic liturgical requirements. Collectively, the mosques of the Anatolian Beyliks and the Seljuks represent a regional interpretation of Islamic sacred architecture, marked by a horizontal emphasis, material pragmatism, and an evolving spatial complexity that bridges Central Asian influences with the emerging architectural identity of Anatolia.

Fig.3 Plan typology of early Ottoman era mosques (**3.a.**Orhan bey Mosque, **3.b.**Yeşil Mosque, **3.c.**The Great Mosque of Bursa, **3.d.**Old Mosque of Edirne, **3.e**.Üç Şerefeli Mosque [16])

In early Ottoman mosque architecture, multiple plan typologies are observed, reflecting a period of experimentation and regional adaptation. One of the principal types is the centralized single-space

mosque, which can be further subdivided into two variants: those covered with a pitched (hipped) roof and those crowned by a central dome. In addition to these, the "reversed T-plan" mosques—more commonly known as zawiya-type (tabhane) mosques—constitute another significant category, typically characterized by a domed central space flanked by side iwans or rooms intended for hospitality and retreat (tabhane). Another typology evident in the early period is the multi-columned, multi-domed mosque, in which the prayer hall is divided by rows of columns supporting multiple small domes. Toward the end of the early Ottoman period, a further architectural innovation emerged: the addition of a forecourt (avlu) placed in front of the main prayer hall. This courtyard, often containing a central şadırvan (ablution fountain) and surrounded on all four sides by domed arcades, introduced a sense of processional entry and spatial layering, as seen in the plan of the Üç Şerefeli Mosque in Edirne. These developments illustrate the transitional and dynamic nature of early Ottoman mosque design, wherein structural experimentation, typological diversity, and the integration of functional spaces collectively shaped the architectural language that would later be canonized in classical Ottoman mosque architecture.

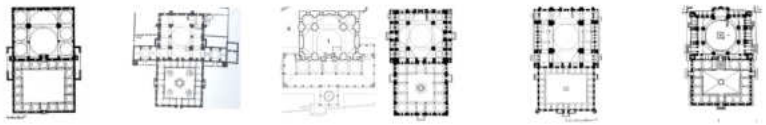

Fig.4. Plan Typology of Classical Ottoman Era Mosques (**4.a.**Old Fatih Mosque, **4.b**.II.Beyazid Mosque, **4.c.**Uskudar Mihrimah Mosque, **4.d.**Şehzade Mosque, **4.e.**Süleymaniye, **4.f.**Selimiye Mosque [16])

The Classical era of Ottoman architecture, is characterized by a refined and highly symbolic architectural language that reflects both imperial ambition and spiritual harmony, when is often anchored by the Fatih Mosque complex in Istanbul as its point of inception, culminates with the construction of the Sultanahmet Mosque (Blue Mosque), representing the stylistic and structural culmination of classical Ottoman design. At the heart of this architectural canon lies the centralized domed prayer hall, which became the definitive typological model of the Classical mosque. This model was fully developed and masterfully executed by Mimar Sinan. His major works, including the Süleymaniye Mosque in Istanbul and the Selimiye Mosque in Edirne, exemplify the architectural sophistication and symbolic clarity of the classical idiom. In these works, the main prayer hall is covered by a monumental central dome, creating a spatial and spiritual focal point that echoes the cosmic geometry found in Islamic metaphysics. In some examples, such as the Süleymaniye Mosque, the central dome is flanked by two half-domes along the longitudinal axis, with smaller domes on the sides helping to transition the mass down to the peripheral spaces. In more complex variants, such as the Sultanahmet Mosque, designed by Sedefkâr Mehmed Ağa, a pupil of Sinan, the central dome is supported by four semi-domes, located on each cardinal axis, with corner domes completing the square footprint, thus achieving a balanced and radial structural composition. A characteristic feature of the Classical Ottoman mosque is the presence of a forecourt (avlu) preceding the main prayer space. These courtyards are typically enclosed by arcaded porticoes covered with small domes and centered around a şadırvan (ablution fountain), which functions both ritually and compositionally. A clear longitudinal axis is observable in these designs, extending from the main entrance of the courtyard to the prayer hall's central door, and culminating in the mihrab on the qibla wall. This axial alignment orchestrates a ritual and spatial procession from the profane exterior to the sacred interior, reinforcing both the theological orientation of Islamic prayer and the imperial order promoted by Ottoman rule. According to architectural historians, the Old Fatih Mosque—constructed originally in the late 15th century—serves as the first prototype of this classical paradigm, integrating Byzantine influences with emerging Ottoman structural logic. Conversely, the Sultanahmet Mosque, completed in 1616, is widely regarded as the last major example of the Classical Ottoman style before the architectural transition into more Baroque and eclectic tendencies in the 18th century. Together, these monuments define a coherent architectural tradition, marked by its emphasis on centralized spatiality, structural clarity, axial symmetry, and metaphysical symbolism, all rooted in the Ottoman imperial worldview and Islamic religious cosmology. From the earliest prototypes of Islamic religious architecture—beginning with the hypostyle mosques of the early Islamic period—through successive regional developments across the Islamic world, a wide array of spatial configurations and formal interpretations emerged. However, it was during the apex of the Classical Ottoman

architectural period that a systematized and symbolically coherent mosque planimetry reached its most codified form. This architectural synthesis, which combined the central dome, axial symmetry, integrated courtyard, and hierarchically ordered spatial zones, was most fully realized in the works of Mimar Sinan. Sinan's canonical designs—such as the Süleymaniye Mosque in Istanbul and the Selimiye Mosque in Edirne—not only integrated structural innovation with spiritual intent but also established a schematic and typological template that would come to define mosque architecture across Ottoman territories and influence Islamic architecture well beyond. Scholars widely acknowledge that the classical mosque typology, as stabilized by Sinan, synthesized centuries of regional experimentation into a spatial language of unity, transcendence, and imperial symbolism. In this sense, the classical Ottoman mosque became not merely a stylistic culmination but a normative paradigm within the broader narrative of Islamic architecture. The most mature and fully articulated development of mosque planimetry in Islamic architecture—both in terms of spatial organization and structural system—was achieved during the Classical Ottoman architectural period, particularly under the influence of Mimar Sinan. This era represents the culmination of a long historical trajectory in which the spatial logic of the mosque was systematically refined and symbolically enriched. Following this period, mosque architecture began to exhibit increasing diversity in its planning approaches, shaped by changing historical conditions, advancements in construction techniques and technologies, and evolving stylistic orientations that reflect the intellectual and cultural milieu of subsequent eras. Among the examples of traditional architecture made from local materials that fall outside this generally accepted typological development, perhaps the most interesting ones are those made of adobe.

3 HISTORIC EXAMPLES OF ADOBE MOSQUES

Among the diverse materials employed in Islamic religious architecture, adobe stands out as one of the earliest and most regionally embedded construction techniques. Rooted in ancient building traditions along with vernecular examples that predate Islam, adobe material based mosque architecture represents a unique synthesis of spiritual function and environmental adaptation. The use of adobe as a primary material embodies not only ecological and climatic responsiveness, but also carries symbolic meaning within the Islamic worldview, which emphasizes humility, transience, and the human connection to the natural world on mosques. The earliest known example of an adobe mosque is often considered to be the Great Mosque of Djenné in present-day Mali, originally constructed in the 13th century and rebuilt in 1907 under French colonial supervision using traditional Sudano-Sahelian methods [17]. Although not the very first mosque built in earth, Djenné represents the culmination of a long-standing vernacular tradition in West Africa, where Islamic worship structures have been integrated with indigenous architectural languages. In terms of historical continuity, West Africa—particularly Mali, Niger, and Burkina Faso—hosts the richest concentration of earthen mosques globally. Beyond the Sudano-Sahelian region, earthen mosque architecture also flourished in parts of the Arabian Peninsula, Iran, Central Asia, and South Asia, particularly in rural or arid zones where wood and stone were scarce but earth was abundant. The Masjid al-Qiblatayn in the Yemeni town of Zabid, the Great Mosque of Agadez in Niger, and numerous village mosques in Iranian and Afghan oases are significant examples that demonstrate the adaptability and spiritual resonance of adobe construction in Islamic contexts [18]. These structures were often constructed through communal labor, using locally available materials shaped into sun-dried bricks or compacted as rammed earth. Their architecture is characterized by thick walls, minimal openings, and soft organic forms that provide natural insulation and thermal comfort. More than stylistic expressions, these forms reflect climatic intelligence and collective memory, linking architectural practice with seasonal rhythms, rituals, and modes of inhabitation deeply rooted in place. Perhaps most importantly, earthen mosques exemplify a theology of simplicity and environmental stewardship, aligning with Qur'anic values that emphasize modesty and sustainability. Their enduring presence—despite fragility—reveals not only a continuity of tradition, but also a resilience of sacred space that transcends monumentalism. As Islamic societies seek contemporary expressions of identity and sustainability, the legacy of earthen mosques offers profound lessons in material ethics, cultural continuity, and spiritual embodiment. The most significant examples of traditional mosques construted with adobe material, reflecting strong local

and vernecular characteristics across the World, are as follows: 1.The Great mosque of Djenne; 2.The Djingareyber Mosque; 3.The Larabanga Mosque; 4.The Jawatha Mosque; 5.The Grand mosque of Mopti.

Fig.6. The most important traditional historic examples of adobe mosque in the World [19].

These mosques share a vernacular grammar defined by earthen materiality, climatic adaptation, hypostyle spatial logic, sculptural massing, and communal maintenance. Their enduring significance lies not only in iconic form, but in the ethical and ecological intelligence of a building culture where matter, climate, ritual, and society are inseparably entwined. They share a robust common core—materially, climatically, and liturgically—so they are more similar than different. At the same time, each mosque expresses local craft, scale, and urban context in distinctive ways. Think of them as variations within a single Sudano-Sahelian vernacular rather than unrelated types. These mosques are not "totally different"; they are regional variants of a coherent Sudano-Sahelian mosque tradition. They share: earthen construction and toron; climate-responsive envelopes; hypostyle prayer halls oriented to qibla; sculptural buttressing/minarets; and community-based maintenance cycles. Their differences—in scale, façade composition, material hybrids, site hydrology, and conservation history—reflect local ecology, craft lineages, and urban roles. In scholarly terms, they constitute a type-cluster: a stable architectural grammar with context-specific dialects.

4 DESIGN PROCESS: Creating a Modern Adobe Mosque

The Dome of Heaven Mosque Project presents a contemporary reinterpretation of Islamic sacred architecture through the innovative use of adobe materiality, contextual responsiveness, and spatial symbolism. Situated in a newly developing area of Istanbul, the project is conceived as an architectural strategy that synthesizes traditional earthen construction methods with modern design sensibilities, offering a reflective alternative to conventional mosque typologies. Drawing upon the ecological, tactile, and symbolic capacities of earth as a building material, the design engages deeply with notions of origin, humility, sustainability, and spiritual return—concepts inherently embedded in both Islamic cosmology and vernacular architectural practices. By integrating adobe within a contemporary architectural vocabulary, the project proposes a mosque that is environmentally grounded, socially inclusive, and spiritually resonant, while simultaneously challenging the dominant paradigms of monumental mosque construction through a language of modesty, tactility, and processual form. In doing so, it contributes to a growing discourse on material ethics, phenomenological space, and the revival of earthen architecture in the 21st century, particularly in the context of Islamic built environments. According to the mosque's principal architect Ertürk, "The idea of using adobe was not only a material decision but an ethical and spiritual one. I was drawn to the earth as a reminder of where we come from and where we return to. The softness and fragility of the material resonated with our approach to space: a space that embraces, not imposes" [20]. Thus the project is envisioned as a contemporary local mosque situated within a newly developing urban area on the periphery of Istanbul. Positioned on a rectangular plot characterized by a natural slope extending along the northeast–southwest axis, the site offers a unique opportunity to integrate architecture and landscape in a manner that resonates with both ecological sensitivity and cultural continuity. The project aspires not only to create a sacred space for worship but also to redefine the mosque as an inclusive urban landmark, fostering community engagement and reinforcing the dialogue between architecture, spirituality, and nature. "At the very beginning," Ertürk reflects, "we didn't want to 'place' the mosque onto the site—we wanted it to grow from the terrain. The slope became not a challenge, but a gift. It allowed us to imagine the mosque as a slow emergence, revealed step by step" [20]. At the heart of the design philosophy is the intention to dissolve the boundaries between the built form and its surrounding context, transforming the mosque into a dynamic element of public life. Rather than positioning the mosque as an isolated object, the design strategy involves merging the structure with the adjacent open land, converting the frontage into a public park that

extends seamlessly towards the sea. This intervention ensures that the mosque functions not only as a religious edifice but as a social condenser, accommodating diverse cultural and communal activities while preserving its spiritual essence. The natural slope of the terrain is employed as a generative design parameter, creating a gradual revelation of the mosque's architectural form. Visitors approach the structure through a sequence of terraces and steps that rise gently from the urban fabric, forming an amphitheatrical park overlooking the sea. This graded landscape serves multiple purposes: it articulates a ceremonial approach, frames panoramic views, and creates contemplative zones that allow individuals to experience a spatial and spiritual transition from the profane world to the sanctified realm of worship. In this way, the mosque establishes a dialogical relationship with the public domain, positioning itself as a tranquil yet prominent anchor within the city's evolving topography. The landscape design introduces a green spine aligned with the site's sloping topography, acting as an organizing element that orchestrates social and cultural interactions. This spine originates at the main prayer hall and unfolds along a linear progression of programmatic elements, including ablution facilities, reflective water pools, shaded gardens for contemplation, and pedestrian pathways interwoven with clusters of trees. These landscape interventions are not merely ornamental; rather, they symbolize a metaphysical journey, guiding users through a spatial narrative that oscillates between openness and enclosure, solidity and permeability. Significantly, the linear traces of the green spine extend the qibla axis into the landscape, reinforcing the mosque's orientation toward the Kaaba while allowing for subtle divergences that metaphorically reflect the cyclical nature of existence. This interpretation of the cycle as an architectural motif underscores the project's conceptual ambition to root the experience of sacred space within the rhythms of nature and the cosmos. "We were very much inspired by the idea of direction and return," Ertürk explains. "The qibla is not just an axis; it's a reminder of alignment—with faith, with the cosmos, and with oneself" [20]. The architectural language of the Mosque negotiates between tradition and innovation, embracing a culturally familiar typology while offering a reinterpretation suited to contemporary sensibilities. Traditional mosque elements—such as the domed prayer hall and its axial alignment—are retained to avoid alienation from the collective memory of Islamic architecture. However, these are reinterpreted through a minimalist vocabulary that dispenses with ornamental excess in favor of expressive materiality and structural clarity. The design eschews rigid formalism, opting instead for a dynamic massing strategy articulated by two interlocking volumetric entities organized around a central core. This dual configuration embodies the philosophical concepts of unity and plurality, inherent in the very etymology of the term 'mosque'. These spiraling forms, enveloping and converging, symbolize embrace and return to the origin, a recurring theme in Sufi cosmology and Islamic metaphysics. Thus, the project transcends typological convention to express a poetics of convergence—between earth and sky, matter and meaning, individuality and collectivity. "In the core of the building," Ertürk notes, "we placed what we called the 'spiritual fulcrum.' The entire mass moves around this point in a spiral logic, echoing both cosmic geometry and the human act of turning inward" [20]. Central to the project's conceptual and aesthetic identity is the exclusive use of earth-based materials, selected for their ontological resonance, environmental performance, and sensory qualities. The choice of rammed earth blocks situates the design within a discourse of sustainability and vernacular revival, while simultaneously evoking the primordial connection between humanity and soil: a reminder of the Qur'anic assertion that humans were created from clay. These materials are celebrated in their raw, unadorned state, allowing the passage of time and climatic conditions to inscribe their patina, thus reinforcing the temporal dimension of sacred architecture. Far from being a mere technical solution, materiality in this project operates as a hermeneutic device, mediating between the physical and the metaphysical.

Fig.7. The Dome of Heaven Design Project [22]

The tactile textures, chromatic warmth, and thermal mass of earth contribute to an atmosphere of serenity, while embodying the cyclical processes of formation, erosion, and renewal—an allegory of

existence itself. If earth constitutes the substantive foundation of the design, light emerges as its transcendent principle. A circular skylight, strategically positioned above the domed prayer hall, dramatizes the descent of natural illumination, transforming the interior into a luminous sanctuary. This vertical aperture serves as both a cosmic eye and a metaphysical axis, channeling light as a manifestation of divine presence: "Allah is the Light of the heavens and the earth" [21]. As daylight modulates across temporal cycles, the interior atmosphere oscillates between radiant clarity and meditative dimness, reinforcing the experiential depth of the prayer ritual. "In the early sketches," she recalls, "we kept asking: how can we make light an active participant in prayer? Not as decor, but as guidance" [20] Light in this context is not merely a functional agent but a symbolic mediator, choreographing an interplay of ephemerality and permanence, materiality and transcendence. Through its calibrated integration, light becomes a didactic element, guiding the worshipper from sensory perception to spiritual illumination, from worldly distraction to contemplative focus. Beyond its typological and material configurations, the Mosque is conceived as a phenomenological environment that fosters inner transformation through spatial experience. The processional sequence, articulated by thresholds and transitional zones, induces a gradual withdrawal from the profane and a progressive immersion in the sacred. Every spatial gesture—whether the embracing curvature of the entry shell, the centripetal organization of the prayer hall, or the continuity of interior and exterior layers—is orchestrated to evoke a sense of spiritual intimacy without sacrificing communal inclusivity. In its absence of ornamentation, the design privileges essence over appearance, stripping the mosque of visual distraction to foreground the existential act of worship: the human encounter with the Divine. This ethos of modesty and restraint, coupled with the semantic depth of material and light, positions the project as a critical reflection on the ontology of sacred space in Islam—an architecture that aspires not to monumentalize faith but to mediate its experience through sensorial and symbolic intensities.

Fig.8. The variations of fired brick works (Slash Architects office Archive material).

Fig.8. The variations of rammed earth blocks (Slash Architects office Archive material).

The material palette of the Dome of Heaven Mosque Project is defined by a deliberate synthesis of rammed earth blocks, fired brickwork, and natural stone cladding, forming a layered architectural expression that is at once tectonically grounded and symbolically resonant. The choice of earth-based materials processed through modern fabrication techniques reflects both an ethical commitment to environmental responsibility and an aesthetic engagement with tactile authenticity.
"The project began with an idea rooted in humility," explains the lead architect Ertürk [20], and added that, "We knew we wanted to build with earth, but not in its raw form. We chose rammed earth blocks and paired them with baked elements to balance permanence with process, fragility with resilience." Adobe-based bricks were mechanically pressed in molds to achieve consistent geometry and higher density, then air-dried and partially stabilized for use in non-load-bearing architectural enclosures. In contrast, fired bricks were used strategically in areas requiring higher durability and moisture resistance, such as plinths, facade articulation, and dome cladding. This dual approach enables the structure to balance thermal insulation performance with weathering resistance, adapting to

Istanbul's seasonal fluctuations while preserving the expressive warmth of earthen architecture. Natural stone—locally sourced and finished with minimal processing—was employed in base elements and landscape interventions, anchoring the mosque in its topographic and geological context. The material transition between stone, rammed earth blocks, and fired brickworks is carefully calibrated to express a hierarchy of material permanence, evoking metaphysical ideas of earth, transformation, and transcendence.

The project's most visually prominent element, the woven dome, is clad in radially patterned baked bricks, composed in a spiraling texture that suggests the movement of light and prayer. Structurally, the dome rests on a subframe system hidden within the shell, ensuring seismic stability and distributing loads evenly through the inner wall system. The central oculus admits natural light vertically, intensifying the spiritual atmosphere below. "We imagined the dome not just as a structural cap," the architect notes, "but as a breathing skin—textured, tactile, open to light. It had to glow, not dominate" [20].

The technical implementation was shaped through collaboration between traditional brick artisans and digital fabrication consultants, ensuring that historical material knowledge could be translated into contemporary precision. Digital simulations were employed to test the solar performance, structural loading, and water runoff behavior of the dome system, while mock-ups guided decisions on mortar type, joinery, and finish durability.

In sum, the construction strategy of the Dome of Heaven Mosque does not merely rely on nostalgic evocations of earth architecture. Instead, it re-articulates ancient material wisdom through modern tools, creating an architectural system that is resilient, poetic, and critically situated in its time.

5 CONCLUSION

The Dome of Heaven Design Project represents an architectural endeavor that translates philosophical and spiritual principles into a tangible spatial experience. Rooted in the deliberate use of earth as the primary material, the design seeks to evoke an elemental connection, emphasizing the cyclical nature of existence and the inseparable bond between humanity and the natural world. By foregrounding the symbolism of earth, the project articulates a profound reminder of human origin and mortality, while simultaneously suggesting regeneration and transcendence. The design framework is underpinned by the concept of duality—manifested through contrasting forms, textures, and colors—that reflects the inherent dichotomies of existence such as sacred and profane, light and shadow, permanence and impermanence. These oppositions are not presented as rigid binaries but as dynamic interactions, fostering a spatial dialogue that invites contemplation and self-reflection. Through its formal language, materiality, and chromatic composition, the mosque transcends mere functionality, positioning itself as an experiential landscape of meaning. Beyond its physical presence, the project aspires to cultivate a heightened sense of spiritual and individual awareness. The architectural journey, structured through thresholds, transitional spaces, and rhythmic progressions, encourages an inward movement toward introspection. This spatial choreography enables worshippers and visitors alike to rediscover their ontological ties with the cosmos, to acknowledge the temporality of existence, and to engage with an environment that mediates between material reality and metaphysical aspiration. Ultimately, the Mosque is envisioned not solely as a locus for ritual performance but as an interpretive medium through which the sacred can be approached experientially rather than doctrinally. It provides a contextual platform where architecture becomes an instrument for remembering origins, reinterpreting traditions, and reestablishing the primordial dialogue between humanity, nature, and the divine. In doing so, the project exemplifies how contemporary mosque design can transcend typological conventions, embracing a holistic paradigm that harmonizes spiritual symbolism, cultural memory, and environmental ethics. Informed by this historical continuum of Islamic architectural evolution—from the earliest spatial typologies to the codified classicism of the Ottoman tradition—Ertürk's decision to conceive a contemporary mosque using adobe material constitutes a deliberate and critical act of architectural re-rooting, one that reclaims earth as both matter and metaphor in the quest to redefine sacred space for the present. Grounded in the ethical imperative of sustainability in the 21st-century architectural discourse—and in profound recognition of the Qur'anic reminder that "from the earth We created you, and to it We shall return"—the Dome of Heaven Mosque Project was conceived as a contemporary act of architectural responsibility, seeking to redefine the mosque not only as a sacred space but as a material and symbolic reconciliation with nature in an era of ecological depletion.

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Designing with Nature: Sustainable and Eco-Resilient Troglodyte Architecture in Tataouine

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ABSTRACT

The horizontal troglodytic houses of southern Tunisia, particularly the ksour of Tataouine, are dwellings that have evolved for economic and social reasons. Their design and architecture are economical and embody the concept of regenerative, resilient housing. These structures have a typical rhythm; they emphasize construction based on local and natural materials and are engraved in the curves of the earth and the high hills, symbolizing a deep sense of belonging to nature. They testify to the harmonious relationship between humans and their environment, providing shelter from climatic challenges while celebrating the authenticity of the local architectural heritage.

This research re-contextualizes the architecture of Ksour to reveal, through this tangible and intangible heritage, a new compositional architectural dynamic that exhibits longevity by adapting to climatic changes and connecting more closely to the land. The structural and modular analysis of troglodytic architecture, similar to parametric compositions, will be developed epistemologically for a historical and theoretical interpretation of the site, questioning and highlighting its viability. Furthermore, parametric modeling is presented to study the rhythmicity and distinctiveness of the forms and their connection with natural and territorial aspects.

This approach speculates on future building modes and scenarios while enhancing the architectural heritage of the Ksour. By revealing their relationship with nature and diagnosing their eco-resilience, this research aims to underscore the relevance of the Ksour in the contemporary context. By integrating these elements, we can gain a deeper understanding of how traditional structures can inspire sustainable architectural practices, highlighting the importance of preserving and enhancing this heritage in the face of current environmental challenges. In this way, the study of the troglodytic houses of Tataouine offers a reflection on local architecture and a perspective on the possibilities of adaptation and resilience.

Keywords: Sustainable, Parametric Design, Heritage, Resilience, Troglodytic architecture

1 INTRODUCTION

To frame this research appropriately, it is essential to consider the summary provided by Bonnet, E., Landivar, D., et al. (2019) regarding the role of design. They emphasized that design cannot be permanently separated from its relationship with the Earth, whether in terms of climate, oceanography, geomorphology, or, more broadly, cosmology [3]. This point of view reflects the concerns of designers, architects, and engineers regarding a contemporary issue: the habitability of our world. The Anthropocene demands this kind of radical synchronization with the state of ecological systems being created or eradicated from all fields of project science [3]. The same logic of synchronization has been applied to the subject of heritage in a valorization context, referring to studies on conservation and protection. All these contexts relate to participatory investments that give rise to solidarity projects and public policies concerning a shared heritage. These efforts must

now recognize heritage not only as a traditional reference point, but also as a connection to nature and its ecological and sustainable construction elements. This is an invitation to see beyond the materiality of the Earth and to adopt a new approach to solid and viable construction, which is now recognized as a connection with nature. In this sense, many theoretical methods and design strategies of biophilic design have been developed to conceptualise and explain the integration of "nature" into architecture [17].

This research will not focus on the manufactured integration of nature, but rather on a new architectural design that coexists with nature. This study explores the characteristics of typical architecture that has been established over decades in a specific natural context and "natural resources" [2]. Inspired by environmental elements, this architecture creates spaces that are harmonious and sustainable. Nature itself has set the parameters for this architecture, defining its essential functionalities and shaping the forms and structures that meet the environment's specific needs. The formal properties of this construction include an arrangement of volumes, proportions, and lines that integrate seamlessly into the landscape. Material properties, such as the use of local and sustainable materials, also contribute to the built space's aesthetics and functionality. These elements promote a deep connection with the surrounding landscape, creating spaces that meet human needs while respecting the local ecosystem.

From a denotative point of view, this research aims to identify the architectural features characteristic of troglodytic dwellings in southern Tunisia. These dwellings are carved into the earth and rise horizontally, forming an architectural heritage. This architecture blends in with the landscape and climate while offering an intriguing generative composition. The proposed method is divided into five sections as demonstrated in Fig. 1.

2 MATERIALS AND METHODS

This scientific exploration is based on an action research project that aims to interpret the relationship between troglodytic architecture and sustainable use. The project focuses on the ksour typology in southern Tunisia and the application of parametric design in architectural practice. A case study of troglodytic architecture enables us to analyse the design process and reveal how these spaces were constructed in response to their immediate natural environment.

From this perspective, we present a theoretical framework that highlights the architectural properties of troglodytic dwellings, as well as their formal and functional aspects. These are reconfigured according to new definitions of parametric rhythm. Thirdly, we will illustrate the regeneration of forms specific to nature and traditional architectural construction through a case study of the Mghabla ksar in Tataouine. The proposed modelling will be interpreted to discuss how we can design a sustainable, viable, and environmentally friendly architectural future.

Figure 1 presents the suggested process for addressing the issue of designing in harmony with nature. How can we theoretically explain the appropriation of nature in architectural design? Following these definitions, we will reveal a nomenclature specific to the uses of materials and habitat-specific scenarios of ksour. Next, we will address modularity and rhythm in these types of constructions. This will lead us to propose a simulation based on programs and parameters that consider urban and socio-environmental factors. This process will be presented according to the duality of conceptual and constructive contexts.

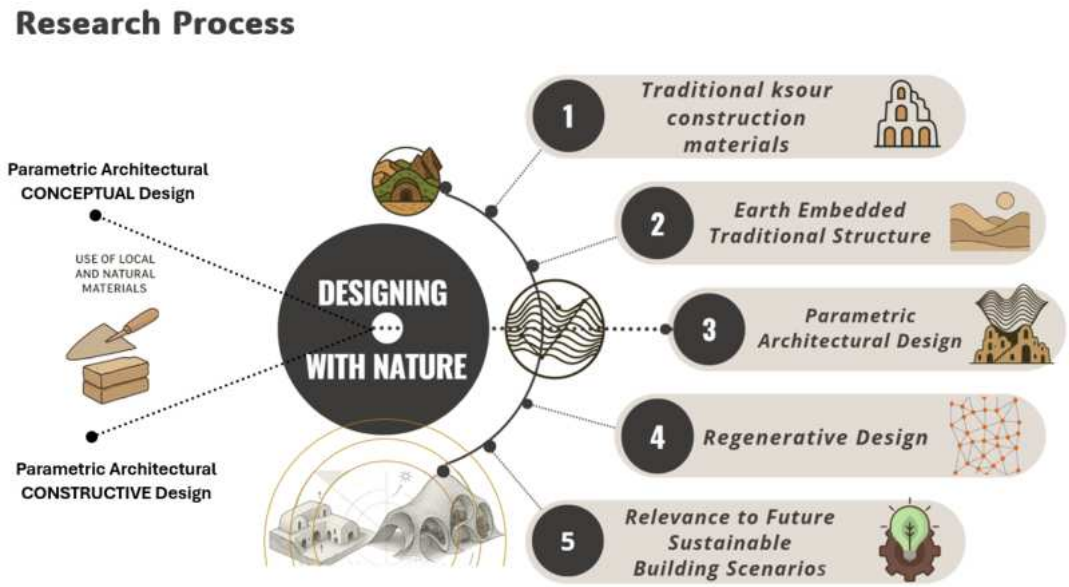


Figure 1. This research project highlights the fundamentals of the architectural construction of ksours, defining their natural properties. The analysis will focus on their conceptual and constructive aspects, incorporating parametric design and a regenerative form approach. (Developed by Authors).

3 DESIGNING WITH NATURE: AN ANTHROPOCENTRIC APPROACH

In order to develop an epistemological design approach about nature, it is most effective to consider the views of contemporary sociologists and philosophers. This enables us to gain a better understanding of their ideas and criticisms regarding the interaction between humans and nature, particularly with a focus on habitat, shelter construction, and the fulfillment of human needs. In his book "The Unconstructable Earth: An Ecology of Separation", philosopher Frédéric Neyrat (2019) highlights this ambivalence by criticising the methods, techniques, and applications of an Earth that could be remade and controlled thanks to absolute engineering prowess. We will refer to this voracious discourse, which treats the Earth as willing prey for total conquest, as 'geo-constructivism'. Geo-constructivism combines different philosophical, economic, and scientific lines of thought and asserts itself at the crossroads of several discourses, including those of engineers and architects who wish to transform the Earth into a controllable machine [10]. In contradistinction to geo-constructivism, design opts for anthropocentric solutions. Although this approach is considered ideological, it is based on both scientific findings and an imaginary world that could be termed a metaphorical "grand narrative" or "meta-narrative" [11].

Every architectural restoration or reconstruction project is firmly grounded in the history of the building or site. This recognition of tradition is based on imagination and narration, to create new ways of living and categorize them. Otherwise, the sense of identity risks dissolving into cold modernity, reducing itself to mere materiality and aesthetics rather than a genuine sense of belonging. From this perspective, contemporary design incorporates patterns that reflect the relationship between humans and nature. Neyrat explained the concept of designing in harmony with nature using the term "Terraforming": "Reconstructing the Earth, recreating life" [12]. Designing with nature, therefore, involves transferring imagination to support this anthropocentric approach. This is part of a concept that puts Earth and life sciences at the center of new research. The goal is to design an organized world born of development and hypergrowth while deconstructing [3].

3.1 Troglodytic Dwellings: An Exploration of Architectural Fantasy

The word "troglodyte" comes from ancient Greek and Latin and means "one who eats or lives in holes." It is composed of "trog," meaning "to eat," and "lodyte," referring to a "hole" or "hollow." The term is also used to describe a person who lives in a cave or rock formations. Troglodyte architecture is characterized by a style of stone construction that utilizes specific natural geological formations. This terminological explanation adopts a perspective that assigns an explanatory function to the ksour while also attributing a narrative dimension to them. Anne-Marie Frérot has emphasized the narrative aspect of the ksour and their architectural singularity, highlighting that the ksour society has endured over time due to places of immortal value, significant landmarks, and crucial sites of memory that serve as collective and individual reference points [5]. These fortified earthen villages are shown in Fig. 2, bear witness to a unique architecture and rich history. They are not only dwellings but also symbols of the culture and identity of their inhabitants. Ksour architecture is not only functional; it is also a form of art that invites imagination and reinterpretation through design. The design establishes a link with the earth through the materiality of the construction, a link with the living through form, and a connection with time and the movement of nature through rhythm.

Figure 2. These dwellings were designed to address local housing needs. They serve as a connection between humans and nature, as well as between architecture and the natural environment. This fully justifies their inclusion in the world's cultural and historical heritage. (Extracted from the book Arena, M., et al, 2007) [1]

This architecture represents a type of habitat adapted to a geographical environment conducive to human life, integrating various spaces. It meets the biological, physical, and environmental conditions necessary for existence. The Roche Desert region appears as a large open-air museum. Each ksar stands on the ground, either ignored by humans or restored and transformed into a welcoming place [1].

This research proposes an architectural reinterpretation that draws upon the imagery shaped by the desert while offering a renewed reading, both dichotomous and simulated, through a parametric approach. Revisiting the ksour's architecture, which is based on modularity, periodicity, and rhythmicity principles, this study aims to revalue an architecture conceived in close harmony with nature. A ksar located in Tataouine, Tunisia, will be used to conduct parametric simulations that illustrate this approach. Having established the conceptual foundations of the research, the study now enters its constructive exploratory phase, as shown in Fig. 1 and as explained by Gaha Ines (2023), who pointed out that starting from an immaterial conceptual vision and interoperating with constructive properties, the city takes shape and form, not only according to its environment and atmosphere but also according to a communal imaginary and social DNA. The interoperability of model generation makes it possible to develop a coexistence between architectural experience and perception [5].

3.2 Modularity and Eco-Resilience in Troglodytic Design

Before analyzing the urban and modular layout of ksour, it is important to recognize that the configuration of the landscape and construction time are fundamental constraints that influence the morphology of ksour. The oldest ksour, which were built on hilly plateaus as configured through Fig. 3, follow the contours of the land, giving them fluid, organic shapes. The ksour's shapes are based on the requirements of the surrounding terrain, such as hills, slopes, and naturally defined surfaces [1]. Their composition does not result from mathematical principles or formal intentions, but rather from a strict adherence to the repetition of shapes and elements, as well as the structural limitations imposed by the building materials, as displayed in [Table 1]. The structure is made of uncut or roughly carved stone combined with cement mortar and finished with a coating of raw clay obtained from natural earth. This plaster is smoothed using wooden tools, palm leaves, or simply by hand. These artisanal techniques produce textures of varying roughness that create subtle plays of light and shadow on the surface. Figure 3 presents an example of a ksar located in Tataouine named Mghabla. The distinctive shape of the plateau on which Mghabla is built is the first argument that will support the later discussion of the parametric aspects of ksar architectural composition.

Table 1. An overview of traditional building materials used in troglodytic architecture: physical properties, functional characteristics, and ecological benefits. this table presents a comparative analysis of six locally sourced materials commonly used in troglodytic architecture. Each material is evaluated based on its physical properties, functional role in construction, and ecological advantages. The selection showcases the sustainable and context-sensitive nature of vernacular building practices in such environments.

Material	*Physical Properties*	*Functional Characteristics*	*Ecological Benefits*
RAW EARTH (PISÉ)	Thick, compacted earth blocks; high thermal mass	Excellent insulation, easy to shape, locally available	Low carbon footprint, biodegradable, recyclable
LOCAL STONE	Dense, durable, high compressive strength	Used for foundations and load-bearing walls	Locally sourced, long lifespan, minimal processing
GYPSUM	Lightweight, soft mineral, good insulator	Used for internal walls and plastering	Abundant, recyclable, low-energy processing
CLAYEY SAND	Stable when compacted, cohesive	Excavated for troglodytic dwellings, good thermal regulation	Natural, no processing required, site-integrated
PALM WOOD	Lightweight, fibrous, heat-resistant	Used for beams, ceilings, and doors	Renewable, locally sourced, biodegradable
LIME	White, alkaline, breathable	Used in plasters and coatings, moisture-resistant	Natural, antimicrobial, reduces humidity

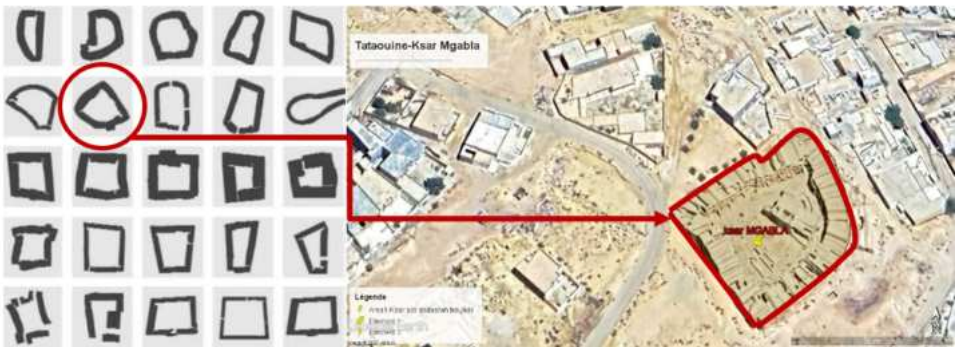


Figure 3. Ksar Mghabla is a particularly notable example, as it illustrates this adaptation through its triangular reception layout, which is softened by an arc that redefines the branching architecture of

the dwellings. This curved articulation responds to the topography and introduces spatial fluidity, enhancing circulation and visual coherence within the ksar (Developed by Authors).

Table 1 showcases the lasting significance and ecological sustainability of traditional building materials employed in troglodytic architecture. Materials such as raw earth (pisé), local stone, clayey sand, and palm wood have remarkable physical and functional properties and are deeply aligned with environmental sustainability. Their low carbon footprint, local availability, and biodegradability reflect a construction logic grounded in ecological balance and cultural continuity.
For centuries, these materials have supported resilient living, preserving values such as thermal comfort, resource efficiency, and community-based construction. Today, parametric design tools allow us to reinterpret these ancestral practices through new conceptual frameworks. Parametric analysis enables the simulation of material behavior, the optimization of form, and the adaptation to environmental data, offering a new perspective on the modularity, rhythmicity, and spatial intelligence inherent in vernacular architecture. By combining tradition with innovation, we can reimagine these materials as active agents in shaping a regenerative architectural future, not as relics of the past.

The next part of our study presents several preliminary architectural modelisations for the Mghabla ksar, as illustrated in Fig. 3. The name Ksar Mghabla can be understood through several cultural, geographical, and spiritual lenses specific to southern Tunisia's vernacular architecture. Ksour are Berber constructions deeply rooted in local traditions, but they are not immune to the influence of Islam, particularly with regard to spatial organization and the orientation of structures. The term "Mghabla" may derive from the Arabic dialect words "maqbala" or "mouqabala," meaning "opposite" or "facing." In this context, it is plausible that the ksar was named as such because of its orientation toward the qibla, the sacred direction of Mecca.

4 PARAMETRIC DESIGN AND RHYTHMICITY: A MULTI-DIMENSIONALITY OF TROGLODYTIC ARCHITECTURE

The primary objective of this section is to elucidate the role of parametric design in uncovering the structural and rhythmic essence of ksour architecture, followed by a reinterpretation of this distinctive architectural cadence. Gaha Ines Sahtout (2023) clarifies what parametric design is by defining it as a design approach based on algorithmic rules that generate adaptable forms, often inspired by natural or contextual logic. It's a design that integrates new functionalities with the spatial geometry of objects. [5]

4.1 Troglodytic Rhythm and Parametric Design: A Morphological Analysis of Ksar Mghabla

Through our analysis of the architectural design of ksour, we observed a composition that was both typical and rigorously structured, as illustrated in Fig. 4. The traditional formal expression of these structures particularly caught our attention, as it combines solidity, functionality, and aesthetics. This led us to ask: How do these buildings, made from natural elements closely linked to the earth, manage to generate an interpretation that is simultaneously poetic, structural, functional, and eco-resilient? This design enhances usability by integrating the users into their immediate environment through their living space. In this sense, Ines Sahtout Gaha noted that: Design plays a critical role in mediating the relationship between space, objects, and users. Through its interdisciplinary nature, design can act as a catalyst for urban development within the framework of the smart city [14].

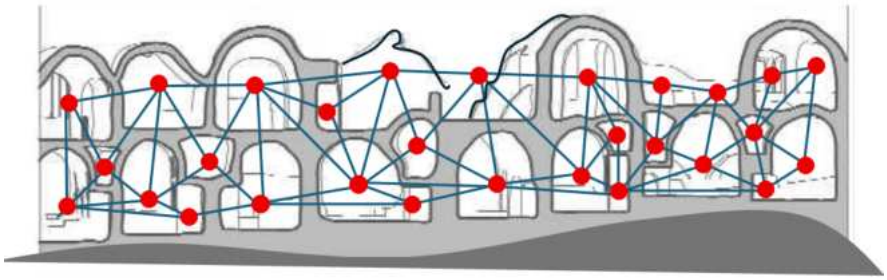
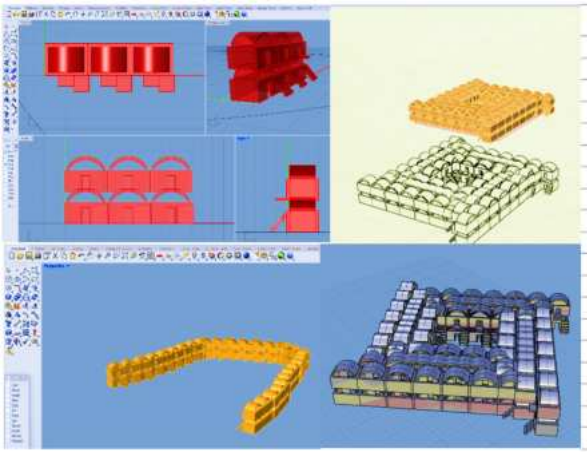


Figure 4. This elevation shows the exact placement of the openings of each ghorfa, which are structural elements of a ksar's composition. The repetitive and orderly arrangement of these openings creates an architectural rhythm that foreshadows the building's spatial organization. This conceptual design reveals the logic of spatial configuration, where formal rhythm becomes an architectural language that conveys meaning. (Developed by Authors).

The Kasar system has a powerful aesthetic appeal and is a dominant feature in the vast emptiness of the plain. It becomes both the stage and the backdrop of the natural composition. Though it appears to be a single structure from the outside, it was built in stages over time. The ghorfa is the basic unit and building block of the entire structure, Fig. 4. The architectural unity is the result of assembling these basic containers, which fit together in a series with infinite potential for development [1]. Ksour architecture is distinguished by its ability to shelter its users according to dual seasonal and architectural logics closely linked to the desert's extreme climate. This duality is evident in the alternation between interior and exterior spaces, protective shade and bright light, and preserved coolness and controlled heat. The harsh climate, particularly the intense summer heat, has played a decisive role in shaping these dwellings, which are designed to provide optimal thermal comfort while utilizing local resources. Thus, the ksar becomes a rhythmic structure, perceptible in its form and imbued with strong symbolic connotations. Born of natural materials and vernacular know-how, this architectural rhythm induces a reading that is poetic, functional, and eco-resilient, revealing constructive intelligence deeply rooted in the environment.



General Design Parameters	
Parameter	*Value (m)*
Cell Width	4.0
Cell Depth	5.0
Cell Wall Height	2.0
Vault Height	1.0
Roof Thickness	0.3
Wall Thickness	0.3
Number of Levels	2
Cells per Level	3
Platform Depth	1.0
Stair Height	0.35
Stair Depth	0.3
Stair Width	1.5
Number of Steps	5
Stair Offset X	1.4
Stair Offset Y	1.0
Door Width	0.8
Door Height	1.5
Overlap	0.02

Figure 5. This figure illustrates a parametric model of the ghorfas in the Mghalba ksar, showcasing the spatial rhythm formed by the repetition of architectural units. This exploratory work is based on typical dimensions that were measured and translated into geometric parameters. (Developed by Authors).

Figure 5 shows a parametric simulation that illustrates the imagined architectural rhythm of a ksour based on the standard dimensions of a ghorfa. First, the shapes were modeled according to their actual configuration, respecting the proportions observed in the field. Next, we carried out

exploratory work using an algorithmic design program, such as Grasshopper. This made it possible to generate spatial rhythm based on defined architectural parameters, such as the width, depth, and height of the walls and vaults; the wall thickness; and the number of levels. Parametric architectural conceptual design is an approach to designing buildings that uses parametric modeling techniques to imagine and then draw 3D models and plans with adjustable parameters [6]. This enables architects and designers to imagine and make [8], to explore, and test different design options quickly and efficiently, based on specific design objectives and constraints.

This process of parametric translation allows us to dynamically visualize the impact of modular repetition on the perception of architectural rhythm. Thus, Fig. 6 highlights that the ksar's structure, though vernacular, obeys a rigorous geometric logic revealed by the simulation. This approach provides a morphological and conceptual interpretation of the ksar Mghabla architecture, demonstrating its potential for regularity, variation, and rhythmicity.

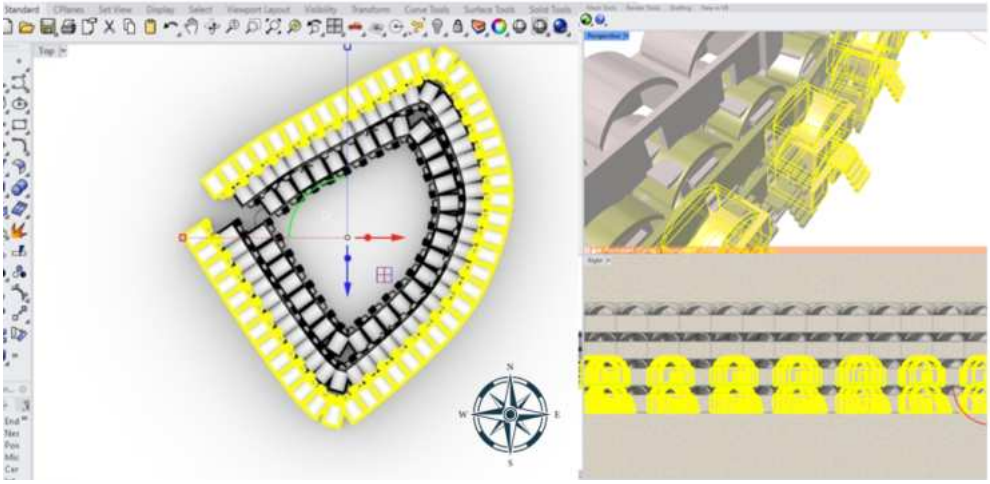


Figure 6. This figure illustrates the horizontal architectural rhythm of Ksar Mghalba, which is organized into a unified plan spread over three interconnected levels. Each level is structured according to the design of the ghorfas. The units are arranged in a chain-like pattern according to their depth, openings, and spatial articulation. (Developed by Authors).

The parametric modeling presented through Fig. 6 is based on standard dimensions measured on-site and translated into geometric parameters. The model also incorporates the site's topography, accounting for the ksar's location on a specific plateau, as shown in Fig. 3. This approach reveals the rhythmic logic underlying the building's organization, highlighting the modular repetition and formal variations characteristic of this troglodytic architecture.

4.2 Heritage-Informed Parametric Design: Sustainable Potentials of Ksar Mghabla

To explain the role of parametric design in reinterpreting the ksar in both conceptual and constructive terms, we refer to Robert Woodbury's analysis, which emphasizes that parametric design represents change [16]. We highlight the term "change" since it is defined in a computer modeling context; the character of a parametric design project is identified in terms of changes during its realization [5].

Table 2. This table compares three architectural approaches: troglodytic ksour, parametric design, and regenerative design across five dimensions: form, material, climate strategy, cultural significance, and objective.

Aspect	*Troglodytic Ksour*	*Parametric Design*	*Regenerative Design*
FORM	Earth-embedded, organic	Algorithmic, adaptable	Nature-integrated, restorative

MATERIAL	Local stone, earth	Simulated, optimized	Local, renewable, circular
CLIMATE STRATEGY	Passive thermal control	Data-driven optimization	Climate-positive, adaptive
CULTURAL LINK	Deeply rooted	Abstracted, reinterpreted	Community-driven, heritage-based
GOAL	Survival & harmony	Efficiency & flexibility	Renewal & resilience

In this exploratory and inventive approach to the relationship between architecture, Community-driven, heritage-based, and nature, a relationship that Ksar Mghabla embodies through its deep roots with the Earth, similarly, what we propose in [Table 2] is merely the evolution of construction logic from tradition, to algorithmic innovation, to contemporary regeneration strategies. The crucial role of parametric modeling as a design process in generating viable, sustainable, and versatile spaces for the cities of the future. Parametric architectural design is an innovative approach in the field of architecture that is intended to create buildings and public spaces using advanced digital tools. It is founded on the use of parameters that control all aspects of an architectural project, from geometry to environmental performance [6].

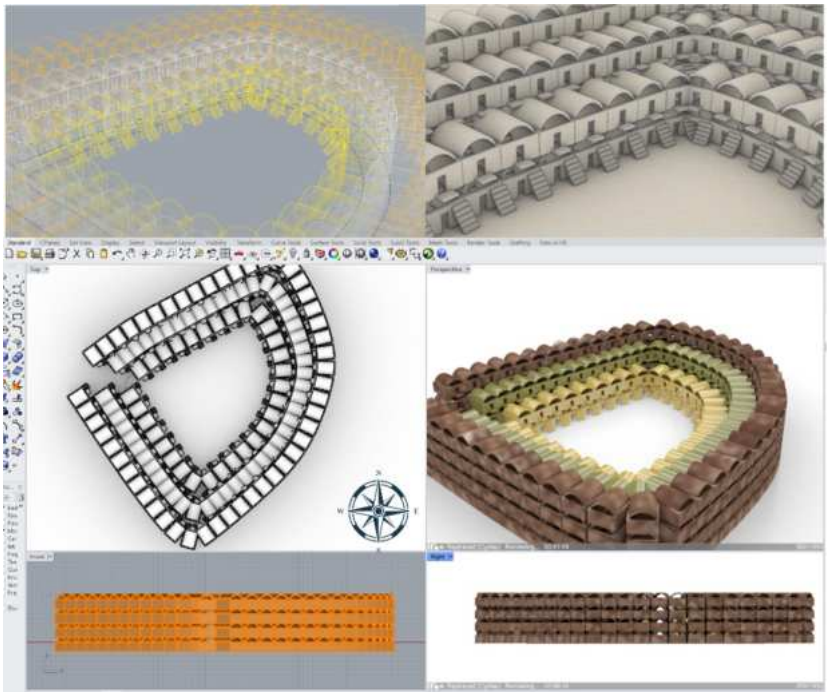


Figure 7. This modeling is part of an exploratory design approach based on the principle of "imagine and make" [7], in which architectural imagination is tested through digital fabrication. The model reveals the formal and structural potential of the ksar, which is translated into a rhythm generated from the geometric parameters of a typical ghorfa. (Developed by Authors).

While this simulation, Fig.7, provides a dynamic interpretation of the inhabited space, it does not accurately reproduce the rhythm depicted in Fig. 4's elevation. It departs from the elevation in Fig. 4 to highlight the spatial function and constructive logic of the ksar. In the conceptual process, imagination is a driving force of creation. However, in the constructive process, one aspect is missing: the model does not fully reveal the interplay of the ghorfa openings, which are often complex, irregular, and contextual.

Through this troglodytic aspect of Ksar Mghabla, we observe a singularity deeply rooted in territory and ancestral knowledge, conveying architectural and cultural messages that remain relevant today. As a critical and creative process, design reexamines the relationship between nature and culture. In

this sense, Neyrat challenges the myth of total fusion between humans and nature, a concept often promoted by dominant technological ideologies. He proposes a new philosophy of nature and the Earth, which he calls the ecology of separation. This philosophy recognizes what in nature cannot be constructed and affirms the Earth's inherent uniqueness. [10]. When this unique aspect of the Earth is adapted to new forms of architectural construction and reintegrated through contemporary design methods and processes, it paves the way for a creative practice focused on the future. Driven by the intention to improve users' world, this design aims to create "livable experiences" [15]. From this perspective, it is important to discuss the scope of contemporary resilient, sustainable, and viable architecture. Ibn Khaldoun raised this real challenge in his Muqaddima when he asserted that humans are products of their material, climatic, and social conditions [7]. We analyze this idea by emphasizing that human beings cannot be understood outside of a relational system in which nature and culture intertwine and coexist.

5 DISCUSSION, THE EARTH AS A VECTOR OF ARCHITECTURAL METAMORPHOSIS

This research highlights the relational dimension of the architectural composition of troglodytic and traditional dwellings by comparing it with the potential offered by contemporary parametric representation technologies. The study relies on the use of Grasshopper software in conjunction with Rhinoceros and various programming and 3D modeling environments. This approach enables the dynamic and adaptive modeling of vernacular structures while revealing a conceptual affinity with the logic of living organisms. Grasshopper extensions, such as Ladybug, Honeybee, and Galapagos, are not merely modules; they operate as specialized computational agents that integrate environmental, climatic, rhythmic, and evolutionary data. Their names, inspired by the natural world, reflect a desire to design sensitive, responsive architectural systems deeply rooted in ecosystemic thinking. Therefore, any architectural design should not only adapt to nature but also embrace its profound configurations, because when a system is unable to address its fundamental issues, it either deteriorates or disintegrates. Alternatively, it can create a meta-system capable of addressing these issues, undergoing a metamorphosis [9]. To metamorphose here means to understand the dictates of the Anthropocene: to decrease, decelerate, broaden the senses, and listen to the voiceless [4].

6 CONCLUSION AND CURRENT LIMITATIONS

Knowing how to read nature and recognizing the Earth's components as a source of original knowledge is becoming a necessity. If architects and designers do not integrate this knowledge into their practice to rebuild the city according to an identity that is both heritage-based and vibrant, and if users do not learn how to act in favor of preserving nature and its elements, then a rupture will occur. Designing with and by nature is no longer optional, but a practical requirement and contextual imperative. And we must never forget that, despite environmental limitations, architecture develops and differentiates itself as an instrument of social life. It is a historical product and a diachronic repository of a multitude of interrelated cultural units [1].

This research has revealed a structural aspect of Ksar Mghabla in Tataouine. The proposed models pave the way for other possible interpretations, especially when more advanced programs and algorithms are integrated. However, the absence of exact measurements and accurately reproduced elevations of the Mghabla ksar limits the precision of the models. This limitation highlights the necessity of maintaining an ongoing dialogue between digital abstraction and built reality, where parametric design through this set of simulations is positioned not as a tool for exhaustive reproduction, but as a means of interpretative exploration. Nevertheless, this study paves the way for further architectural and urban research by linking the intrinsic properties of nature with the imprint of the earth. This approach deepens our understanding and appreciation of this ancestral know-how. The city can only become resilient if it adopts solutions that work in harmony with nature, benefit

the Earth, and integrate the practices of its users while negotiating usage. Gaha Ines Sahtout underlines this and argues that the city is a physically and spatially complex entity, combining economic, social, cultural, and environmental aspects. For this reason, urban design is a disciplinary field that links architecture and spatial planning. It is also a meeting hub for designers, engineers, artists, architects, and garden planners, all working together to satisfy human needs and expectations [6]. To interpret nature and design built environments in harmony with it, we must mobilize our collective imagination, engage in debates about desirable outcomes, and explore alternative public policies. These approaches could lay the foundation for resilient, sustainable architecture. As Nicolas Nova points out, it's not just about imagining objects or technologies; it's about proposing visions of the world, ways of living, moving, producing, and consuming [13]. This approach invites us to transcend purely technical logic and reinvigorate the realms of the sensory, the living, and the territory.

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Syrian Earthen domed buildings as a Resilient Resource for a Sustainable Futures: Challenges and Opportunities

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ABSTRACT

On the steppes of Idlib and Aleppo in northern Syria, the domed houses made of adobe bricks have, for millennia, provided a habitat that is finely adapted to the environmental context, characterized by a scarcity of resources and an arid and hostile climate. The morphology and building technique of earthen domes offers significant advantages fin terms of environmental comfort: their oval shapes reduce minimize radiation, thus helping to moderate the indoor temperature; the earth material, due to its intrinsic properties, allows a great thermal inertia and the regulation of internal humidity. Despite their environmental and cultural value, these structures have been often marginalized and neglected, burdened by social stigmas and a lack of institutional recognition. The Syrian conflict has further exacerbated their decline, leading to widespread destruction of villages and the interruption of intergenerational transmission of traditional building knowledge. This paper presents a systematic analysis for the enhancement of the knowledge system concerning Syrian domed habitats, adopting an interdisciplinary approach. Further, it investigates the socio-cultural and technical barriers that hinder the contemporary use of these structures, drawing on findings from a participatory design workshop conducted with Syrian refugees in Jordan. This building culture, now almost completely in decline, also due to the devastating effects of the Syrian conflict, could be a model for sustainable and resilient post-war reconstruction. Reconstructing and disseminating the knowledge embedded in this vernacular building culture is therefore essential—not only for preserving cultural heritage, but also for enabling its transmission to future generations and its reintegration into contemporary design practice.

Keywords: Earthen vernacular Architecture, Syrian Domes, Resilient Reconstruction, Participatory Design, Transitional shelters.

1 INTRODUCTION

The steppes and uplands of northern and central Syria have long been inhabited by both nomadic and sedentary populations who developed adaptive strategies in response to arid conditions, scarce resources, and limited access to water [1]. Within this context, a distinctive vernacular architecture emerged: earthen dwellings with corbelled domes, built using local soil and minimal timber [2]. Corbelled dome buildings are common in the Mediterranean area, but they are usually built in stone and used as shelter for shepherds and farmers [3]. Syrian dome dwellings use local earth as their main construction material and are grouped together, shaping habitats that are highly adapted to environmental constraints [4] (fig.1).

Figure 1. Corbelled domed houses in the villages of Oum Aamous Seghir and Rasm Hamd in 2009.

This type of housing is the expression of a mobile and resilient culture which lies halfway between the settled and the nomadic, a culture of uncertainty that finds in its essence the potential capacity for flexibility, for adaptation from the sedentary to the nomadic in response to fluctuations in social and natural conditions. Unfortunately, even before the start of the conflict in Syria, the cultural, social and economic changes undergone by the planet, together with a progressive loss of technical knowledge regarding the building processes and the benefits of dome constructions, have determined a decay in the perception of this way of living and its social value, and the loss of local and 'tacit' technical knowledge: the final result has been the progressive aban-donment of these settlements or the replacement of buildings with constructions that use the technique of concrete, which is considered more reliable and a symbol of modernity [5].
It is from these considerations that the interest in the study of these buildings arises, in particular, what are their qualities and how do people today perceive them This paper reports on the findings of two projects conducted in different time periods; pre-conflict documentation of earthen domes in Syria and post-conflict study of attitudes and perceptions of proposed 'superadobe' shelters with Syrian refugees.
The main aims of this paper are: 1) to document the unique historical landscape of earthen dome villages in northern Syria, experimenting with an interdisciplinary approach to the analysis and enhancement of traditional knowledge system; 2) to bring to light the value of this architecture as an intense and permanent expression of a local system of knowledge; 3) to investigates the socio-cultural and technical barriers that hinder the contemporary use of these structures, drawing on findings from a participatory design workshop conducted with Syrian refugees in Jordan.

2 RESEARCH METHODOLOGY

2.1 Documentation methods

This research employs an interdisciplinary methodology to document and analyze the earthen domes of northern Syria, viewed as both tangible structures and expressions of intangible heritage. Combining architectural, technical, environmental, and ethnographic approaches, the study recognizes the inseparability of traditional knowledge and built form [6].
Fieldwork missions (2008–2009) generated a robust dataset through architectural surveys, direct observation, and interviews with residents and builders. These were complemented by geomatic tools—topographic surveys, photogrammetry, and laser scanning—which enabled accurate 2D and 3D modeling and spatial interpretation of the domed structures. Construction techniques were analyzed through on-site observations, material identification, and oral accounts.
Mechanical performance was assessed via field tests, FEM-based numerical simulations, and lab-scale models to investigate structural behavior and vulnerabilities. Archaeometric analysis of material samples provided data on composition, granulometry, plasticity, and degradation processes, informing an understanding of traditional mixtures and maintenance practices.
Ethnographic insights, drawn from interviews and literature, helped reconstruct the knowledge systems underpinning this architecture. The methodological framework (Fig. 2) illustrates how

multiple analytical domains converge to interpret the architectural, environmental, and socio-cultural dimensions of Syria's corbelled earthen domes.

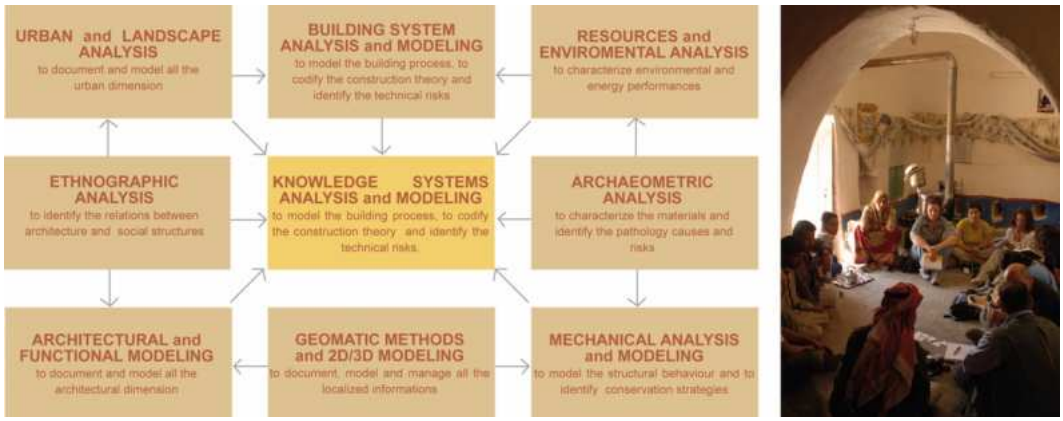

Figure 2. Conceptual scheme of methodology applied for the analysis and modelling of the local knowledge system. On the right: interview with the inhabitants during the fieldwork.

2.2 Participatory research

'Superadobe' constructions are similar in appearance and concept to traditional domed earthern structures and are indeed inspired by them. They were first popularised by Iranian architect Nader Khalili in 1992 [7] and adopted by UNHCR in 1995 as temporary shelters for Iraqi refugees in Baninajar Camp in Iran (Fig. 3). However, rather than build with mud bricks superadobe structures are made by filling long bags with earth taken from the site. These bags are then layered, compressed and reinforced with barbed wire, then plastered on the inside and outside. This concept has become very popular across the world and used in several disaster relief housing projects including Haiti and Pakistan. Whilst it's a different construction technique, created for displacement context where local expertise for building with earth may not be available; it shares its shape and primary construction material with the traditional domes.

Following the war in Syria in 2011, the Zaatari and Azraq refugee camps were established in Jordan and together hosted over 120,000 Syrian refugees. The refugees were housed in temporary shelters made mostly of metal sheets with little insulation and as such suffered from extreme temperatures and significant levels of thermal discomfort [7]. Therefore, we conducted participatory design workshops to understand whether superadobe can be used as an alternative, due to its superior thermal performance. The workshops were conducted with 80 refugees over several days in both Zaatari and Azraq camps. The workshops were organised in groups of 5 participants and equal gender representation was achieved. Physical models or computer representation and images were used as tools to communicate the design [7]

Figure 3: Left: Baninajar Refugee Camp in Iran, 1995; Right: Superadobe construction technique, (Photo credit: Calearth.org, 2017)

3 ENVİRONMENTAL AND MORPHOLOGİCAL FEATURES OF EARTHEN DOME VILLAGES

3.1. Envıronmental context and settlements morphology

The study focuses on three areas in northern Syria—between Lake Jabboul, Lake Al-Assad, and eastern Hama—located at the arid fringes of the Fertile Crescent, straddling the 200 mm isohyet. Characterized by a continental Mediterranean climate, the region undergoes prolonged dry periods and extreme summer temperatures, shaping a steppe landscape dotted with basaltic plateaus (djebel) and plains historically used for grazing. The settlement pattern reflects alternating waves of nomadic and sedentary occupation, punctuated by periods of abandonment and reoccupation from the 14th to 20th centuries. Many villages are built atop former Byzantine sites, reusing carved basalt and hydraulic infrastructure. Prior to the 2011 conflict, the region was inhabited by a mosaic of ethnic and religious communities and supported by agro-pastoral economies.
The spatial organization of domed villages reflects the transitional lifestyle and subsistence economy of Bedouin culture. This is evident in the modular grouping of units, the emphasis on outdoor communal life, and the preference for open, multifunctional spaces. The distribution of dwellings recalls the informal layout of nomadic camps, with the dome form evoking the symbolic continuity of the tent [1, 3].
The spatial arrangement of the villages is predominantly organic, with structures scattered and connected by irregular pedestrian paths. Public spaces emerge informally in residual areas through repeated communal use. Only a few villages show evidence of a planned structure, with regular circulation routes and defined collective areas.
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3.2. Architectural and functional characters of a living unit (*dar*)

The living unit, locally referred to as *dar*, forms the basic module of domestic architecture in northern Syrian villages characterized by corbelled earthen domes. Each unit typically comprises 2–3 interconnected domed cells, often complemented by auxiliary spaces such as a kitchen, storeroom, stable, toilet, henhouse, and occasionally a small guest room or workshop. These elements are arranged either around a central courtyard (Fig.3)—in the closed unit typology—or in a more open, organic pattern when spatial constraints or topography require it.
The main cell, known as *ghurfa*, serves as the central living and reception space. This room is typically a domed volume with an ogival profile, constructed without centering, using a dry-laid corbelling technique. It may be formed by one large dome or two smaller domes connected through an interior arch (*qaws* or *qanṭara*), allowing for functional zoning within the same space. Its orientation—most often north–south with the entrance facing south—maximizes solar exposure in winter while protecting from prevailing winds. The interior is multifunctional: used for social activities and rest during the day and as a sleeping area at night, when mattresses and blankets are laid out on the floor.

Furnishings are minimal and integrated into the architecture. Niches embedded in the walls serve for storage, while decorative plaster shelves and reliefs, often handmade using earth and straw, express both aesthetic and symbolic values through geometric or floral motifs. A raised platform or terrace (*mastaba*) in front of the main cell, built with stone and finished with earth plaster, is used for drying food and as a sleeping area during hot summer nights.
Domed units are designed with minimal openings to optimize thermal performance: typically one door and small ventilation holes facing east or west. These allow for cross-ventilation, cooling in summer, and minimal heat loss in winter. The courtyard, when present, functions as an extension of the indoor space—used for daily chores, food preparation (especially bread baking), childrearing, and animal tending. A well is often located within or near the courtyard, ensuring water access.
These modular units were traditionally expandable: new domes could be added to accommodate growing families or increased storage needs. Temporary tents were sometimes set up alongside permanent structures, especially in transitional periods following seasonal migration. These were used for livestock, firewood, or dairy processing.

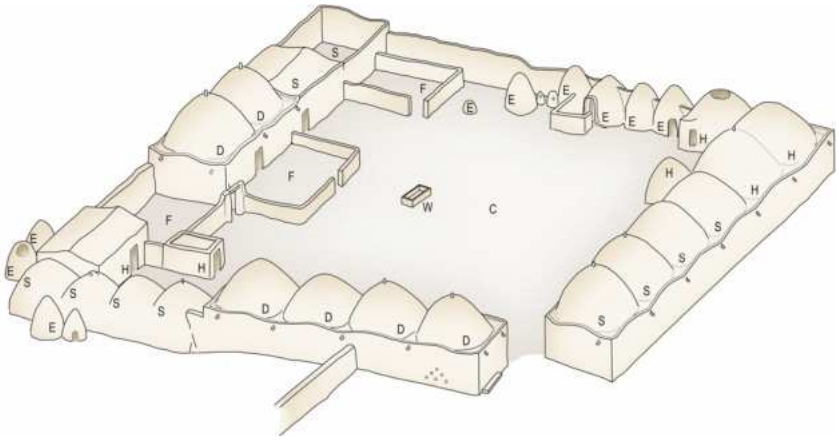

Figure 3. Architectural and functional characters in a living unit. C. Court (Hush Sahn); D. Dwelling-house; E. Hen-house; F. Animal fence; H. Stables (Hazera) or (Qabu); S. Stores; T. Terrace (Mastaba).

4. MATERİALS, BUİLDİNG SYSTEM AND PROCESS

4.1 Main Types of Syrian Corbelled Domes

The vernacular architecture of northern Syria features a diverse typology of corbelled domes, distinguished by morphological and constructional variations [1, 4, 6]. The typical cell is quadrangular, built with stone or adobe brick walls, and surmounted by a pseudo-conical dome. Arched openings connect adjacent units. Based on wall height, dome profile, and structural elements, five principal types can be identified (Figure 4):

Figure 4. Axonometric views of the main typologies of earthen domes: a) Simple dome, b) Sultanya domes; c) Dome set on a low stone basement; d) Flat roof Domes; e) Smaller domes in cob

- Simple Domes: Among the earliest forms, these domes rest directly on a stone base slightly raised above floor level. Characterized by an ogival profile, they span 3–3.5 m per side and reach heights of 4–6 m.
- Sultanya Domes: These feature a more elongated ogival-paraboloid profile, set atop perimeter walls ranging from 1 to 2.5 m in height. Base dimensions vary from 3 to 4.5 m, with an overall height of 4–6 m.
- Domes on Stone Basements: Raised on a substantial stone plinth, these structures expose the full dome profile internally and externally. Heights range between 2.5 and 4 m.
- Flat-Roof Domes: With a truncated conical form, these domes are capped with timber, reed, and earth layers. Common in the Euphrates valley, their diffusion is linked to the availability of long wooden elements, which eliminate the need to complete the uppermost corbelled section.

- Small Cob Domes: Built using hand-shaped stone and earth, these serve utilitarian purposes—typically for storage or animal shelters.

4.2 Building materials and processes

Earthen domed dwellings in northern Syria are built using locally sourced materials—primarily clay-rich earth, often combined with basalt, limestone, plant fibers, or reused fragments from ancient settlements. The construction system reflects adaptation to resource availability, geomorphology, and community expertise. Earth mixtures for bricks, mortars, and plasters are manually prepared, incorporating wheat or barley straw. Mineralogical analyses identify the use of marly clay with calcite, silts, and coarse inclusions, resulting in lean mixes with low cohesion, yet appropriate for earthen construction. Plasters vary in composition—lime and straw for interior finishes; lime, gypsum, and straw for external coatings—while whitewashes use fine limestone or gypsum. Construction is a communal activity: men prepare earth mixes, women mold bricks, and children often assist in plastering. Foundations are laid on compacted soil with dry-stacked stone footings; above, thick adobe walls rise atop a stone base. The corbelled dome is formed via a continuous helical course, transitioning from square to circular plan using corner corbels (*haclab*), without centering. The dome's thickness corresponds to the brick width; mortar joints are thick, yielding a monolithic structure with composite behavior. Finishing includes layered clay plaster to ensure waterproofing and durability, renewed annually, particularly on dome tops and around base junctions. Openings are minimized to control light, heat, and ventilation, and are framed with wood or stone lintels using trilithic techniques. Small *taqa* windows ensure cross-ventilation; larger ones are rare. Adjacent domes are connected by earthen arches built without wooden formwork. The vaulted interior is plastered up to two-thirds height; the apex receives liquid limewash for reflectivity and sanitation. Overall, these techniques reveal an architecture rooted in ecological adaptation, material efficiency, and resilient communal practices.

5. LESSONS OF SUSTAİNABİLİTY AND RİSK FACTORS FOR A VULNERABLE ARCHİTECTURE

The corbelled earthen domes of northern Syria represent a sustainable settlement typology rooted in environmental adaptation, social cooperation, and technical resilience. Developed in response to a scarcity of timber and a harsh semi-arid climate, these structures embody low-tech, high-performance solutions that integrate construction, culture, and ecology. Characterized by ogival profiles and corbelled geometry, the domes exhibit excellent static stability and hygrothermal performance. The dome's curved surfaces reduce solar gain through self-shadowing and facilitate rapid nocturnal heat dissipation; their form also enables efficient water runoff and resists seismic and wind stresses. Thick earthen walls, composed of locally sourced marly clays, possess high thermal inertia and vapor permeability, supporting passive climate regulation and indoor comfort. Few openings—strategically oriented—enhance cross-ventilation while minimizing thermal exchange. These dwellings emerged through a transition from nomadic to semi-sedentary life, retaining a modular and regenerative logic based on basic needs and material self-sufficiency. The construction process, shaped by a principle of mutual aid (*tacawon*), involves collective labor where the entire community contributes according to capacity, strengthening social bonds and reducing economic costs (Fig. 5). Only the master builder (*muʿallem*) typically comes from outside the village. Beyond technical efficiency, these habitats express a cultural ecosystem: spatial arrangements reflect communal life, and construction methods rely entirely on local resources without energy-intensive transformation or transport, drastically reducing embodied energy and emissions. Furthermore, earth's non-toxic and sound-absorbing qualities enhance environmental health. As a whole, Syrian corbelled domes exemplify an architecture of resilience—deeply integrated into the landscape, socially embedded, and environmentally attuned.

Figure 5. Collective maintenance work in 2009.

However, despite these qualities, this architectural heritage is increasingly at risk. The socio-political crisis since 2011 has compounded longstanding vulnerabilities—such as aridity, isolation, and resource scarcity—accelerating the abandonment of villages and interrupting maintenance traditions. Corbelled domes, sensitive to moisture, rely on routine upkeep—particularly annual replastering—to withstand degradation processes such as erosion and infiltration [5]. The loss of intergenerational knowledge and diminishing demand have further contributed to their decline. Even prior to the war, these structures were often perceived as obsolete, associated with poverty and labor-intensive upkeep, particularly affecting women. The aspiration for modernity—embodied in concrete houses—has led to a cultural shift, reinforced by social pressures, such as marriage expectations. In this context, the loss of skilled builders has become critical. Yet efforts toward recovery persist. A notable initiative in Lebanon [7] brought together Syrian and Lebanese masons to construct a dome using traditional methods, accompanied by training programs and the production of a manual to encourage the replication and transmission of this vernacular knowledge.

6. REFUGEE PERSPECTİVES ON EARTHEN ARCHİTECTURE İN CONTEMPORARY CONTEXTS

The workshops conducted in the Zaatari and Azraq refugee camps revealed a complex set of perceptions toward earthen shelters [7]. Most participants expressed awareness of the benefits of earthen constructions in terms of thermal comfort, citing the thickness of the walls and the insulating properties of sand as beneficial for maintaining indoor comfort during both summer and winter. Several referred to this form of construction as part of their cultural heritage and appreciated its potential for privacy, thermal comfort, and sound insulation. The low cost and local availability of materials were also viewed positively. However, significant concerns were raised about the durability and maintenance of earthen shelters. Participants feared that exposure to rain would compromise the structural integrity, lead to unpleasant odors, and accelerate decay—especially in flood-prone areas. They also worried about pests, cleanliness, and the annual effort required for maintenance. Despite their environmental and thermal advantages, superadobe domes were not preferred over caravans or metal shelters. The dominant barrier was the social stigma attached to earthen buildings: they were perceived as primitive, unsuitable for modern living, and symbolic of marginalization. As several participants stated, such dwellings were "for animals" or "a thousand years behind," and might further mark and isolate them as refugees. Even when their aesthetic or economic potential (e.g., as tourist attractions) was acknowledged, these benefits did not outweigh the deep-rooted association of earthen architecture with poverty and exclusion. Thus, stigma—not technical or environmental performance—emerged as the primary obstacle to the acceptance of earthen dome shelters.

5. CONCLUSIONS: A POSSIBLE FUTURE SCENARIO

In the uncertain context of post-conflict Syria, large-scale reconstruction efforts have largely prioritized urban centers, leaving rural areas at risk of further marginalization. Yet for returning displaced families, the reactivation of village life represents both a challenge and an opportunity. In this scenario, earthen architecture offers an accessible and contextually appropriate solution. Its reliance on local materials and skills supports not only ecological sustainability but also the revitalization of local economies and cultural practices.

However, embracing earthen construction today must go beyond preservation—it requires innovation. Traditional knowledge systems, once transmitted through lived experience, must be reactivated and integrated with contemporary needs and standards of comfort, durability, and resilience. The perceived obsolescence of earthen techniques stems not from their intrinsic limitations, but from a cultural and economic devaluation of non-industrial knowledge.

Reframing earth as a strategic material for future human settlements calls for a renewed epistemological framework—one that recognizes its adaptability, cultural expressiveness, and environmental performance. The key scientific challenge lies in reconstructing value chains, enhancing knowledge transmission, and bridging traditional craftsmanship with scientific inquiry.

Ultimately, the conservation of vernacular heritage must be embedded in the broader aim of sustainable development. It must serve the aspirations of communities and align with their visions of a dignified future. Only by making earthen architecture a living, evolving practice—rather than a relic of the past—can we ensure its continued relevance in shaping inclusive, resilient, and culturally gr1ounded environments.

ACKNOWLEDGMENTS

This article is the result of two research projects: "Earthen and Domes and Habitats, an Architectural Tradition Shared by East and West" (a funded by the EU Culture 2000 program: project leader: University of Florence-IT; partners: Hellenic Society-EL, Université de Liège-B, CNR – ICVBC-IT, École d'Avignon-FR, Universitat Politècnica de València-ES, Direction Générale des Monuments et des Antiquités-SY) and "Healthy Housing for the Displaced" funded by the Engineering and Physical Sciences Research Council Global Challenges Fund EPSRC/GCRF (EP/P029175/1).

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Heres: Digitally Aided Knowledge Transfer in Traditional Earth Building Crafts of Southern Morocco

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ABSTRACT

Traditional earth building crafts in Southern Morocco are under serious threat due to climate change, migration, declining interest in traditional lifestyles, modern construction methods, and a lack of formal training. The traditional knowledge underpinning these crafts has made life in the Sahara possible for centuries, allowing the development of oasis settlements in its harsh environment. In line with UNESCO's Convention for the Safeguarding of Intangible Cultural Heritage, this study focuses on protecting the knowledge and skills behind earthen architectural heritage.

Today, with fewer young people learning the crafts through traditional means, new tools are needed to support their practice and transmission. While digital technologies have shown potential in safeguarding intangible heritage, no efforts have yet been made to digitally document Morocco's earth building practices. This study addresses this gap through *Heres*, a free, interactive, multimedia manual offering step-by-step guidance on mud bricks, rammed earth, tadelakt, and mud finishing.

Using M'Hamid Oasis as a case study, a team of researchers from ArCHIAM, the Centre for the Study of Architecture and Culture Heritage of India, Arabia and the Maghreb, based at the University of Liverpool, embarked on a participatory research journey through interviews, observation, drawn and audio-video documentation, and workshops. The aim was to aid hands-on learning, revive interest, improve skills, foster deeper engagement with intangible cultural heritage, as well as highlight the cultural and religious practices linked with earth building, and the important but often overlooked role of women.

Heres is available in English and Moroccan Arabic as an offline, mobile-friendly e-publication. Aimed at craftspeople, conservation experts, and enthusiasts, it seeks to make traditional knowledge more accessible, encourage integrated off-site and on-site learning, and help ensure the continuity and resilience of earth building heritage in the face of change.

Keywords: Digital Technologies; ICH Transmission; Traditional Earth Building Crafts; Earth-Built Heritage Resilience; Morocco

Aveiro Adobe: Composition and Characteristics

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ABSTRACT

In Portugal, earthen construction can be found in almost all the territory, in which three techniques stand out, Rammed Earth, Adobe and Wattle and Daub (a mixed construction technique of wood and earth). In the Aveiro region, adobe defined a unique construction culture and sustained an industry active until the 1970s. The knowledge related to adobe production has since been largely forgotten, becoming part of a distant memory.

Nowadays there is a need for intervention in a significant percentage of the relevant adobe-built heritage in the Aveiro area. To this end, it is necessary to establish the compositions and characteristics of the adobes used until now, a production which was discontinued decades ago. This work proposes a synthesis of this information, allowing the establishment ofa basis for intervention in the present moment.

The purpose of this article is to provide reliable data on the materials used to produce adobes, their proportions. In addition to the data on the composition of adobes in this area, the article will link this composition with its mechanical and physical characteristics. Through these characteristics it will be possible to outline the architectural intervention for the rehabilitation of the existing one or, eventually, the construction with new adobes. In addition to the desirable reuse of existing materials, the article will also provide a solid foundation for the production of new adobes.

The methodology used will be fundamentally bibliographical research. Given the volume of work already carried out both at the University of Aveiro and by other entities, which is currently dispersed, this article will compile and interconnect this information in a systematic way. At the University of Aveiro, laboratory work was extensive, resulting in projects, Master's and Doctoral theses, where diverse results are expressed. The systematization and analysis of this range of results will be carried out to provide the necessary information to architects and conservators-restorers.

Keywords: Adobe, Composition, Properties, Earth, Lime.

1 INTRODUCTION

"When man began to transform natural resources into construction materials, adobe was the first, obtained from a plastic mixture of soil and water that, after drying naturally (in the sun or in partial shade), produced rigid blocks for building walls, similar to the use of stone." [1].

The Aveiro region (Portugal) developed a unique adobe construction culture that thrived until the 1970s, representing approximately 30% of the existing built heritage in the area [2]. This earthen construction technique, which defined architectural identity in the region, has since been largely forgotten as knowledge related to adobe production has faded into distant memory [2][3]. Today, there is an urgent need for intervention in a significant percentage of the adobe-built heritage, requiring a comprehensive understanding of traditional compositions and characteristics to guide contemporary conservation efforts and competitive new construction.

The adobe from Aveiro region is notable for a distinctive adobe construction tradition that utilizes sandy soils stabilized with air lime, setting it apart from the predominantly clay-based found globally. The progressive loss of traditional knowledge, combined with the growing need for intervention in this built heritage, necessitates a systematic synthesis of the dispersed literature and experimental data relating to local adobe production. This article aims to support conservation, restoration, and the possibility of authentic new productions with technically reliable references.

2 UNDERSTANDING THE MATERIALS

Adobe production typically employs clay-rich earth, with straw added for reinforcement and crack control, leveraging the binding capacity of clay and the tensile resilience of straw fibres [4][5]. However, the Aveiro region stands out: local sandy soils with inherently low clay content prompted the widespread adoption of lime as a chemical stabilizer [2]. To clarify the essential differences between these adobe types, it is critical to consider the roles and interactions of each constituent - clay, sand, straw, and lime - as they collectively secure quality, durability, and resistance in the final construction product [4][5].

Earth as a building material consists mainly of clay, silt, and sand, often with small amounts of gravel, stones, and other minerals. Clay in soil are responsible for its tendency to shrink and swell with humidity changes, which can cause cracking, internal or surface damage, water infiltration, and eventual structural deterioration [6]. Due to its high absorption and cation exchange capacity, clay can capture organic molecules and absorb water, gases, grease, or odours. Some clays are also adsorbent, attracting toxins and exchanging them for minerals, an important property for improving indoor air quality.

Effects of clay types in earthen construction:

- Montmorillonite: Increases mortar viscosity, doubles water absorption. In walls promotes cracking due to swelling–drying cycles [7].
- Kaolinite: Provides dimensional stability and low shrinkage; mixes well with sand and gravel, ensuring good workability even with low water content [8].
- Illite: Shows intermediate behavior; a 20% illite and 80% sand mix achieves high fracture energy (4.9 $J \cdot m^{-2}$) [9].

Soils vary widely in grain size distribution, mineralogy, clay content, organic matter, water, and air. Proper balance of these elements is essential for stability, workability, performance, and aesthetics. Accurate identification of soils suitable for construction requires several tests.

Purpose of each test for earth construction:

- Organic mater - >2% should be avoided in earth construction due to risks of decomposition, poor cohesion, and long-term durability failures [6].
- Colour – Earth colour is determined not by its clay content, but by the presence of extremely small mineral particles, such as iron oxides. For instance, red, yellow, ochre, brown, and occasionally blue and grey in soil are often associated with iron atoms found in iron oxides. [5]
- Granulometric composition / texture - Guides mix design to balance strength and shrinkage.
- Plasticity - Depending on its moisture content, soil can be liquid, plastic, or solid. The appearance and consistency of soils vary significantly depending on the amount of water it contains and the amount and type of clay [6]. Defines workable moisture range and predicts cracking potential.
- Cohesion - Is the force that holds together particles within the soil. Cohesive soils tend to bond and retain a shape. They have an ability to be moulded which is known as "plasticity." They are difficult to break apart when dry.
- Shrinkage - Important to understand the type and quality of clay and water performance, within the earthen elements, and possible need for correction / stabilisation.
- Compressibility - Indicates clay content and strength. Lab test - Estimates load-bearing capacity.
- Water absorption - Predicts durability under wetting/drying cycles.
- Mineralogy - Clay mineral types, quartz content. Informs stabilization strategy and long-term dimensional stability.
- Chemical composition - Ionic content and acidity/basicity. Detects salts or acidity that may effloresce or degrade binders.

Table 1 presents soil texture categories and illustrates how granulometric composition affects the use of earth as a construction material.

Table 1. Four broad soils texture categories classification and its characteristics [10]:

Soil Type	Characteristics
Sandy Soil	High amount of sand (>50%) - drains well but weak cohesion
Clayey Soil	High amount of clay (>40%) - good plasticity, shrink-swell risks
Loam	Balanced sand, silt, clay - optimal workability, strength, and shrinkage
Silty Soil	Silt-dominant - moderate cohesion, prone to frost damage

2.2 Stabilization

The use of soil from the site where the construction will be carried out should be prioritized as should the use of only one type of soil. However, most of the time the original earth, extracted on site, does not have the necessary characteristics to ensure good construction.

The information resulting from soil characterization allows for the appropriate construction technique and the need for correction/stabilization to achieve target mechanical and durability properties.

Stabilization techniques aim to improve the durability, mechanical strength, and water resistance of adobe blocks. Various stabilization approaches work differently with earth elements:

- **Sand Stabilization**: Sand particles provide structural stability and reduce shrinkage cracking. The angular, sub-angular, or rounded particle shapes create mechanical interlocking that enhances compressive strength [11], mitigates crack propagation, and promotes even drying [5].
- **Silt Stabilization**: Silt particles, with intermediate size between sand and clay, contribute to workability and reduce plasticity. However, excessive silt content can lead to weak adhesion and poor durability [11].
- **Clay Stabilization**: Clay content must be carefully balanced. Expansive clays should comprise no more than half the clay content, with the remainder being non-expansive illite or kaolinite [4]. Too much expansive clay causes uneven drying and cracking [4].
- **Natural Stabilizers**: Traditional methods incorporate organic materials including:
  - Straw fibres: Provide tensile reinforcement and reduce shrinkage cracking [4].
  - Plant juices: Act as natural binders [12].
  - Animal dung: Offers binding properties similar to straw [4].
- **Chemical Stabilizers**: Modern stabilization employs:
  - Lime: Initiates a series of chemical reactions - "cation exchange," "flocculation," and ultimately "pozzolanic" bonding - creating new mineral phases and greatly enhancing both water resistance and compressive strength [2].
  - Cement: Occasionally employed (especially in experimental or modern contexts) for rapid strength development and maximum durability. Up to 10% by weight, compressive strength increase [4].
  - Emulsified asphalt: For water resistance [4].

The balance among these components is critical and varies according to local requirements.

In Aveiro, due to the typically lower clay content of local soils, lime was specifically used to address the natural lack of binding agents present in the available earth.

2.3 Lime

There are multiple lime types, each with specific characteristics:

- **Air lime**: consists primarily of calcium oxide or hydroxide and hardens slowly in air by reacting with atmospheric carbon dioxide [3][4]. It has no hydraulic properties and does not set in water. It is available in the form of quicklime (CaO) or hydrated lime ($Ca(OH)_2$) [3].
- **Calcitic Lime** (CL): Consists primarily of calcium oxide, containing a minimum of 75% CaO [3]. It is best suited for mortar production.

- **Dolomitic Lime** (DL): Consists of calcium oxide and magnesium oxide, with a minimum of 20% MgO [3]. It has a greater resistance to moisture. Known in Aveiro as "cal churra" because of its grey colour. [16]
- **Natural hydraulic Lime** (NHL): consists primarily of calcium hydroxide, calcium silicates, and calcium aluminates, produced by the calcination of more or less clayey or siliceous limestones. It has the property of setting and hardening underwater, combining air and hydraulic setting in a single substance. [3]

Lime stabilization operates through the fundamental "lime cycle", a well-established chemical process - Calcination (transforming limestone through heating), Hydration, and Carbonation.
When choosing the type of lime to use, it is necessary to consider:

- Type of soil – granulometry and type of clay;
- Type of construction to which the final product will be applied – exposure to moisture (e.g., interior or exterior), mechanical resistance (e.g., height of construction);
- Environmental impact, material life cycle;
- Construction cost

In lime stabilization, the pozzolanic reaction is the main one among several reactions that lime establishes with the soil. This involves the dissolution of clay minerals in an alkaline environment, produced by lime, and the combination of silica and aluminum from the clays with calcium to form aluminum and calcium silicates, which bind the particles together. [14]

- Cation Exchange: Calcium ions from lime replace weaker cations (like sodium) in clay particles, reducing plasticity and improving workability.
- Flocculation and Agglomeration: Calcium ions promote grouping of fine clay particles into larger aggregates, improving soil structure and reducing water susceptibility.
- Pozzolanic Reaction: The most critical long-term reaction involves lime and water reacting with silica and alumina in clay under high pH conditions (>10.5).

Reactions with different clay types
The effectiveness of lime stabilization varies significantly with clay mineralogy [15]:

- Kaolinite: Shows excellent reactivity with lime, producing substantial pozzolanic reactions and strength gains.
- Smectite (Bentonite): Highly reactive but requires careful control due to high plasticity and swelling characteristics.
- Illite: Moderate reactivity with lime, providing balanced performance in stabilized adobe.

The "optimum lime content typically ranges from 5-10%" of the dry soil weight, with specific percentages depending on clay type and desired performance characteristics. [16]. Lime stabilization enhances the durability and long-term strength of adobe through pozzolanic, and carbonation processes, improves workability by reducing plasticity, and supports environmental and heritage values. However, it requires careful handling due to its caustic nature, involves higher initial costs, and depends on proper curing conditions, with slower early strength development compared to cement stabilization. [2]

3 CLAY ADOBE VERSUS LIME ADOBE

3.1 Clay Adobe

The most common adobe is composed of fine sandy-clay soils with little silt [1]. When water is added, the mixture reaches a plastic consistency that enables it to be shaped or moulded into small and slender elements.
Opinions vary regarding the suitable proportions of each component of earth materials (clay, silt, sand, gravel), and some sources specify only the acceptable range for clay content. As demonstrated in the data derived from case studies conducted across various countries and soil types, by the recommendations provided in Table 2.

Table 2. Characterization of Earth for Adobe Production According to Different References [1].

References	Clay (%)	Silt (%)	Sand (%)	Stabilizer
Barrios et al (1987)	35-45		55-65	0-5% manure
Houben e Guillaud (1994)	5-29	-	-	straw
Graham McHenry (1996)	15-25	-	-	-
NTE E 080 standard	10-20	15-25	55-70	-
Carazas Aedo (2002)	1volume clay earth: 2 volumes sandy earth			straw
HB 195 (2002)	10-40	10-30	30-75 (sand and stones)	/
Proyecto Hornero (2007)	50 clay earth		50 sandy earth	straw
Minke (2009) [5]	14	22	62+2 (gravel)	-

Interpretation of these data reveals several important trends:

- **Clay Content:** Optimal clays for adobe generally range from 15% to 35%. High clay contents provide strong binding but may require more sand or fibrous additives to control shrinkage and cracking. [2]
- **Sand Content:** Constitutes the majority of the mix (50–75%), ensuring dimensional stability and helping avoid cracking [4][5]. Very sandy soils, tend to need stabilization through lime or cement.
- **Silt Content:** Typically ranges from 15–20%. While it contributes to workability, excessive silt can reduce block strength and durability. [4]

To control hight clay content, sand addition is common to be used, hither sandy-earth or washed-sand. Also, addition of straw or manure, improves tensile strength and crack control but does not alter water resistance significantly. [4][5]

3.2 Lime Adobe

The earth used historically for adobe production in the Aveiro region is characterized by variable particle size distributions and notable mineralogical diversity. Detailed studies of traditional adobe blocks from Aveiro reveal that the primary clay minerals are kaolinite, illite, and smectite, with quartz and other phyllosilicates also present in significant proportions [17][18].

Particle size analyses demonstrate that Aveiro adobes generally contain moderate to high sand content, lower clay content, and some silt. This composition echoes the constraints of the local soils, which are often sandy and thus require stabilization for adequate mechanical performance and durability [17]. Typical proportions such as 15–25% clay, 55–70% sand, and 10–20% silt are representative ranges [17], as demonstrated in table 3 examples.

Table 3. Typical Ranges for Particle Fractions and Stabilization in Aveiro and Central Portugal Adobes

Location	Clay (%)	Sand (%)	Silt (%)	Dominant Clays	Main Stabilizer
Aveiro, Anadia1 [17][18]	15–22	60–70	10–18	Kaolinite, Illite, Smectite	Lime (5–10%)
Murtosa [17]	10–20	65–75	10–15	Kaolinite, Smectite	Lime (5–10%)
Pinhal Novo* [18]	18	65	17	Kaolinite, Quartz	None

Note: Pinhal Novo is not in Aveiro but illustrates regional variation in Portuguese adobe.

The fundamental distinction between Aveiro lime adobe and conventional clay adobe lies in the stabilization approach and material composition as Table 4 illustrates:

Table 4. Lime Adobe vs Clay Adobe [16][19][4]

Aspect	Aveiro Lime Adobe	Common Clay Adobe
Binding Agent	Air lime (5-10% by weight)	High clay content (25-45%)
Base Soil	Sandy soil, low clay	Balanced sand-silt-clay mix
Fiber Addition	Minimal or no organic fibres	Straw usually present
Curing Process	Air drying and Carbonation (days-week - continuing hardening)	Air drying with clay binding (days–weeks)
Water Resistance	High, due to lime	Moderate. Depending on clay

These variations reflect both different soil resources and tailored adaptations to achieve adequate mechanical strength, durability, and resistance to environmental exposure.
Traditional adobes rely on a balance between clay (for binding) and sand (for bulk and stability), with straw commonly added where no chemical stabilizer is present.
In specific contexts like Aveiro, the use of lime as a partial or total replacement for clay allows successful adobe production from locally available sandy soils.
This spectrum of compositions and stabilizations highlights the importance of adapting mixtures to local resources and intended performance, ensuring the finished adobe blocks demonstrate adequate workability, strength, durability, and resistance to environmental stress.
As already mentioned, and according to several authors, lime stabilization enhances water resistance, durable internal matrix, improved mechanical strength. [2][5]

3.2.1 Characteristics of existing Lime Adobes
The research conducted by University of Aveiro has been focused on characterizing existing buildings and adobes. In the search to understand the pre-existences, their weaknesses and produce solutions for their rehabilitation and maintenance. Table 5 shows the mechanical strength values of adobes in the Aveiro region, based on bibliographic references, collected from work carried out at Aveiro University for several years.

Table 5. Mechanical strength values of adobes in the Aveiro region

References	Mechanical strength		
	Cs (MPa)	Fs(MPa)	Observations
Varum, Martins e Velosa, 2005 [19]	0,5 – 2,0	-	Murtosa
Coroado et al, 2010 [20]	0,25 – 1,44	-	Aveiro
Varum et al, 2011 [2]	0,53 - 1,72	0,20*Rc	Zona Aveiro
Silveira et al, 2012 [21]	0,66 - 2,15	0,13 – 0,19	Casas
Silveira et al, 2012 [21]	0,80 -1,72	0,12 - 0,40	Muros
Costa et al, 2019 [18]	0,6 – 8,3	Most common between 0,8 and 3,5	
Costa, 2019 [22]	1,97 - 3,58	-	Anadia
Costa, 2019 [22]	1,32 – 2,63	-	Murtosa

The analysis of the compressive strength evaluation works of adobes in the region (mainly lime adobes) reveals a compressive strength usually considered low in terms of the use of construction materials. However, there is some variation, and it is a fact that adobe houses with this mechanical behaviour have performed adequately. Also, Silveira et al, evaluated the Modulus of Elasticity of these materials, reaching values between 94 and 340 MPa, corresponding to the low mechanical resistances found, demonstrating heterogeneity and existence of porosity [21].
In addition to mechanical properties, the interaction with water (capillary absorption) is crucial for understanding the performance of adobe structures, as Table 6 demonstrates.

Table 6. Capillarity coefficient values of adobes in the Aveiro region

References	Capillarity coefficient		
	Value	un	Observations
Coroado et al, 2010 [20]	3,17 – 21,22	kg/m2.h1/2	Aveiro
Costa et al, 2019 [18]	3-21	kg/m2.h1/2	Aveiro Region

This fundamental characteristic, less evaluated, reveals a high capillary absorption by the adobe material. However, the adobe construction systems in Aveiro have demonstrated their resilience, withstanding floods and seismic activity over the years. In addition to the characteristics mentioned in the consulted literature, other factors such as the ability of hydrothermal regulation, have a critical contribution to the quality of the indoor environment.

4. LIME ADOBE PRODUCTION

Traditionally, two types of lime were used in Adobe production; the most prevalent are Limestone lime (white lime), used for housing, and Dolomitic lime, used in well construction due to its greater resistance to moisture.

In Adobe production, quicklime stone would be used. However, we find two distinct methods of adding it to the earth.

1. Hot hydration - earth and the quicklime stone were layered, wetted to activate the lime reaction and left to extinguish for 3 to 4 days. [23]
2. Slaked lime mix - previously "burned" in the "lime house" for 4 to 5 days. Lime was then mixed with earth, already extinguished in the form of slaked lime. [24]

Although there is no information demonstrating, in existing buildings, how these different processes can affect the quality of adobes, various testimonies [16] claim that the addition of limestone, results in an easier mix and stronger mortar and adobes. The lime "slaking" process releases a large amount of heat during hydration. The rapid rise in temperature can agglomerate clay and sand particles, improving the cohesion of the mixture. Furthermore, the volumetric expansion of CaO as it transforms into $Ca(OH)_2$ can close voids and increase the densification of the adobe.

Adobe production in the Aveiro region was concentrated among several key producers who served distinct geographical areas within the broader region, each developing slight variations in recipes and techniques based on local soil conditions and lime sources.

Key findings demonstrate that the optimal composition for Aveiro adobe utilized sandy soils with 5-10% air lime content, producing compressive strengths of 0.5-1.2 MPa and exceptional longevity when properly maintained [2]. Also different dimensions and constitution of adobe blocks can be found across the region, the most common being approximately 0.45×0.30×0.15m when used in houses and 0.45×0.20×0.15m when used in the fence walls [19]. This variability results from the diverse typologies developed over time to meet the specific requirements of each construction.

5. CONCLUSION

Aveiro's lime-stabilized adobe tradition exemplifies a sophisticated response to local soils and climate. By understanding and enhancing the interplay between earth components - especially lime in sandy soils - builders achieved high durability and performance while remaining true to heritage techniques. The adapted recipes and production methods, confirmed by experimental data and historic practice, continue to inform sustainable, compatible restoration and construction strategies.

The extensive research conducted at the University of Aveiro has established a comprehensive database of mechanical and physical properties that provides essential guidance for contemporary conservation efforts [2]. These findings reinforce the potential for intervention strategies that align with traditional building techniques while satisfying contemporary safety and performance standards, promoting a sustainable and climate-appropriate approach to environmentally responsible construction. [3]

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An Investigation into Architecture Students' Perceptions of Sustainable Design

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ABSTRACT

Global warming intensifies the frequency and severity of natural disasters and has profound impacts on all living beings. The construction sector plays a key role in combating global warming. A significant portion of greenhouse gas emission worldwide is caused by the construction industry. In terms of infrastructure, more than half of the world's energy consumption occurs in large cities, which leads to significant CO_2 emissions. To mitigate the negative impacts caused by the construction sector, strategies such as using ecological materials, recycling gray water, and generating energy from natural resources like the sun and wind are employed to promote a sustainable environment.

Promoting awareness of sustainability is recognized as an essential component of architectural education. Architecture schools at universities worldwide have incorporated this topic into their curricula, with environmental sustainability being covered through both theoretical and practical courses across many institutions. Istanbul Medipol University School of Fine Arts, Design and Architecture is one of the architecture schools that aim to raise awareness about sustainability in architecture. From the first year of education, the subject of environmental sustainability is carried out in both compulsory and elective courses in all terms with theoretical and practical studies. The aim of this paper is to measure architecture school students' perception on sustainable architecture through a survey. The sample is determined as the students who have reached the last year of their education and are entitled to graduate. With this study, the sustainable architectural design awareness targeted by the architecture school is to be measured.

Keywords: Architectural education, sustainable design, student perception, sustainability awareness.

1 INTRODUCTION

Sustainability is evaluated through three primary and interrelated dimensions: social, economic, and environmental. These dimensions form the foundation of a sustainable future and are essential considerations in any discipline that interacts with the physical and cultural fabric of society. Architecture, by its very nature, lies at the intersection of these domains, as it directly shapes human habitation, resource consumption, and urban development. As such, the integration of sustainability into architectural discourse is not only appropriate but necessary. The built environment, as a reflection of cultural, technological, and ecological values, plays a critical role in either mitigating or exacerbating the pressing challenges of our time; climate change, resource depletion, and social inequity among them. Consequently, sustainability, now one of the most globally acknowledged and prioritized criteria, must be regarded as an integral component of both architectural education and professional practice [1].

Architects are among the primary agents responsible for shaping the built environment. Through their design decisions, they influence how space is experienced, how resources are utilized, and how communities function. Buildings and urban environments conceived without consideration of sustainability can have far-reaching and long-lasting adverse effects on ecological systems and public health. On the other hand, well-considered architectural solutions can support energy efficiency, enhance indoor environmental quality, reduce carbon footprints, and foster social cohesion. Therefore, architects bear a critical ethical and professional responsibility to embed sustainable thinking into every stage of the design process [1].

The growing urgency of environmental issues has led to a global re-evaluation of educational priorities within architectural programs. A globally conscious, forward-thinking, and holistic approach to architectural education, especially with regard to sustainability, is not only desirable but imperative. The built environment accounts for a significant portion of global environmental impact; buildings alone are responsible for over 40% of global energy consumption and contribute nearly one-third of greenhouse gas emissions worldwide [2]. As such, future architects must be equipped not only with technical skills but also with a critical understanding of environmental systems, life cycle thinking, and sustainable design strategies [3]. Due to the inherently multidisciplinary nature of architectural education, sustainability-related topics are typically integrated into various stages of the academic curriculum, from materials and construction methods to environmental design, building physics, and studio projects. However, the effectiveness of this integration, and the extent to which it influences students' actual design behavior, remains a subject of ongoing investigation. This study seeks to assess the tangible impact of sustainability education on architectural design thinking.

Specifically, this article explores architecture students' perceptions of sustainable design as developed throughout their academic journey. It examines how students interpret, prioritize, and apply sustainability principles in their design work, and to what extent these principles influence their evolving professional identities. Through this lens, the study aims to offer insights into the efficacy of current pedagogical approaches and to contribute to the discourse on improving sustainability education in architecture.

2 LITERATURE REVIEW

It is crucial to promote a sustainable built environment by preparing future architects with the necessary skills to design and build resource-efficient structures. The significance of education in fostering sustainability among architecture students is paramount, considering their essential role in shaping the future of sustainable building practices. Educational institutions worldwide have undertaken deliberate measures to reduce the growing energy dependence of the built environment by fostering the education of sustainability-conscious professionals. Given that a significant share of global energy consumption is attributed to the building sector, the integration of sustainability-focused coursework into architectural curricula represents a logical and necessary progression [4]. Raising awareness among future generations of architects regarding the environmental impact of architecture on human behavior has become a critical concern in architectural education. As a result, schools of architecture have been increasingly compelled to integrate sustainability into their curricula and to advance the principles of sustainable architectural education [5].

A study from Nigeria examined the level of sustainability awareness and the extent to which sustainability principles are integrated into building design projects among architecture students, underscore the critical importance of embedding sustainability within architectural education from an early stage and ensuring that graduates are adequately equipped to apply sustainable practices in their future professional work [6].

A study conducted in India examining the impact of architectural education on architects' knowledge of sustainability emphasizes the importance of strengthening the role of architectural

education. It advocates for integrating a sustainable approach into both the profession and curriculum to position architecture as a leading contributor to sustainable development [1].

A study investigating the architectural education curricula of accredited institutions in Pakistan found that, although most programs emphasize sustainability concepts, many fall short in effectively transferring sustainability knowledge and facilitating its practical implementation due to the absence of a defined framework and methodology. The study recommends increasing the number of credit hours dedicated to sustainability, introducing a clear instructional framework, and ensuring continuous and frequent curriculum revisions as key measures to enhance the integration of sustainability into architectural education [7].

A study examining the role of architectural education in Nigeria in preparing professionals for sustainable architectural practice found that faculty development programs, interdisciplinary collaboration, and partnerships with industry can significantly enhance the integration of sustainability principles into the curriculum and support the adoption of innovative teaching methodologies [8].

A study involving academicians and architecture students in Northern Cyprus, which explored the link between architectural education and sustainable design, highlighted differing priorities between the two groups. While students identified "energy and atmosphere" and "indoor environmental quality" as key components of sustainable design education, academicians placed greater emphasis on "innovation" and forward-looking approaches [9].

Research from various countries highlights common challenges about architecture students' perceptions of sustainable architecture. Also equipping future architects with the competencies to design resource-efficient, environmentally responsible buildings is widely recognized, as architectural education plays a crucial role in shaping sustainable building practices. Global efforts in architectural education increasingly emphasize the integration of sustainability principles into curricula to address the construction industry's energy consumption and environmental impact.

3 METHODOLOGY

This study aims to evaluate architecture students' awareness and understanding of sustainability. To achieve this objective, the study first examined the courses in the architecture curriculum that address sustainability. The analysis focused on determining the proportion of sustainability-related content in both compulsory and elective courses in relation to the program's total credit requirements. Students' knowledge of sustainability may enable them to integrate this concept into their studies, even in the absence of a formal requirement within the course.

Istanbul Medipol University's School of Fine Arts, Design and Architecture is one of the institutions that prioritize fostering sustainability awareness in architectural education. Starting from the first year, the curriculum incorporates environmental sustainability through a combination of compulsory and elective courses offered each term, blending theoretical instruction with practical experience. The study sample comprises final-year students who have completed the program's graduation requirements. These students were surveyed to evaluate their perceptions of sustainable architecture. The questions focused on issues related to environmental sustainability, with the aim of evaluating students' understanding and attitudes toward sustainable design practices.

The survey includes multiple-choice questions which are related to the following subjects:

- Perspectives on sustainable design
- Priority criteria in a project where sustainability is at the forefront
- The place of sustainability in architectural education
- Courses associated with sustainable design in architectural education

3.1 Curriculum of Architecture Department in IMU

The Architecture Program curriculum comprises five course categories: compulsory courses, common compulsory courses, program-based electives, optional electives, and an internship. It outlines the required courses for each academic year and semester, along with the corresponding ECTS. To meet the graduation requirement, students must complete a total of 240 ECTS credits.

The curriculum includes 42 compulsory courses with a total value of 166 ECTS credits. To fulfill the 240 ECTS graduation requirement, students must complete a minimum of 46 ECTS credits from program-based and/or optional elective courses. The number and total ECTS credits of program-based electives offered each year are mentioned in Table-1.

Table 1. The number and total ECTS credits of program-based electives and Sustainablity related elective courses per years.

Year	*Total Elective Course nr.*	*Sustainability Elect. Course Nr.*	*Total Ele. Course ECTS*	*Sustainability Ele. Course ECTS*	*Ratio*
2021-2022	65	5	211	20	%9
2022-2023	65	5	211	20	%9
2023-2024	58	5	183	20	%11
2024-2025	37	5	153	20	%13

Compulsory and elective courses related to sustainability in the architecture department curriculum are presented in Table 2.

Table 2. Sustainability related courses in Architecture Department of IMU

Course Name	*Course Type*	*Term*	*ECTS*
Introduction to Environment and Sustainability	Elective	3	4
Sustainable and Healthy Urban Design and Planning	Elective	4	4
Design after Drought	Elective	5	4
Project Design after Drought	Elective	6	4
Sustainable Arc. and Green Building Rating Systems	Elective	6	4
Interdisciplinary Design Studio 1	Compulsory	4	4
Interdisciplinary Design Studio 2	Compulsory	7	4
Integrated System Design	Compulsory	8	7

"Introduction to Environment and Sustainability" is a course that covers a range of topics related to sustainable architectural practices including the principles of sustainable architecture; the efficient use of resources; life-cycle design; the selection and use of sustainable construction materials; passive solar design; and the integration of renewable energy sources in architectural applications. The course aims to provide a comprehensive understanding of environmentally responsible design approaches in the built environment.

"Sustainable Architecture and Green Building Rating Systems" is a course that introduces students to the concepts of sustainability, sustainable development, and sustainable architecture. It explores the objectives of green buildings, as well as the principles and functions of green building rating systems. The course aims to provide comprehensive knowledge on sustainable architectural practices, green building strategies, and the evaluation criteria used in recognized green building rating systems.

"Design after Drought" is a course that focuses on developing sustainable systems by minimizing dependence on external resources through the regeneration and multifunctional use of existing ones. It emphasizes the creation of self-renewing, self-repairing, and self-sustaining systems as a fundamental aspect of sustainability.

"Sustainable and Healthy Urban Design and Planning" is a course that examines a range of approaches and concepts through which design, planning, and policy are shaping the development of healthier, more sustainable, and more livable cities. The course addresses key topics such as green and eco roofs, healthy ecosystems within urban environments, sustainable city planning, the relationship between urban spaces and urban life, the definition and characteristics of a healthy dwelling, and the concept of smart and healthy homes.

"Interdisciplinary Design Studio 1" is a course designed for students of Architecture, Interior Architecture and Environmental Design, Urban Design and Landscape Architecture, and Industrial Design. The primary objective is to develop students' ability to define and address complex problems through design-oriented thinking methodologies, utilizing approaches specific to their respective disciplines. The course emphasizes collaborative research and design skills within the framework of assigned themes. Key components of the course include an introduction to the United Nations Sustainable Development Goals (UN SDGs), along with short seminars on topics such as Sustainable Cities, Accessibility, Smart Farming, and Disaster and Earthquake Resilience.

"Interdisciplinary Design Studio 2" aims to facilitate collaborative research and project development among students majoring in Architecture, Interior Architecture and Environmental Design, Urban Design and Landscape Architecture, and Industrial Design. This project focuses on collaborative design across disciplines to develop systems for alternative energy production and recycling. Students are expected to explore and apply methods such as photovoltaic panels, heat pumps, wind turbines, and water reuse systems (e.g., rainwater collection and greywater recycling). Emphasis is placed on using recyclable, eco-friendly, and sustainable materials.

“Integrated System Design” is a course that focuses on the preparation of application projects and tender documentation for the designs developed within the scope of the Interdisciplinary Studio 2 course. The project planning and management processes are carried out within a Building Information Modeling (BIM) environment to ensure coordination and efficiency. The primary objective of the course is to design sustainable, energy-efficient buildings that are environmentally conscious and make optimal use of natural and renewable energy sources.

3.2 Survey

I. Participants were asked whether they have incorporated sustainable design criteria into their design process through other means except for the compulsory and elective courses related to sustainability. The options provided include architectural projects developed within the Architectural Design Studio course, projects or research conducted as part of an elective course, or no such experience at all.

II. Participants were asked to rank a set of sustainability-related criteria in order of importance (1 being the most important and 8 the least) for a project developed within a conceptual framework of "Sustainability." The criteria to be evaluated include utilizing solar energy, recycling water, orientation according to directions, influence of weather conditions, recycling of waste, selection of ecological materials, application of green roofs, and the use of local materials.

III. Participants were asked to indicate the extent to which they agree with a series of statements using a 5-point Likert scale, where 1 represents "Strongly Disagree" and 5 represents "Strongly Agree." The statements include: "I first came across the concept of sustainability

during my university education," "I first came across the concept of sustainable design during my university education," "The issue of sustainability should have an important place in architectural education," and "The structure and content of the courses I took are sufficient for understanding sustainable design."

IV. Participants were asked to rate the extent to which different areas of study were covered in course content related to sustainable design throughout their architectural education, using a 5-point scale ranging from 1 ("Not Included at All") to 5 ("Included to a Great Extent").The areas assessed include urban design, architectural design, interior design, green area design, restoration and renovation, material selection, and energy-efficient systems.

V. Participants were asked to evaluate the extent to which they agree that specific fields of study should be integrated into architectural education with a focus on sustainable design. Using a 5-point Likert scale where 1 means "Strongly Disagree" and 5 means "Strongly Agree", they are asked to assess the importance of including the following areas: urban design, architectural design, interior design, green space design, restoration and renovation, material selection, energy-saving systems, and systems for water reuse.

4 SURVEY RESULTS

The survey was distributed to fourth-year architecture students enrolled in both the Turkish and English programs Out of a total of 329 students who received the survey, 42 completed it, resulting in a participation rate of 13%.

The results of the first survey question, which asked whether students had incorporated sustainable design criteria into their design process outside of the compulsory and elective sustainability-related courses, are as follows: The majority of students (62%) reported integrating sustainable design principles into their work in the Architectural Design Studio course. Additionally, 24% stated that they applied these criteria within the scope of elective courses.

The result of the second question of survey, which is about ranking the criteria they would implement in a project with a conceptual framework of 'Sustainability,' in order of importance, is as follows: %38 of the students ranked "Utilizing solar energy (producing hot water, electricity, etc.)" and %43 of the students ranked "orientation according to directions (natural lighting, sun-shadow analysis, temperature effects, etc.)" is the most important criteria.

The results of the third survey question, which asked students to indicate their level of agreement with a series of statements using a 5-point Likert scale (1 = "Strongly Disagree" to 5 = "Strongly Agree"), are presented in Figure 1. The responses reveal that most students were first introduced to the concepts of sustainability and sustainable design during their university education. Notably, the statement "sustainability should hold an important place in architectural education" received a "Strongly Agree" rating from more than half of the participants.

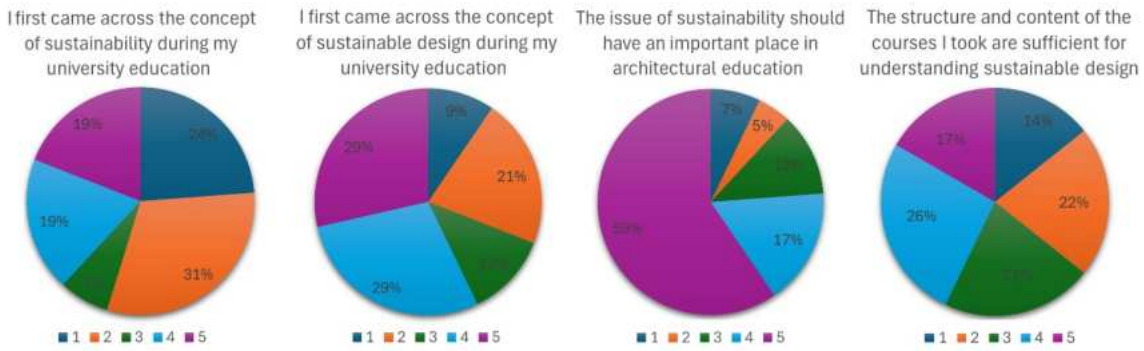

Figure 1. Students' level of agreement with a series of statements

The results of the fourth survey question, where students rated the extent to which various subject areas were covered in course content related to sustainable design during their architectural education using a 5-point scale (1 = "Not Included at All" to 5 = "Included to a Great Extent"), are presented in Figure 2.

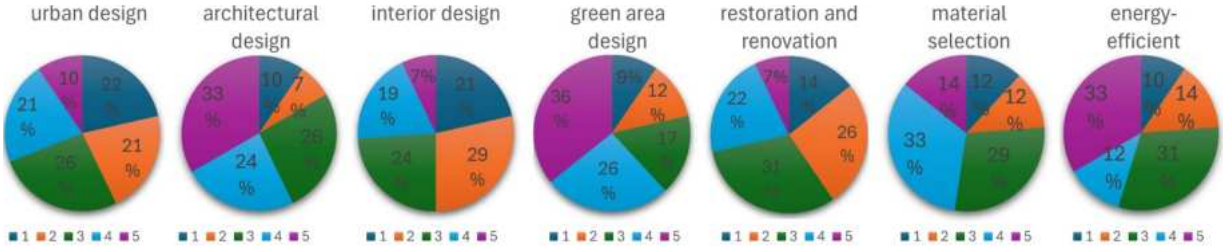

Figure 2. Student ratings about the extent to which various subject areas were covered in course content related to sustainable design

The result of fifth question of survey, which is about their opinion on the fields of study should be integrated into architectural education with a focus on sustainable design using a 5-point Likert scale where 1 means "Strongly Disagree" and 5 means "Strongly Agree", is presented in Figure 3.

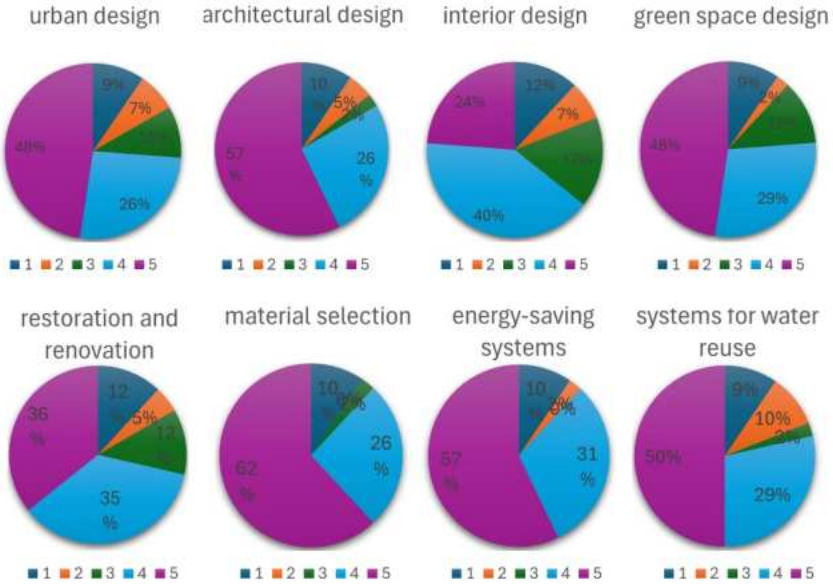

Figure 3. Students' opinions on the fields of study should be integrated into architectural education with a focus on sustainable design

5 DISCUSSION

The survey findings offer key insights into how architecture students view and incorporate sustainability in their education and design studios.

Starting with the first question, most students (62%) reported integrating sustainable design criteria mainly through their work in the Architectural Design Studio course, rather than just through dedicated sustainability courses. Additionally, 24% of students reported using sustainability criteria in elective courses, showing that these courses play a significant role in broadening students' understanding of sustainable design.

The second question asked students to rank sustainability criteria by importance in design projects. The results indicate a strong emphasis on environmental responsiveness. The finding that students ranked "using solar energy" (38%) and "orientation based on directions" (43%) as the most significant criteria suggests that they understand the importance of renewable energy and passive

architecture. These choices are in line with contemporary sustainable architecture best practices, which emphasize ecologically conscious and energy-efficient design.

This finding shows that there is broad agreement that sustainability needs to be more fully integrated into the curriculum. It also demonstrates how well students comprehend the significance of sustainability for the built environment's future.

In order to provide a summary of the curriculum's coverage, the fourth question asked students to score the degree to which various sustainability concepts were covered in their classes.While the detailed results are shown in Figure 1, this question helps assess how successfully sustainability is incorporated across various subjects in the program. This broad examination of the course titles can identify any weaknesses and potential areas for improvement in sustainability education.

Overall, these results indicate that architecture students are actively engaged with sustainability, mainly through their studio work and elective courses. Their focus on using solar energy and climate-responsive design shows their awareness of practical ways to reduce environmental impact. Furthermore, the strong support from students for including sustainability in education stresses the need to keep developing the curriculum to prepare architects for future environmental challenges.

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Educating for Sustainable Futures: The Role of Turkish Architecture Curricula in Advancing the UN SDGs

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ABSTRACT

This study investigates the extent to which architecture departments in Turkish universities—specifically those accredited by the MiAK-MAK (Architectural Accreditation Board)—contribute to the achievement of the 17 United Nations Sustainable Development Goals (SDGs). As universities worldwide increasingly align their strategies with the SDG framework, understanding the specific role of academic programs, such as architecture, become crucial for fostering sustainability and addressing global challenges.

The research focuses on the curricular content of all accredited architecture programs in Turkey, aiming to assess the relative weight of architectural courses in relation to the broader SDG commitments of each institution. Through a detailed mapping of course offerings, pedagogical approaches, and institutional sustainability strategies, the study evaluates how architectural education supports specific SDG targets. Special attention is given to critical themes such as climate-responsive design, energy efficiency, sustainable materials, social equity, and interdisciplinary collaboration, which are central to achieving sustainable development in the built environment.

Ultimately, this research aims to position architectural education as a more evidence-based, strategic, and effective driver of sustainable development, supporting the advancement of the architecture profession and helping institutions fulfill their sustainability commitments in Turkey and beyond.

Keywords: Architectural education, sustainability, curriculum development, sustainable development goals (SDGs)

1 INTRODUCTION

The growing environmental, social, and economic challenges of the twenty-first century, including resource scarcity, urban inequality, climate change, and biodiversity loss, have made sustainable development a key topic in academic discussions. To guide efforts across various fields and sectors, the United Nations updated the 2030 Agenda for Sustainable Development in 2015. This agenda now includes 17 Sustainable Development Goals (SDGs) [1]. It is acknowledged that Higher Educational Institutions play a critical role in accomplishing these objectives and need to include sustainability in their operations, research, teaching, and community engagement [2,3].

In this broader context, architecture education plays a crucial role. The built environment directly impacts several SDGs, including SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate

Action), SDG 7 (Affordable and Clean Energy), and SDG 12 (Responsible Consumption and Production). Decisions in architecture influence social inclusion, economic stability, public health, and environmental quality [4,5]. Therefore, architecture schools face two important tasks: they must train professionals who can tackle complex sustainability issues and also support the global sustainability agenda.

Recent studies show that design studios, elective courses, and thematic modules often incorporate sustainability into architectural curricula [6,7]. However, this integration is still inconsistent and fragmented. It often contains only vague references to sustainability and does not always align with SDG targets [8]. Moreover, there is a lack of thorough research evaluating how architecture programs engage with the SDGs as an integrated framework. This is especially true in rapidly urbanizing settings, even though global guidelines like the UNESCO-UIA Charter for Architectural Education emphasize sustainability as a key skill.

While many Turkish institutions have included sustainability in their strategic goals, how deeply these principles are woven into the curricula is still largely unexplored. This study aims to fill that gap by analyzing all undergraduate architecture programs in Turkey that are accredited by MiAK-MAK (Mimarlık Akreditasyon Kurulu, the Architecture Accreditation Board of Türkiye) as of 2025. MiAK-MAK accreditation offers a helpful framework for assessing curriculum focus and indicates compliance with national and international standards for architectural education. This study will look at how architecture programs reflect the 17 UN Sustainable Development Goals (SDGs) by examining publicly available course titles, focusing on key topics such as climate-responsive design, sustainable materials, energy efficiency, social equity, and community involvement.

2 LITERATURE REVIEW

To prepare future professionals with technical skills and a commitment to social and environmental responsibility, architecture schools worldwide are gradually including the Sustainable Development Goals (SDGs) in their programs. This is in line with the 2030 Agenda of the United Nations [9]. According to Wiek et al. (2011), this integration demonstrates a heightened understanding of the critical role that higher education plays in advancing sustainable development [10].

A global effort to connect higher education institutions (HEIs) with sustainability goals includes embedding SDGs in architecture education. Schools are urged to include key SDGs, especially SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action), in both design studios and theoretical classes. Frameworks such as the UIA/UNESCO Charter for Architectural Education [11] and accreditation requirements that emphasize sustainability serve as a baseline for integration [12,3]. These frameworks place a strong emphasis on instructional methodologies that integrate technical knowledge with social, ethical, and environmental concerns.

Salama and Burton (2022) point out that actual implementation of SDGs in curricula varies, despite growing policy support for sustainability in architecture education [13]. While sustainability is often part of design studio projects, thorough engagement with all 17 SDGs is uncommon, according to their comparative study across nine countries. This aligns with findings by Lozano et al. (2013), who argue that sustainability in higher education often remains fragmented and specific to certain sectors rather than being fully integrated [14].

In a similar approach, Moondra and Khan (2024) provide a framework that highlights goal alignment, awareness of the context, and social inclusion for integrating SDG objectives in undergraduate architecture studios [15]. Their research indicates that students are more engaged and understand design challenges better when they connect directly to practical SDG targets such

as affordable housing and low-carbon infrastructure [15]. According to their findings, active learning and problem-based learning are crucial for improving sustainability skills [16].

Also, studies by region show different levels of SDG integration progress. For instance, El-Kholei and Yassein (2023) examined architecture programs in Egypt and found that although sustainability concepts are taught, students often lack a strong ethical commitment to sustainable design [8]. They attribute this to insufficient faculty development focused on sustainability teaching and weak curriculum integration. Other regions face similar challenges, underscoring the need for institutional support and faculty development on a global scale [17,18].

Design studios remain the main setting for exploring SDG-related topics in architectural education. Akgün, Doğrusoy, and Özsöyler (2024) noted that second-year design studios in Turkey were specifically focused on SDGs such as resource efficiency, inclusivity, and climate responsiveness [6]. Their study shows that when design briefs relate directly to SDG goals, students' critical thinking and awareness of sustainability improve. However, recent assessments of Turkish architecture programs suggest that while some courses cover sustainability and urban resilience, the integration of the full SDG framework remains limited and inconsistent [6].

Incorporating all 17 SDGs into architectural education requires systematic approaches as Türkiye engages more with global sustainability agendas. Possible actions include implementing assessment tools, enhancing faculty training, and developing frameworks across the curriculum to measure the effectiveness of sustainability education [19,20]. Future architects need to be ready to address complex environmental, social, and economic issues of sustainable development in a comprehensive way, which demands these efforts.

3 METHOD

3.1 The Sample

This study focuses on architecture departments accredited by the Mimarlık Akreditasyon Kurulu (MiAK-MAK). MiAK's mission is to improve the quality of architectural education through accreditation, external evaluations, and advisory activities. The organization aims to enhance societal well-being and the quality of both natural and built environments by promoting excellence in architectural practice. MiAK collaborates with educational bodies to support architectural education through skills-based assessments and recommendations. Accordingly, the selection of MiAK-accredited programs as the basis for this study is considered appropriate, as accreditation signifies commitment to recognized international standards and to continuous improvement in architectural education.

3.2 Data Collection

To examine their conformity with the 17 Sustainable Development Goals (SDGs) of the UN, we collected the titles of both required and elective courses offered by architecture departments authorized by the Mimarlık Akreditasyon Kurulu (MiAK-MAK). The following requirements were used to determine which programs were included in the sample: they had to offer a full-time undergraduate architecture degree, be currently accredited by MiAK-MAK as of 2025, and have an official website with an up-to-date, publicly accessible curriculum or course listing.

The first step of the data collection process was the examination of course titles that were posted on faculty or departmental websites. These course titles were compiled into a database for each department and categorized according to their thematic significance to particular SDGs. The compliance of each course with one or more of the 17 Sustainable Development Goals was then coded.

As a second step, we attempted to detect indirect links between the course titles and SDG's. Identifying these indirect links enables a more thorough understanding of how architecture education connects with sustainability across several dimensions.

The study faced several limitations, however. First of all, we decided to restrict the analysis to course titles as detailed curriculum content was unavailable for some departments. However, since course titles may not fully reflect the actual content, some sustainability-related topics embedded within studio themes or courses might have been overlooked. Notwithstanding these limitations, the study provides a scalable and reproducible method for tracking the inclusion of SDGs in architectural education and provides insightful information on curriculum trends in various universities.

4 FINDINGS

MIAK-MAK has authorized 17 architectural programs at private universities and 11 at public universities as of 2025. The following descriptive data show that 71 courses in all were found to be aligning with the 17 UN Sustainable Development Goals:

Table 1. Course Alignment with SDGs

SDG Number	*SDG Title*	*Course Count*
3	Good Health and Well-being	2
6	Clean Water and Sanitation	1
7	Affordable and Clean Energy	14
9	Industry, Innovation and Infrastructure	5
11	Sustainable Cities and Communities	20
12	Responsible Consumption and Production	5
13	Climate Action	22
15	Life on Land	8

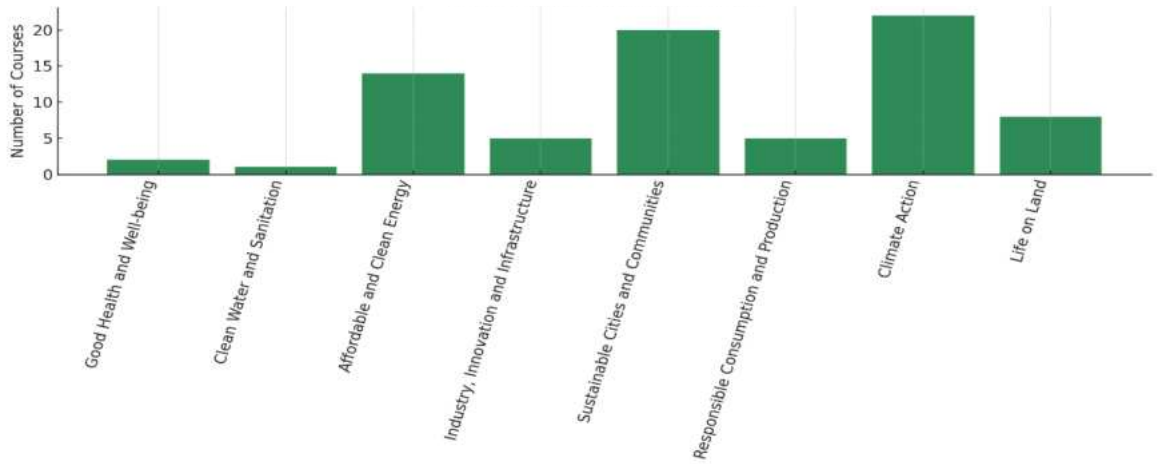

Figure 1. Course Alignment with SDGs

We conducted an additional analysis of SDG alignment by examining indirect links, resulting in the following table:

Table 2. Course Alignment with SDGs

SDG Number	*SDG Title*	*Course Count*	*Indirectly Linked SDGs*
3	Good Health and Well-being	2	SDG 10 (Reduced Inequalities), SDG 4 (Quality Education)
6	Clean Water and Sanitation	1	SDG 2 (Zero Hunger), SDG 15 (Life on Land)
7	Affordable and Clean Energy	14	SDG 8 (Decent Work), SDG 9 (Industry, Innovation)
9	Industry, Innovation and Infrastructure	5	SDG 17 (Partnerships), SDG 8 (Decent Work)
11	Sustainable Cities and Communities	20	SDG 1 (No Poverty), SDG 5 (Gender Equality), SDG 16 (Peace, Justice)
12	Responsible Consumption and Production	5	SDG 8 (Decent Work), SDG 13 (Climate Action)
13	Climate Action	22	SDG 15 (Life on Land), SDG 12 (Consumption)
15	Life on Land	8	SDG 2 (Zero Hunger), SDG 13 (Climate Action)

5 DISCUSSIONS

The analysis of 71 architecture-related courses reveals a clear alignment with multiple United Nations Sustainable Development Goals (SDGs). In particular, SDG 13 (Climate Action) and SDG 11 (Sustainable Cities and Communities) are the most well represented, underlining the emphasis on urban sustainability and ecological resilience. Additionally, SDG 7 (Affordable and Clean Energy) and SDG 15 (Life on Land) are represented in curricula, highlighting a focus on energy efficiency and natural solutions.

On the other hand, SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 10 (Reduced Inequalities) are missing from course titles, indicating potential gaps that warrant curricular enhancement. The integration of interdisciplinary approaches and a greater focus on social sustainability may promote a more thorough educational framework that is more in line with all 17 SDGs.

Additional connections between a number of goals are revealed by examining the indirect connections between architecture courses and the Sustainable Development Goals (SDGs). SDG 13 (Climate Action) is associated with the highest number of courses, totaling 22. It is also indirectly related to SDGs 12 (Responsible Consumption and Production) and 15 (Life on Land), emphasizing the interdependence of ecosystem preservation, climate action, and sustainable resource use.

SDG 11 (Sustainable Cities and Communities), with 20 courses, is indirectly related to social goals such as SDG 1 (No Poverty), SDG 5 (Gender Equality), and SDG 16 (Peace, Justice and Strong Institutions). This suggests that while social sustainability is not always directly addressed, it is linked through themes of urban and community development.

Indirect links between SDG 8 (Decent Work and Economic progress) and SDG 9 (Industry, Innovation, and Infrastructure) and SDG 7 (Affordable and Clean Energy), which is covered in 14 courses, suggest that energy-related subjects are intertwined with infrastructure development and economic progress. Other goals like SDG 3 (Good Health and Well-being) and SDG 6 (Clean Water and Sanitation) appear in fewer courses but are indirectly linked to key goals such as SDG 10 (Reduced Inequalities), SDG 4 (Quality Education), SDG 2 (Zero Hunger), and SDG 15 (Life

on Land). This reflects that these areas may be underrepresented but still relevant within architectural education.

Overall, the indirect link analysis shows that architecture curricula address the SDGs in a complex and interconnected way, and there are opportunities to enhance the focus on social and health-related goals.

Certain goals, like Climate Action (SDG 13) and Sustainable Cities and Communities (SDG 11), predominate the curriculum according to a review of the direct and indirect connections between architectural courses and the SDGs. Related topics like resource utilization, social sustainability, and ecosystem protection are also linked to these objectives. Other important goals, such as Good Health and Well-Being (SDG 3) and Clean Water and Sanitation (SDG 6), are indirectly related to relevant SDGs, despite the fact that they are underrepresented. This implies that the way architecture education now approaches the SDGs is connected but skewed, with a greater emphasis on urban and environmental issues and a lesser emphasis on social and health issues.

6 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

By examining the course titles that correlate to each of the 17 Sustainable Development Goals (SDGs) of the UN, this study examined how undergraduate architecture curricula relate to these goals. The findings show imbalance in the priority given to the various SDGs in the curriculum. The results indicate that SDGs 11 (Sustainable Cities and Communities) and 13 (Climate Action), together make up the majority of the course titles and imply that environmental sustainability, energy efficiency, and urban resilience are the main topics of current architectural education.

SDG 7 (Affordable and Clean Energy) and SDG 15 (Life on Land) are moderately represented in course titles, reflecting an emphasis on clean energy technologies and nature-based design strategies. There is a clear underrepresentation of social and economic SDGs, including SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender Equality), and SDG 10 (Reduced Inequalities), indicating a gap in the curricula regarding broader sustainability objectives. In particular, issues of equity, social justice, and inclusivity seem to receive little direct attention, even though they are connected to the curriculum. To create a more complete education that fits all SDGs, curricula should broaden their focus to include social sustainability, health, and interdisciplinary viewpoints. This change would encourage a more balanced and well-rounded understanding of sustainable development.

As far as limitations of the current study are concerned, future research should extend beyond course titles to include a detailed analysis of syllabi, learning objectives, and teaching materials, providing a more comprehensive understanding of how thoroughly the SDGs are integrated into architecture curricula. Additionally, looking into how both faculty and students view the importance of the SDGs and their willingness to engage with sustainability can help find challenges and opportunities for better curriculum design.

Comparative studies across different institutions, both in Türkiye and abroad, as well as research that tracks curriculum changes over time, can provide valuable insights into new trends and effective practices in sustainable architectural education. Examining collaborations between architecture and related fields like social sciences, engineering, and public policy can also help develop more complete and innovative methods for sustainability education.

Additionally, it is important to assess how curricula focused on the Sustainable Development Goals (SDGs) impact graduates' skills, career choices, and contributions to sustainability. These evaluations can guide improvements to the curriculum based on solid evidence. By focusing on these areas, academic programs can better meet the goals of sustainable development. They can

prepare future architects to create solutions that are environmentally safe, socially fair, and economically viable.

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Study of The Characteristics of Ancient Adobe Used in a Heritage Ksar (Jnane Ba El Kadi, Marrakech, Morocco)

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ABSTRACT

This study aims to develop compatible and sustainable earth bricks for the restoration of historic monuments in Morocco, where earth construction, widely used in pre-Saharan regions and medinas, is now regaining importance in the face of eco-construction challenges. Samples of adobe dating from the 19th century were taken from the facades of the historic Ksar of Jnane El Kadi in order to analyze their physical and mechanical characteristics, which are comparable to those of modern materials. The results showed that stabilized clay soils have interesting density and performance characteristics, confirming that, despite the passage of time, adobe remains a durable material, provided it is regularly maintained, and is therefore a suitable solution for the conservation of local built heritage.

Keywords: Architecture, Adobe, Historic Site, Restoration, Marrakech.

1 INTRODUCTION

For thousands of years, raw earth has been one of the most widely used building materials by humankind to meet its housing and infrastructure needs. Naturally available, it has the advantage of adapting to different geographical and climatic contexts, which has enabled it to contribute to the construction of an exceptional heritage recognized worldwide [1]. In Morocco, particularly in the Haouz plain and the pre-Saharan regions, the richness and diversity of vernacular earthen architecture testify to the cultural and constructive value of this material. The main techniques used, such as rammed earth and adobe, have enabled the construction of ksours, kasbahs, ramparts, and urban complexes of great architectural quality [2]. This traditional architecture, passed down from generation to generation, was not the result of scholarly design by architects, but rather of empirical and collective know-how, the fruit of long experience in the field, a perfect mastery of local materials, and the strong creativity of master builders. It thus reflects essential social and cultural values such as equity, community cohesion, and respect for the environment.

Today, the use of earth as a building material is attracting renewed interest in the context of sustainable development and ecological architecture. Many contemporary projects, particularly in the Marrakech region, are reviving this traditional material by promoting its use in modern, environmentally friendly constructions [3]. The built heritage of earth, whether historic monuments or more modest urban complexes (housing, public facilities, fortifications, etc.), represents not only a unique cultural and artistic heritage, but also a living environment that conveys identity and memory. Its preservation and rehabilitation have become priorities for urban policy, both to revitalize old neighborhoods, enhance tourist appeal, and boost the local economy [4].

In this context, this study is part of efforts to promote earth as a sustainable building material and to enhance Morocco's architectural heritage. It aims to develop compatible and resistant earth bricks suitable for the restoration of historic monuments, while providing a scientific and technical basis for the development of the earth sector in contemporary construction projects.

2 MATERİALS AND METHODS

2.1 Presentation of the study area

One of the characteristics of our area of intervention is the presence of one of the oldest earthen buildings constructed in the late 19th and early 20th centuries in the city of Marrakech.

This architectural heritage is located in a vast garden planted with olive trees, now known as Jnane Ba lkadi. The building served as a two-story pavilion.

At the foot of the pavilion is a large basin fed by water from the mountains located 30 km from the city, which served as a water reservoir to irrigate the olive groves.
The pavilion is designed on a long, simple rectangular plan (4.5 x 40 m) with a height of 9 m.

Among the construction techniques used are rammed earth on the ground floor and terracotta bricks on the two upper floors.

Figure 1. Site location

Figure 2. Current state of the pavilion (Jnane bal kadi)

2.2 Macroscopic analysis

Visual examination of the sun-dried adobe brick (Figure 3) reveals a heterogeneous composition characteristic of non-industrialized natural materials. The presence of silt, gravelly particles, and rock fragments of varying sizes, integrated into the clay matrix, is clearly visible. This coarse texture suggests that the brick was made from local soil, without extensive grain sorting, probably extracted near the construction site. The abundance of coarse elements, particularly rock fragments, indicates that it came from soil with mixed grain size [5], which is common in regions where adobe is still made by hand, directly on site.

Figure 3. Sample fragment, 15 cm long

3 RESULTS ANS DİSCUSSİONS

Given its natural heterogeneity, identifying the raw material is a crucial step in the decision-making process regarding the choice of construction technology for transforming earth into building material. When considering earth that could be used for construction, it is important to carry out a few identification tests. There are two types of tests that can be performed on earth: in situ tests and laboratory tests. Both provide the information needed to make a decision about the use of earth.

3.1 Sedimentation test

The sedimentation test is a process in which particles of material (gravel, sand, silt, clay) move and gather in layers that vary in number and proportion. It allows us to identify the textural fraction of the soil and the quantities of its distinct fractions [6].

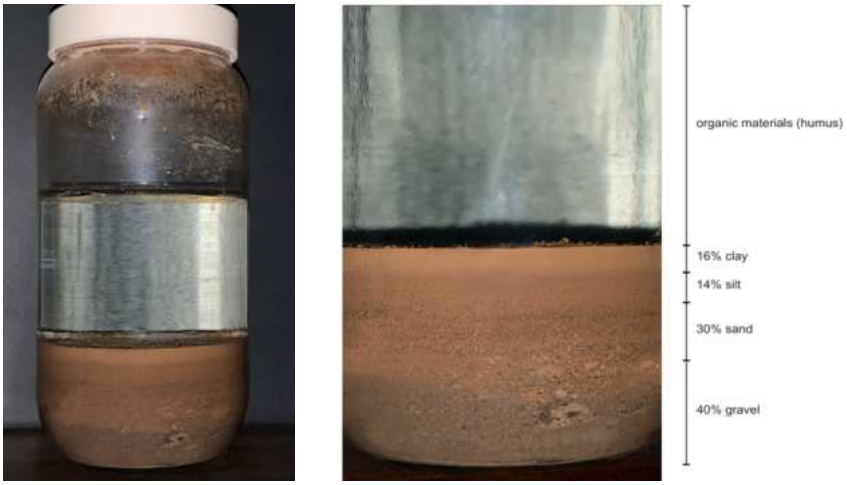

Figure 4. Soil sedimentation test at intervention site

We can see that the mixture is separated into four layers: approximately 40% gravel at the bottom of the bottle, topped by a 30% layer of sand, followed by a 14% layer of silt, and finally a 16% layer of clay. Organic debris floats on top of the water.

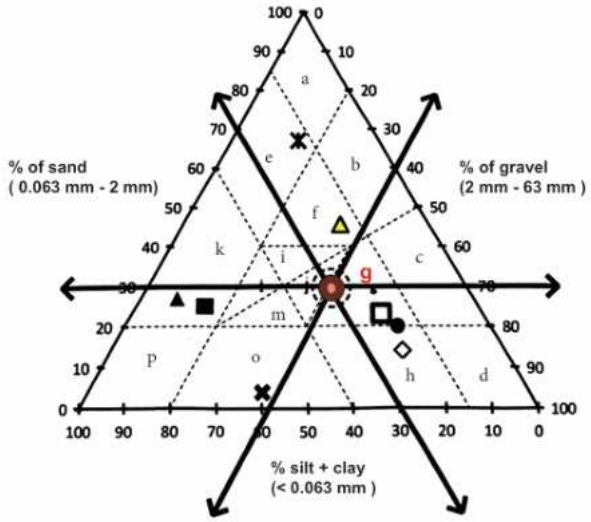

Figure 5. Location of debris from the wall of KSAR JNANE BA EL KADI.

According to the triangular diagram of soil classification granularity (NF EN ISO 14688-2 standard of April 2005), the intervention area has soil that is silty-sandy gravel/clayey-sandy gravel.

Based on these results, the clay sample was classified according to the McManus diagram (Figure 5). These materials have moderately high porosity and average permeability according to this classification. According to the literature, the particle size distribution of raw materials directly affects the properties of the final bricks produced [7].

According to the CRATerre standard [8], it can be said that the soil used to manufacture bricks in Jnane B'Lkadi is well suited to earth construction, particularly the adobe technique, as the percentages of clay and silt are within the recommended ranges.

3.2 Mechanical resistance to compression

Mechanical compressive strength is currently the most important topic attracting the attention of researchers, especially in the field of bio-housing, with a view to reducing the harmful effects of modern materials on humans and their environment.

Three clay samples, S_1, S_2, and S_3, were taken from the debris of the KSAR JNANE BA EL KADI wall located northwest of the city of Marrakech in western Morocco.

The experimental force-elongation curves (Figure 6), obtained from compression tests, were used to determine compressive strength. These parameters, detailed in the table below (Table 1), are:

Table 1. Geometric and mechanical properties of test specimens for compression testing.

Sample	*a x b x h (mm)*	F_{max} *(N)*	R_c *(N/mm²)*
S_1	155 x 110 x 63	4420	0,259
S_2	135 x 105 x 65	3255	0,229
S_3	140 x 95 x 75	4135	0,310

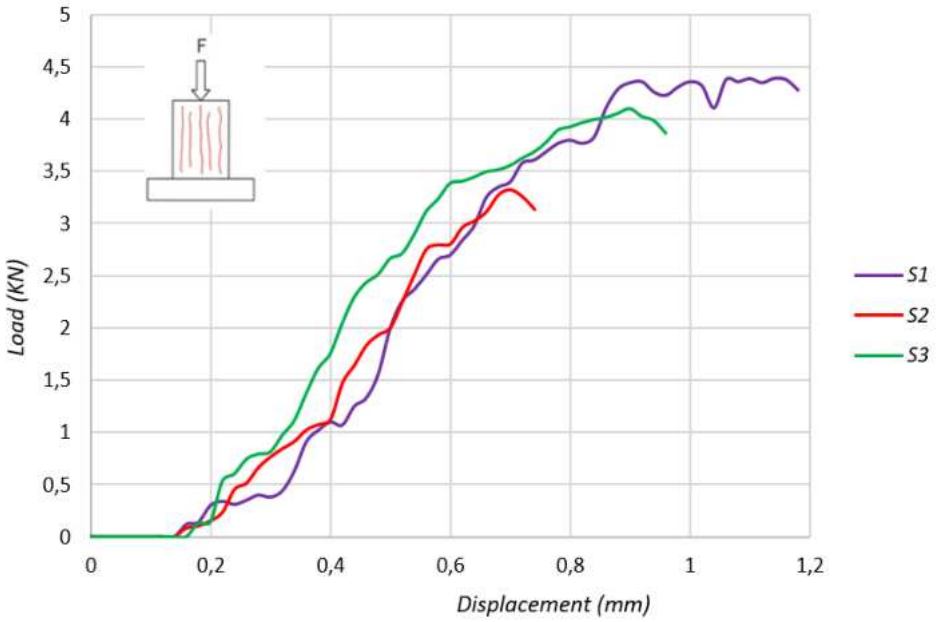

Figure 6. Experimental force-elongation curves F-d for compression tests

The experimental compressive strength results obtained for the tested samples (S1, S2, S3), ranging from 0,229 MPa to 0,310 MPa, are within a range comparable to that reported in the literature (Table 1) for adobe bricks from traditional constructions in several countries. Indeed, these values are close to those measured in Portugal (1,17 MPa) and Mexico (1,18 MPa), slightly higher than some values observed in Italy (0,29 MPa), but lower than the higher resistances recorded in Colombia (3,03 MPa) and Morocco (2,83 MPa), the latter having been obtained by in situ tests using a sclerometer [9, 10].

Based on analyses carried out on adobe and bibliographic research conducted on other building materials (concrete blocks, fired bricks, etc.), adobe can be classified as a local building material with physical and mechanical properties equivalent to those of modern building materials [11].

4 CONCLUSİON

Analysis of elements designed to reinforce old buildings, from a cultural perspective, this approach is also particularly valuable for old buildings, ensuring the continuity of their heritage.

Adobe construction has existed for centuries and is known for its durability and resistance to various stresses and actions. This experimental work gives us a clear idea of this durability through various identification tests carried out on the physical and mechanical properties of adobe.

At the end of this practical section, and based on examples of adobe constructions around the world and the tests we have carried out, we can conclude that time has no negative influence on the durability of adobe, i.e., the resistance of adobe blocks does not decrease over time, and with

simple and regular maintenance work, adobe can be classified as the most suitable building material locally.

5 ACKNOWLEDGMENTS

The authors would like to thank the Modeling and Simulation in Mechanics and Energy (MSME) team at the Faculty of Sciences in Rabat for their technical support during the compression tests.

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Deterioration of Historical Masonry Monuments: The Calcarenite Stone of The Moroccan Atlantic Coast (Bouknadel)

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ABSTRACT

Calcarenite stone from the Atlantic coast is the most widely used natural material in the construction of historic monuments in the Moroccan cities examined in this study. This gray, compact, and hard calcarenite has suffered irreversible damage due to the enrichment of atmospheric aerosols with pollutants such as sulfur dioxide, nitrates, heavy metals, and sea salts like chlorides. The present work forms part of the broader effort to conserve built heritage by studying the alteration mechanisms of building stones in historic monuments. Understanding these mechanisms is essential to develop strategies that ensure the longevity of this heritage for future generations.

Given that existing studies are often incomplete and the traditional expertise of craftsmen is diminishing, this research focuses on the degradation of Bouknadel calcarenite. Initial characterization was performed on small cubic blocks (5 × 5 × 5 cm) of virgin material sourced directly from Bouknadel quarries. Physical and mechanical properties, including volume, density, porosity, and mechanical strength, were measured to assess the stone's initial state.

Accelerated aging tests involving salt crystallization through imbibition-drying cycles were then conducted. Results revealed the stone's fragility and low resistance to salt weathering, highlighting the critical role of salts in degradation processes. This study emphasizes the need to further investigate the impact of environmental factors such as temperature and salt composition on stone decay. Such knowledge is vital for restorers to select appropriate materials that can withstand climatic extremes and ensure the durability of restoration works.

Keywords: restoration, calcarenite stone, geotechnical tests, salt crystallization, imbibition-drying cycles

1 INTRODUCTION

Stones used in the construction of historic monuments are exposed to environmental conditions over very long periods of time, which can lead to their gradual degradation. Calcarenite was widely used in the construction of most of the cultural heritage buildings in Atlantic Morocco, such as the famous Kasbahs of Oudaya and Challa. Calcarenite undergoes a progressive degradation mechanism where the stone's surface can become pulverized or cracked. Today, these stones show considerable damage in many monuments, particularly due to alveolar weathering, which is often very intense.

Indeed, alterations linked to the presence of soluble salts in building stones induce textural and mineralogical changes in these stones. Halite (NaCl) and especially gypsum ($CaSO_4.2H_2O$), produced by the dissolution of calcite and its recombination with dissolved sulfur, are among the most common and destructive salts. These salts are the cause of many types of degradation encountered on monuments, such as crusting, slabbing, sandy disintegration, and honeycombing. A

widely used method for experimentally simulating natural in-situ weathering and observing the behavior of stones in the laboratory when exposed to different weathering agents is to perform imbibition-drying cycles ([1] [2] [3] [4]).

Accelerated aging tests using cycling were conducted on calcarenite (mined at the Bouknadel quarry) a sandstone-limestone with a high total porosity of around 45%. Calcarenite is widely used in the construction of historic monuments in the Rabat-Salé-Kenitra region. The stone underwent imbibition-drying cycles. Imbibition is carried out in the presence of saline solutions of different concentrations of NaCl and a dilute solution of sulfuric acid H_2SO_4 ([5]).

2 MATERIALS AND METHODS

2.1 Study Areas and sample collection

Historical Context and Location

We sampled the rock from the abandoned Sidi Bouknadel quarry (34°108′660″ E, -6°747′942″ N) (Fig. 1). This region benefits from a Mediterranean climate with Atlantic influence, characterized by an average annual temperature of 13.5 °C and average annual precipitation of 450 mm. Approximately 60% of the rainfall occurs between October and December. The rocks are calcarenites, a sandstone cemented by micritic calcite ([6]). Historically, this stone has been used in the construction of all the historical monuments in the region.

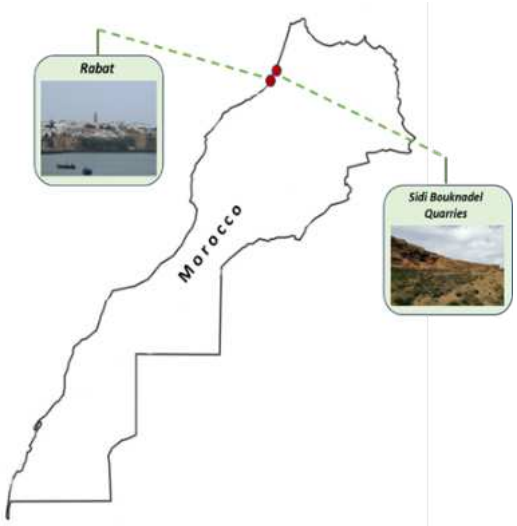

Figure 1. Map of Morocco with location of study sites mentioned in this paper.

Indeed, the historical monuments and old medinas of Morocco belong to the Islamic civilization and to other periods of Roman, Portuguese, and Spanish colonization, and are built using local limestone. Despite past conservation efforts, many of these Moroccan monuments still suffer from severe deterioration. The most common forms include alveolization, differential weathering, efflorescence, decohesion, exfoliation, and detachment (Figure 2).

Figure 2. Some Types of Deterioration Found on Historical Monuments in the Rabat-Salé Region

2.2 Material and Methods

2.2.1 Characterization of the Calcarenite Rock

Bouknadel calcarenite, a Plio-Quaternary ornamental stone from quarries near Rabat and Salé, exhibits high porosity (18–47%) and permeability but poor geotechnical quality. It is mainly composed of calcite (50%), quartz (40%), and shell fragments, with grain sizes between 0.2- and 0.8-mm. Mechanical tests indicate low compressive strength (<10 MPa), typical of soft rocks ([7]).

2.2.2 Sampling

Several stone samples required for laboratory tests and analyses were collected from the Sidi Bouknadel quarries and selected from a homogeneous rock mass. These samples were prepared in cubic form, with dimensions set at 5 cm × 5 cm × 5 cm (Fig. 3).

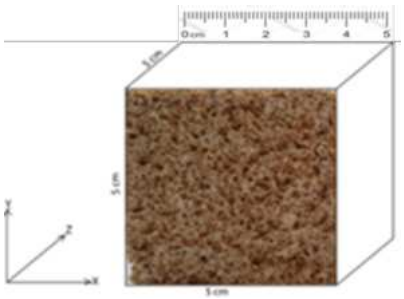

Figure 3. Calcarenite sample from the Bouknadel quarry, dimensions: 5 × 5 × 5 cm

2*.2.3 Procedure's experimental*

Artificial weathering tests using imbibition–drying cycles with sodium chloride, sodium sulfate, and distilled water revealed the Bouknadel calcarenite's high vulnerability to salt-induced deterioration. Samples showed progressive damage, including efflorescence and easily detached salt crusts, due to crystallization pressure within the stone's pores (Fig. 4) [8]). These results confirm the material's susceptibility to saline stress, particularly in marine and polluted urban settings, emphasizing the need for targeted conservation strategies to protect structures made with this culturally important stone ([9] [10] [11]).

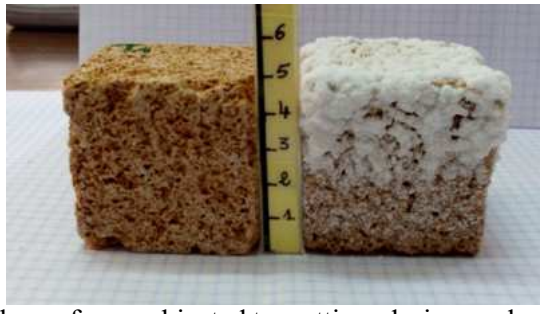

Figure 4. Salt deposits on the surfaces subjected to wetting–drying cycles after the final drying stage.

2.2.4 Analytical techniques

The surface condition of the samples was monitored after each wetting–drying cycle, with most stages of the experiment documented through photographic records. At the end of the aging cycles, the physical properties of the weathered stones were determined and compared to those of the untreated reference samples (Control). Notable differences were observed among the various treated specimens in terms of salt distribution (manifesting either as efflorescence or sub-florescence) along with distinct damage patterns and material responses during salt crystallization.

Macroscopic color changes and surface alterations were systematically documented using photographic techniques. Following visual inspection, the assessment of physical properties was carried out through water saturation methods, enabling the evaluation of porosity variations and material degradation linked to salt-induced stress ([9]).

3 RESULTS AND DISCUSSION

The figures present the observed deterioration characteristics of stone samples exposed to saline solutions in the laboratory. After 25 wetting–drying cycles in 10% Na_2SO_4 and NaCl solutions, the samples showed signs of degradation: salt efflorescence, increased water absorption, and visible damage starting from the second cycle. Progressive surface expansion and weight changes peaking in the second week indicated significant salt retention (ranging from 5.3 to 6.16 g, with an average of 5.85 g). Capillary absorption of Na_2SO_4 showed no significant differences among the tested stones, suggesting relatively uniform porosity.

3.1 Visual Changes and Mass Evolution of Samples Exposed to Distilled Water

When calcarenite samples are subjected to imbibition-drying cycles using distilled water, only minor changes in appearance are generally observed. As illustrated in (Fig. 5), mass variation across cycles remains minimal. The application of 25 wetting–drying cycles with pure water was not sufficient to induce significant structural changes within the samples. This suggests that, in the absence of soluble salts or aggressive agents, distilled water alone has a limited impact on the physical integrity of the calcarenite under the tested conditions.

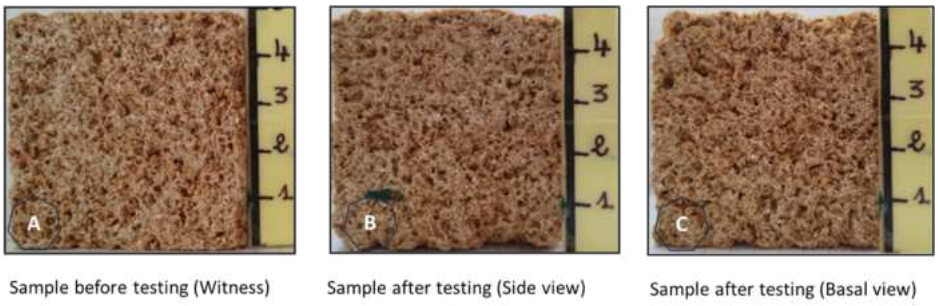

Figure 5. Texture Modification of Calcarenite Samples Exposed to Distilled Water

A slight color change can be observed between samples A and B, while surface roughness appears to be reduced. On the submerged face of sample C, minor grain degradation is visible, which corresponds to a slight decrease in mass (Fig. 6).

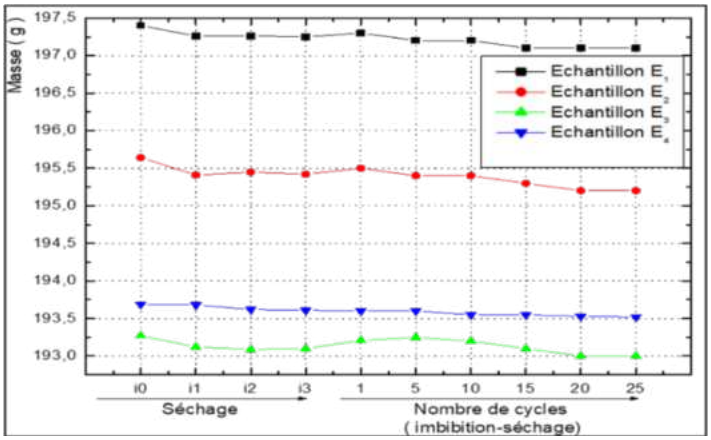

Figure 6. Evolution of mass as a function of the number of cycles

3.2 Visual Alteration and Mass Variation of Calcarenite Samples Degraded by Sodium Sulfate (Na_2SO_4)

Photographs and data show the degradation of calcarenite samples exposed to a 10% sodium sulfate solution over 22 days and multiple cycles. Early signs included salt efflorescence and surface expansion due to salt crystallization. Mass increased notably in the second week, reflecting salt absorption. Degradation became visible after 2–3 exposure cycles, with grain detachment and roughness. By the seventh cycle, chemical attack signs (brownish grains) appeared, and after 25 cycles, mass loss confirmed ongoing deterioration from salt crystallization and subflorescence (Fig. 7).

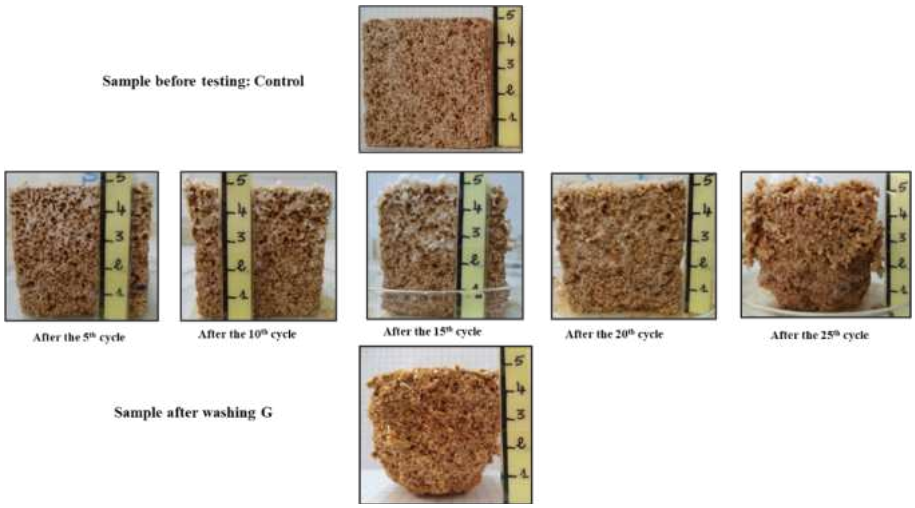

Figure 7. Volume Reduction of Calcarenite Samples Following Aging Test with Sodium Sulfate

The mass loss observed from the 20th cycle onward indicates that a portion of the grains precipitated on the sample surface were degraded during submersion in the sodium sulfate solution. A significant mass reduction was recorded after grain detachment and rinsing, confirming material loss from the stone matrix (Fig. 8).

During the wetting–drying cycles, degradation began with a competition between two opposing processes: a mass increase, attributed to salt absorption and secondary gypsum formation (gypsum results from the reaction between calcite and sodium sulfate within the pores), and a mass decrease, resulting from material disintegration. This degradation phase started around the 5th cycle and continued until the 25th cycle in most samples.

At this stage, the corners of the samples became noticeably rounded, and grain detachment increased, contributing to a visibly rougher surface texture.

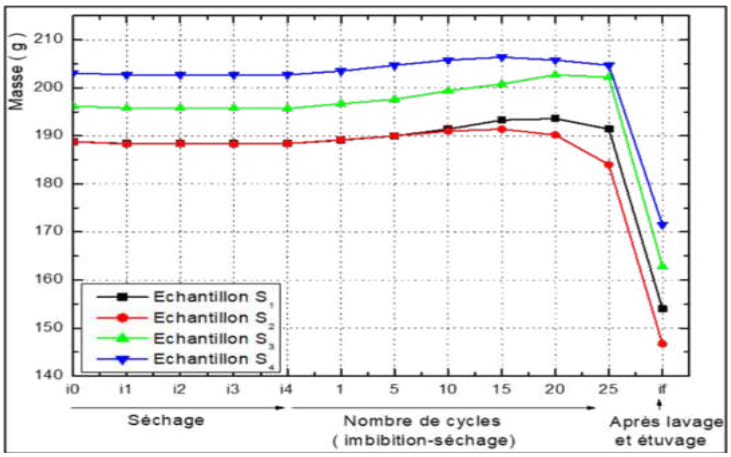

Figure 8. Mass Evolution of Calcarenite Samples Exposed to Na_2SO_4 Solution During Wetting–Drying Cycles

3.4 Visual Alteration and Mass Evolution of Calcarenite Samples Degraded by Sodium Chloride (NaCl)

Significant morphological changes were observed in the calcarenite samples throughout the wetting–drying cycles (Fig. 9). A control sample (A) shows the state of the calcarenite prior to the aging test, while sample G represents the same specimen after 25 cycles and subsequent rinsing.

Samples B through F illustrate the intermediate stages of degradation during the aging process. From the 5th cycle onward, visible salt crystallization began to form on the stone surface, gradually developing into a white crust, particularly concentrated toward the upper portion of the samples as a result of capillary rise and evaporation (Fig. 9).

Mass changes over the cycles reflected this accumulation and subsequent degradation, with salt deposits contributing initially to an increase in weight, followed by material loss due to granular disintegration and surface erosion.

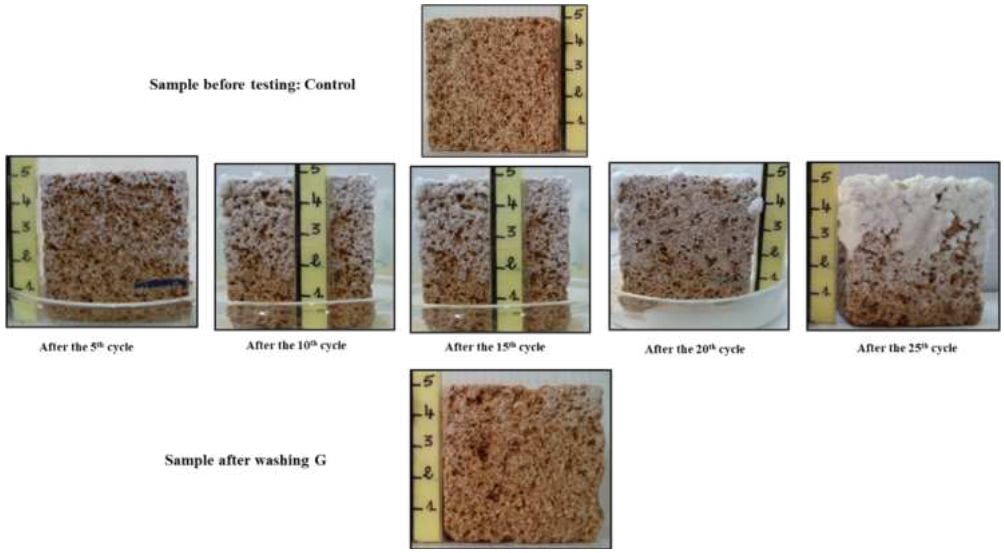

Figure 9. Texture Modification of Calcarenite Samples Exposed to Sodium Chloride (NaCl)

Salt crystallization tests on calcarenite samples showed progressive degradation over repeated wetting–drying cycles. While no damage was visible in the first cycle, surface alterations appeared by the second or third due to NaCl crystallization pressure. By the 15th cycle, white saline crusts began forming and thickened with further exposure. At the 25th cycle, mass increased due to internal salt accumulation, and the NaCl crusts detached easily. Sample E showed surface roughening and color change after cleaning, indicating salt-induced degradation. Salt accumulation was mainly near the exposed surface, suggesting uneven porosity changes from sub-florescence. Mass evolution data (Fig. 10) trace the stages of this salt-related deterioration.

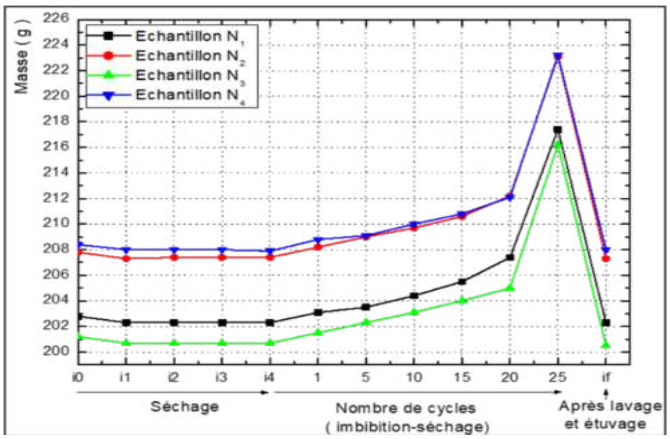

Figure 10. Mass evolution of calcarenite samples exposed to NaCl solution as a function of the number of wettings–drying cycles.

3.5 Post-Test Porosity

Macroscopic analysis of the samples at the end of the wetting–drying cycles (Figure 11) shows that the Bouknadel calcarenite is unimodal, with most of the pore space concentrated in a size range between 1.5 mm and 0.5 mm.

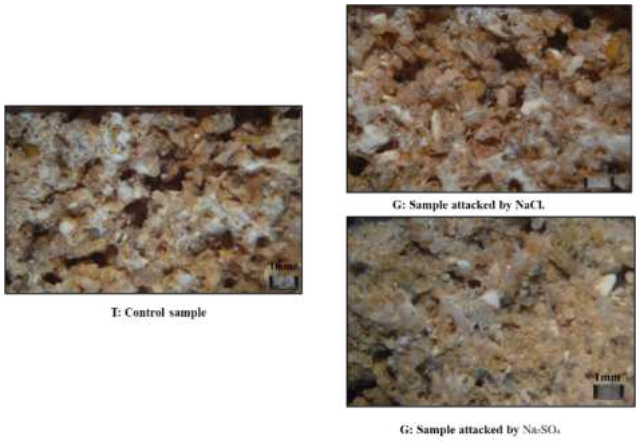

Figure 11. Comparison of porosity before and after testing

3.6 Weathering Products

After washing the samples at the end of the imbibition–drying cycles, the recovered filtrates revealed the presence of two primary salts: sodium chloride (NaCl) crystals in the NaCl test, and gypsum [$CaSO_4 \cdot 2H_2O$] crystals in the Na_2SO_4 test (Fig. 12). These salts crystallize within the rock's pore network, inducing internal stresses that contribute to the deterioration of the material. The extent of weathering varies depending on the type of salt, as some salts are more damaging than others, and is further influenced by salt concentration ([12]).

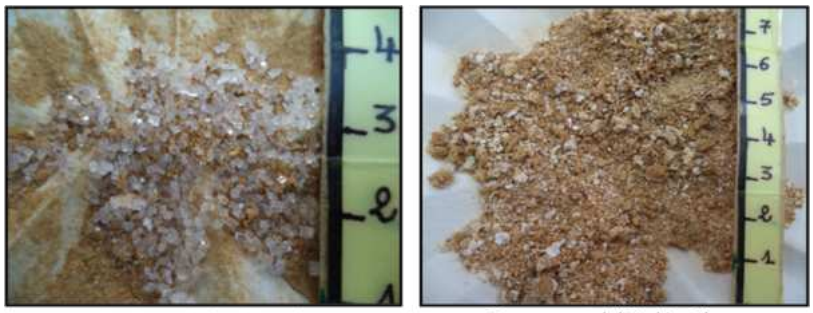

Figure 12. The filtrates

The Bouknadel calcareous sandstone, valued for heritage use, is highly vulnerable to environmental degradation, especially in coastal and urban climates. Key deterioration processes include surface blackening and crust formation caused by sulfate attack from atmospheric SO_2. Experimental studies confirm that salts like halite, thenardite, and especially gypsum lead to significant material loss through surface disintegration after repeated wetting–drying cycles. The stone's high porosity and interconnected pores enable rapid water infiltration, accelerating salt crystallization and weathering. Despite some variation, the stone shows generally uniform behavior, indicating consistent composition. Further testing under simulated marine and rainfall conditions is needed to develop effective conservation strategies.

4 CONCLUSION

The calcareous sandstone of Bouknadel, despite its recognized heritage and ornamental value, presents a marked vulnerability to natural degradation agents, particularly salts, due to its high porosity and low mechanical strength. This study, through an accelerated aging protocol combining saline immersion and washing cycles, has shed light on the specific alteration mechanisms affecting this lithotype. The results demonstrate that while the stone shows relative resistance to sodium chloride crystallization, it remains highly sensitive to gypsum formation. These findings underscore the critical role of pore structure and mechanical fragility in the stone's deterioration processes. In this context, an in-depth understanding of the physico-mechanical properties and site-specific environmental stresses is essential for developing effective preventive conservation strategies, especially in humid and marine environments. Given the evolution of conservation practices in Morocco, from traditional stone replacement to modern preservation approaches, the integration of multi-method evaluation techniques provides a robust framework for anticipating and mitigating the degradation of heritage materials.

5 ACKNOWLEDGMENTS

The authors thank the Géoressources Laboratory **LGR** (Hassan II Agricultural and Veterinary Institute) for its technical support in carrying out the aging tests.

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Earth Roof and Green Roof in Türkiye

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ABSTRACT

Permanent structures, which began with the adoption of a settled life, were constructed from materials readily available in the immediate vicinity, especially in rural areas, from the earliest times. Stone, earth, and wood were the primary materials used. Environmental conditions also influenced the construction techniques. Roof coverings were also constructed from materials found in the immediate vicinity and shaped according to geographical features. Flat roofs were constructed in arid regions, while sloped roofs were preferred in rainy regions. In Anatolia, the use of earth roofs was first seen among the Hittites in the 1600s BC. This practice, which dates back to much earlier times, continues today.

When it comes to today's technology, reinforced concrete structures have been used mostly since the industrial revolution both in the world and in our country, and with climate change, environmental problems and energy efficient construction becoming important, the concept of green roof has developed and started to spread rapidly.

This study aims to highlight the use of earth roofs in Türkiye, which have been in use for thousands of years, and the increasing use of green roofs today. This process highlights the millennia-long use of earth for roofing and highlights the advantages of its continued use as a structural element. Today, the use of earth for roofing continues, albeit with some variation, throughout the ages. This study aims to highlight the sustainability of earth roofs, both throughout history and today, and to reiterate their benefits.

Keywords: Traditional buildings, earth roof, green roof, advantages of earth roofs, types of earth roofs, history of earth roofs

1 INTRODUCTION

The use of soil in building began with the transition of a settled life. Soil was widely used in ancient civilizations throughout the world. For example, the use of soil as a building material in Mesopotamia dates back 10,000 years. The use of soil in building is seen in all climates, hot, cold, and temperate. Due to its affordability and easy accessibility, it was widely used until the late 19th century. From then on, the introduction and widespread use of concrete in the construction industry led to a decline in the use of soil materials. With the widespread use of reinforced concrete, soil structures continued to be used by low-income groups, making them less preferred by high-income groups [1]. Despite the widespread use of building materials following the Industrial Revolution, approximately 30% of the world's population still lives in earthen buildings [2].

However, the recent energy crisis and environmental pollution have brought into question the construction materials and industry in many countries, leading to efforts to return to earthen

structures with new technologies. And indeed, today the use of soil as a building material has come to the fore again in developed economies [1]. Studies are ongoing worldwide on the use of cement, lime, and certain chemicals to strengthen soil against water. In our country, Ruhi Kafesçioğlu's formula provides a water-resistant soil building material. Especially Prof. Dr. Bilge Işık is carrying out personal and institutional studies on this subject in our country and in another study of her, enzyme and polymer based additives were used for waterproofing of adobe structures and it was determined that these substances increased the resistance of the soil to water [3].

The aim of this study is to highlight the thousands of years of use of earth as a roof covering in Türkiye. The study will highlight the process and diversity of its use in traditional buildings, as well as examples of its use in contemporary structures. The economic, social, and environmental impacts of earth roofs will be discussed. Ultimately, the aim is to highlight the importance of this topic for the preservation of traditional structures.

The study methodology was conducted through a literature review, theoretical knowledge was provided, and then earth roof applications were presented. Tables for these sample roof applications were created and analyzed. Green roof applications, which were created by adapting soil materials for use on contemporary roofs, were also presented both as theoretical information and as practical examples. In addition to theoretical and practical examples, the study also explored the historical process of using soil as a roof covering.

2 USE OF SOIL FLAT ROOF (DAM) AND GREEN ROOFS IN TODAY'S BUILDINGS IN TÜRKİYE

Traditional architecture in Türkiye has been shaped by the materials available and climatic conditions in the immediate surroundings. For example, in the Black Sea and Marmara regions, where rainfall is heavy, sloped roofs are preferred, while in the Mediterranean, Aegean, Eastern, and Southeastern Anatolia regions, flat earth roofs are preferred. In continental climates, especially in regions with prolonged snowfall in winter, clearing accumulated snow from roofs is quite challenging. Despite this difficulty, flat earth roofs have continued to be used for reasons such as high thermal insulation and affordability [4], [5]. Today, buildings play a significant role in the climate crisis and the rise in environmental pollution. One of the measures taken to address this is the practice of covering roofs with soil. This practice, known as green roofing, has become quite widespread in Türkiye.

This section discusses soil roofs under two subheadings. The first section focuses on soil roofs used in traditional structures, and the second section discusses green roof applications in contemporary buildings.

2.1 Earth Roof Applications in Traditional Buildings

Earthen roofs must have emerged around the time humans began building. Hittite-era building remains indicate that their roofs were flat earthen roofs, used as terraces, as they are today. It is estimated that roofs in Anatolia were constructed as flat earthen roofs until the late 2000s BC. [6].

Soil offers many benefits, including high thermal comfort, high insulation properties, moisture control, recyclability, and affordability. In Türkiye, soil roofs are generally flat. Flat soil roofs are also used as living spaces for activities such as drying vegetables and preparing food. The application of flat earth roof varies by region. The most common schemes for this application are shown in Figures 1a and 1b as two basic application examples. In this application, the ceiling carrier (base) is formed by round-section beams with a diameter of 15-25 cm as the load-bearing structure. These beams are spaced 30-50 cm apart along the short side of the space. The use of a 2 cm thick wooden sheathing or a layer of vegetation (reeds, twigs, wicker) over the wooden beams that form the ceiling floor is seen in Figures 2 and 3., 10 cm layer of soil is laid over this wooden layer. This application example demonstrates the most basic flat roof construction technology. Of course, these applications

vary by region and climate. For example, in some applications, nylon is laid over the wooden sheathing layer for insulation [7], [8]. Another method for insulation in flat soil roofing is to lay a layer with a high amount of clay on the soil or sometimes to mix this clay with straw 'Fig.4' [9].

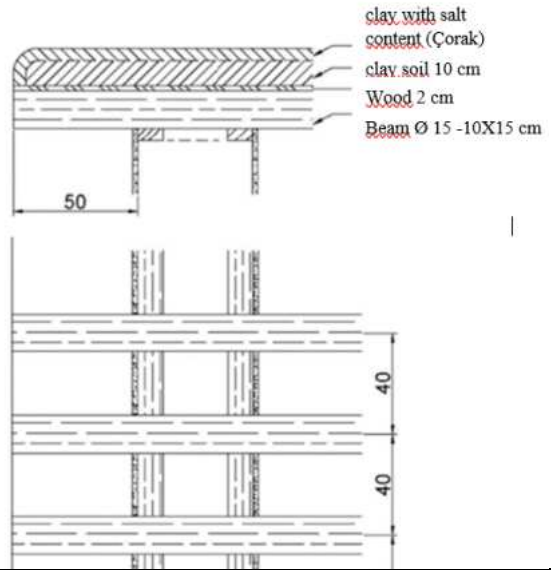


Figure 1 a. Flat soil roof application example (earthen roof with eaves) [10]

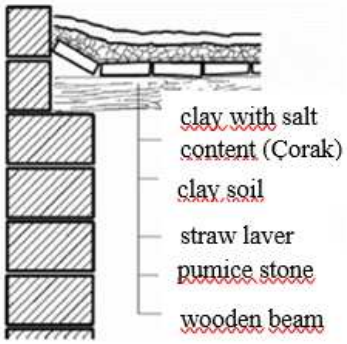


Figure 1 b. Soil roof layers (eavesless roof) [9]

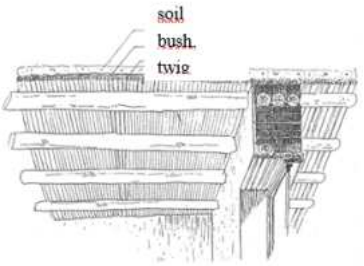


Figure 2. Example from Kayseri where thin bush and twig were used instead of wood on the beams [4]

Figure 3. Twings and reeds placed over the beams [11]

Figure 4. Clay with salt content (Çorak) [11]

Gravel can also be laid on top of this mud. In some regions, mud made by adding salt to clay for insulation purposes is called 'çorak' (barren) (a type of mud) and this mud is spread over the entire surface. The use of salt also provides protection against roof pests. Earth roofing materials can be applied with or without eaves 'Figs 5a and 5b', 'Fig 6'.

Figure 5a., 5b. Application of earthen roof with eaves in Diyarbakır (Photo: Şefika Ergin)

Figure 6. Diyarbakır eavesless roof application (Photo: Şefika Ergin)

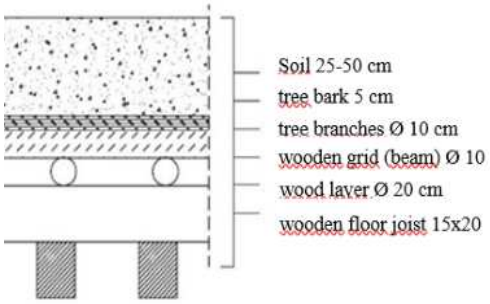
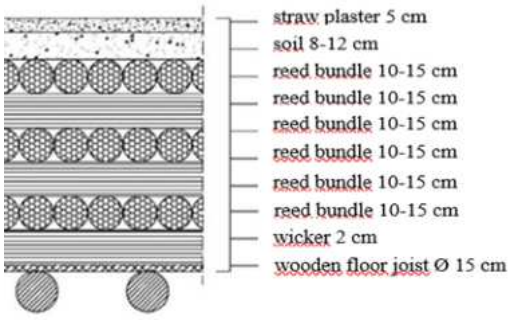
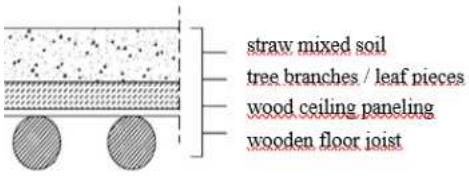
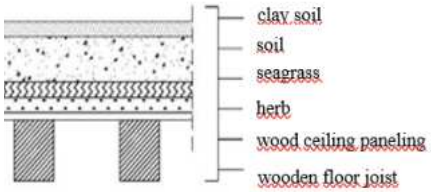
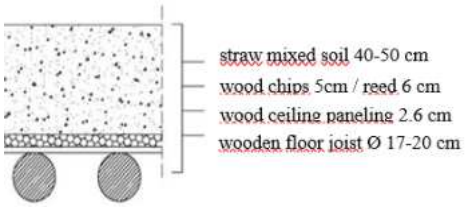
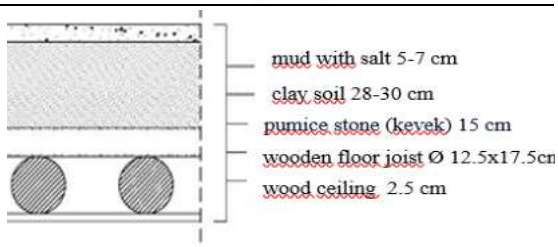
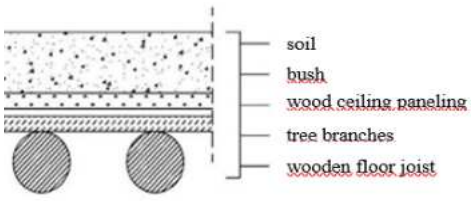
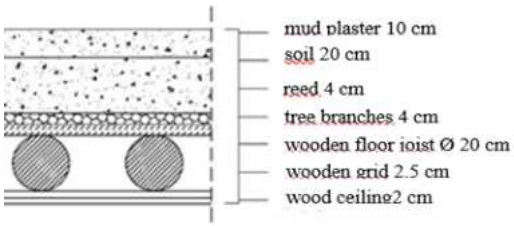
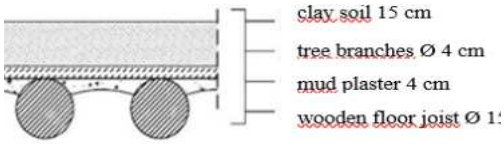
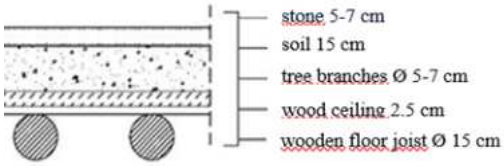
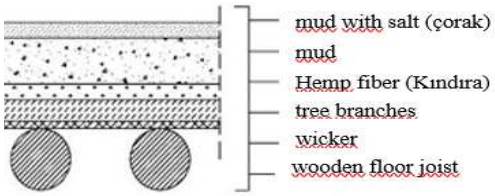
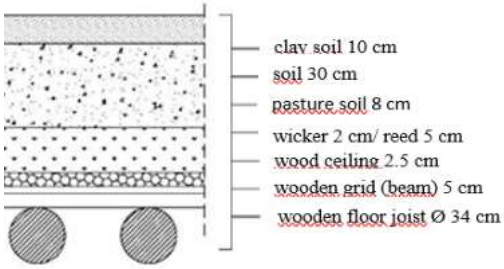
In some applications, the soil thickness reaches 30-40 cm, and in the southern regions, 50 cm 'Figs. 7a and 7b'. All these layers are compressed using a heavy cylinder called a loğ stone 'Fig. 8' [9], [4]

Figures 7a, 7b. Example from Siverek Houses where the soil thickness is greater [12]

Figure 8. Loğ stone (Photo: Berfin Akçay)

Many different applications and details have been developed regarding earth roof applications depending on the region [Table 1].

Table 1. Sections of different application examples [edited from source 13]

Region	*Layers of the section in the roof covering*	*Region*	*Layers of the section in the roof covering*
1- Antalya - Muğla/ Fethiye		2-Konya / Akşehir / Yeşilköy	
3-Mersin / Bozyazı / Dereköy		4- Çanakkale / Ayvacık	
5- Diyarbakır		6- Kayseri / Ağırnas	
7-Manisa		8-Bitlis	
9-Ankara, Eskişehir ve Afyon		10- Erzincan / Kemaliye	
11-Konya		12- Erzurum	

2.2 Green Roofs in Today's Buildings

Green roofs were built as terraces on Ziggurats in ancient Mesopotamia from 4000 BC to 600 BC. Stairs leading to the top of the ziggurats provide access to terraced gardens built along the pyramidal heights 'Figure 11'. In the hot climate of Babylon, these gardens of ziggurats provided people with opportunities for rest and cooling off [URL-1].

Figure 11. An image resembling a ziggurat built by King Ur-Nammu in Babylon [URL-1]

The most well-known example of rooftop gardens is the Hanging Gardens of Babylon, built by King Nebuchadnezzar for his wife in 500 BC. Some sources state that the trees in these gardens grew up to 15 meters. 'Figs. 12a and 12b'. These gardens were used both as gardens and for insulation by many civilizations in Mesopotamia [14], [URL-1]. It is believed that a bitumen-like material was used for waterproofing in the Hanging Gardens of Babylon [15].

Figs 12a. Hanging Gardens of Babylon [15]

12b. Hanging Gardens of Babylon [URL-1]

Later applications of such roof gardens were encountered in villa structures during the Roman period in the 1st century A.D. Roof gardens and courtyards were also used in palace structures during the Byzantine period, from the 5th to the 13th centuries. Roof garden design resurfaced at the 1867 Paris World's Fair with Carl Rabite's roof model. Le Corbusier and Frank Lloyd Wright contributed to the popularization of green roofs [15], [16].

Whether flat or green roofs, soil has always been present in human structures. Flat roofs have been used in Türkiy for thousands of years. While their popularity has declined with their use among low-income residents, the use of soil in green roofs has resurfaced. This development is leading people to re-evaluate soil structures and roofs, highlighting the importance of sustainability.

Due to numerous reasons, including current environmental pollution, the trend toward making buildings more environmentally friendly has become increasingly important. In this

process, green roofs have also become a hot topic alongside the concept of sustainability. It is generally suggested that green buildings can reduce energy use by 24% to 50%, CO^2 emissions by 33% to 39%, water consumption by 30% to 50%, solid waste by 70%, and maintenance costs by 13% compared to standard buildings (United States Green Building Council, USGBC) [17].

Compared to the entire building, roofs play a significant role in these criteria because they are a crucial structural element exposed to all external influences. Green roofs have also become crucial for overall building sustainability. In addition to their energy-saving benefits, green roofs also offer economic, environmental, and social benefits.

Green roofs vary in terms of the materials used and the thickness of their applications. Figure 9 shows the required layers for general application principles.

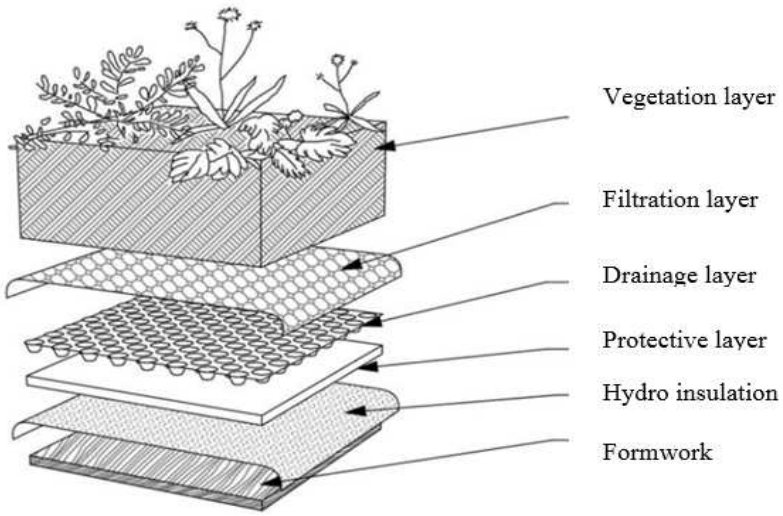


Figure 9. Green roof layers (Adapted from the work of Joshua Woodsman)

Plants and the Vegetation Layer: This layer allows plant growth and also allows water to accumulate. This soil layer can be made in varying thicknesses and with different mixtures.
The Filtration Layer: Prevents small plant particles from entering the drainage layer.
The Drainage Layer: Collects excess water in its perforations and, if necessary, drains the remaining water away from the roof. It also protects the waterproofing from plant roots.
The Protective Layer: (also called the Root Retention Layer) protects the waterproofing from growing plant roots.
Hydro insulation-The quality of this layer is crucial for the protection of the roof.
The Formwork roof construction must be capable of providing the necessary strength for roof loads [18].

Beyond this general approach, green roofs can be designed in many different ways, but they are generally grouped. Green roofs are divided into two groups based on their planting methods: intensive and extensive roof systems.

- Intensive green roofs are characterized by a thicker soil layer (more than 15 cm deep) due to the dense vegetation and include trees and large plants as vegetation. When the vegetation is well planned, this type of roof can accommodate biodiversity.
This type of roof can be installed on new buildings with prior planning. This type of roof is expensive to maintain and is preferred for visually significant structures. These roof types are also more suitable for social use.

- Extensive (intensive) green roofs utilize plants with less soil depth and require little maintenance. Plant species that require little or no irrigation are preferred on these roofs. Unlike intensive roofs, these roofs utilize herbaceous plants, shrubs, and grassy vegetation. These roof solutions are designed primarily to protect, enclose, insulate, and contribute to the environment. Therefore, these roof types have fewer social uses [19], [20] Intensive and extensive green roof layers based on soil layer thickness are shown in Figs. 10a. and 10b.

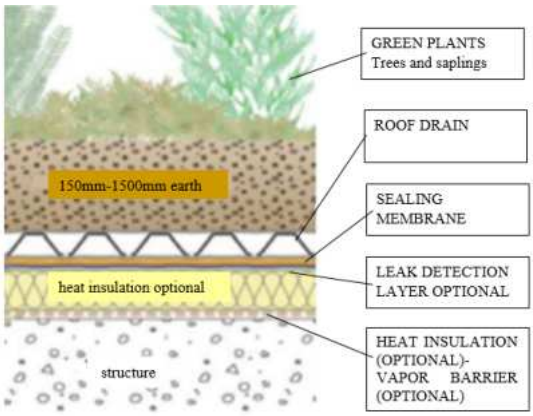


Figure 10a. Intensive green roof layers

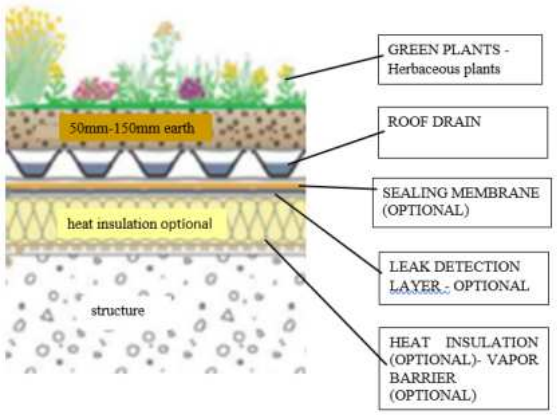


Figure 10b. Extensive green roof layers

Adapted from the source by [9]

Intensive green roof layers;
Green plants - Trees and saplings
Roof drain - Excess water drainage (geotextile laminate on top and bottom)
Sealıng membrane - Root barrier (Optional)
Leak detectıon layer - Optional
Heat ınsulatıon (Optional)- Vapor barrier (Optional)

Extensive green roof layers;
Green plants - Herbaceous plants
Roof drain - Store and drain excess water (geotextile laminate on top and bottom)
Sealıng membrane - Root barrier (Optional)
Leak detectıon layer - Optional
Heat insulation (Optional)- vapor barrier (Optional) [İner G., Çağlarer E., 2013]

In addition to these two basic applications, semi-intensive applications are also used. Semi-intensive roof systems are a blend of intensive and extensive roof types. In other words, the soil thickness and vegetation are located between the roofs in these two systems [21].
[22], [23]. A look at examples of green roofs implemented in Türkiye reveals a growing number of applications in recent years. Several notable examples are included in this study (Table 2).

Table 2. Examples of green roofs

examples	images	
Meydan Shopping Center Ümraniye, Istanbul, 2007 Green roof 30,000 m² Roof type **extensive** (sparse) [22]		
	[22]	[URL 2]

Forum Istanbul Shopping Mall
Bayrampaşa, Istanbul
Green roof 3,500 m²
Roof type **intensive**
[22]

[22]

Turkcell R&D Building
Gebze, Istanbul, 2008
Green roof 2,500 m²
Roof type **extensive**
[24]

[25]

Four Seasons Hotel
Beşiktaş, Istanbul
Green roof 1000 m²
Roof type **extensive**
[22]

[22]

Zorlu Center Shopping Mall
Ulus, Istanbul 2013
Green roof 72,000 m²
Roof type **intensive**
[URL- 3].

[URL 3]

[URL-43]

Küçükçekmece Municipal Service Building
Küçükçekmece, İstanbul 2014.
Green roof 3,600 m²
Roof type **extensive** (sparse)
[URL-5]

[URL-5]

2. 3 Findings

The examples in Table 1 demonstrate that traditional earth roof applications in Türkiye utilize specialized details and readily available materials suited to climate conditions. The material layers and thicknesses were modified according to the needs of the region's climate. These specialized solutions ensured the roof was designed to provide the most economical and energy-efficient construction. While the soil thickness was reduced in warmer regions, a thicker layer of soil was used in colder and hotter regions to control thermal conductivity. This reduced energy consumption.

Specialized solutions have also been developed using materials found in the immediate surroundings. For example, roofing materials used on wooden joists include tree branches, wood siding, even leaves, shrubs, and reeds. In coastal areas, it's seagrass (meadows) and, where stone is readily available, stone veneer.

The materials used in traditional buildings are remarkably meticulous and environmentally friendly. Industrial and polluting materials are generally avoided, and natural materials sourced from the nearest available area are used. This environmentally friendly approach is crucial for preserving the ecological balance.

The special solutions and advantages of traditional earth roofs are also seen in green roof applications.

Green Roofs when considered in terms of general benefits;

- Green roofs prevent heat islands that occur due to the heating of reinforced concrete surfaces.
For example, in hot climates, when air temperatures rise to 35 °C, the roof surface temperature can reach 65 °C. Green roofs maintain this temperature at ambient temperatures.
- In cities, concrete surfaces can prevent rainwater from being absorbed by the soil, causing floods. Because green roofs are covered with soil, much of the rainwater is absorbed by the soil or can be diverted to storage areas within the roof for later use through established systems. This feature of green roofs can reduce or even prevent flooding.
- By providing protection against soil, heat and UV rays on the roof, it extends the life of the roof and reduces maintenance costs.
- It improves air quality by absorbing harmful gases released from traffic and industry. The vegetation on green roofs adds oxygen to the environment, helping to purify the air. For example, 25 m^2 of leaf surface produces the same amount of oxygen as a human being consumes in an hour.
- Plants release moisture into the environment through their leaves during the summer, reducing ambient temperature. They trap airborne dust. Studies have shown that a 10-square-meter leaf surface can remove 2 kg of dirt from the air each year.
- Green roofs absorb and reduce loud noises from traffic, etc., and the soil layer on the roof provides sound insulation for the building. A green roof, depending on the green texture, can reduce sound intensity within the building by 40-50 decibels. It can also reduce outdoor sound intensity by 10-30 decibels.
- Green areas green spaces create natural biodiversity
- It balances moisture in exterior and interior areas.
- It creates a fire-resistant surface.
- Various "Electromagnetic Resonance" fields naturally exist on Earth. Electromagnetic fields can cause many diseases. Today, the spread of Electromagnetic Resonance is increasing with things like cell phones. Humans can easily maintain their balance through contact with the earth. It has been reported that a 10 cm layer of soil on green roofs reduces electromagnetic radiation by up to 99 %.
- Air pollution can sometimes contain heavy metals. When heavy metals in the air reach the soil through rainwater, they are retained by the soil and the water is purified.
- Green roofs contribute to the preservation of the natural environment. They can also provide psychological and social benefits for people. Examples include serving as meeting points for employees, hobby gardens, food production areas, observation terraces, and recreational areas.

For many reasons that have not yet been listed, green roofs positively affect the energy performance of the building and contribute positively to the environment [26], [23], [27], [İner G., Çağlarer E.,]. Findings show that the use of soil on roofs is environmentally friendly in many respects, both in traditional buildings and in contemporary green roofs.

3. CONCLUSION

The materials used in traditional earth roofs are fully recyclable and natural. All these materials used in construction are sourced from the surrounding area. Because they are not industrial products, they do not create environmental pollution during production or transportation. When we examine the

roof types in Türkiye, we see that all of them were developed according to their geographical characteristics and the materials available in their immediate surroundings, were applied in the most appropriate way to suit climatic conditions, and are the most affordable and readily available natural materials in their respective environments.

Traditional earth roofs balance the humidity of the space, control heat transfer with their heat retention feature, protect heat transfer, maintain indoor temperature according to cold or hot weather outside, have low construction costs, do not require an industry for production, can be recycled at the end of the structure's life, do not harm the environment, have the disadvantage of being sensitive to water, but many precautions have been developed to take this into account.

The contributions and benefits of soil to both the structure and the environment have been mentioned in detail in the subject with the use of soil in green roofs. In addition to all these, it should be taken into account that it also contributes to the sustainability of the structure due to the use of soil, and that it is a recyclable material and provides natural environments for the environment and people.

The importance of using soil in roofs has been recognized, and it is being preferred in special projects as a green roof. It is essential to understand the importance of soil as a building material, to preserve traditional earthen buildings, and to draw attention to these buildings so that they receive the value they truly deserve.

Following the abandonment of soil structures in both green roofs and traditional building structures over the last two centuries, the reuse of soil, particularly in roof coverings (green roofs), is a remarkable development. This process has ultimately demonstrated the indispensability of soil as a building material.

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Evaluation of Vernacular Architecture with Adobe for Sustainable Cities

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ABSTRACT

The Adobe construction is the oldest building practice on the world. Around 30% of the world population lives in buildings made of earth materials. Adobe construction is a type of sustainable architecture with great application in vernacular constructions, where the materials used reflect local traditions. Adobe can become the cornerstone of sustainable cities of the future because of the longevity and preservation of materials is important when using local earth materials in sustainable cities. These materials offer economic and environmental benefits, because of that the interest of these types of construction are being increased. Adobe needs to be recognized and embraced as a viable and sustainable construction material.

Adobe has several advantages such as easy-to-construct with material, easy availability, thermal conduciveness and low-cost maintenance features. The costs are minimized in this type of construction because local materials may be employed, and it is relatively simple and easy to perform. Adobe buildings usually have a lower embodied energy and carbon footprint than the other buildings with sophisticated processes, like concrete, steel, or masonry. The construction industry generates about 30% of total greenhouse gas emissions because of these sophisticated processes.

Vernacular architecture is a form of building that is closely related to sustainability, where materials contribute to the environment and distinctive to the region where it is practiced, based on local needs and preferences. It is an aspect of cultural expression rooted to a particular place. Vernacular architecture refers to something that comes from a certain culture or that has its own characteristics. The most important reasons why Vernacular adobe buildings are preferred are that they are used to design architectural design in a sustainable way that manages to minimize the harmful effects on human health and the environment, trying to protect air, water and soil.

The main objective of this study is to assess the development of local adobe city examples that can facilitate today's sustainable cities. In this study, the topics of Vernacular Architecture for Sustainable Cities, Sustainable Architecture, Adobe Buildings will be discussed. Cities consisting of adobe buildings, of which there are still examples today, are protected as cultural heritage. The preference and widespread use of earth structures for sustainable cities will be evaluated according to the geographical and climatic factors of the cities.

Keywords: Earth Architecture, Historical Adobe City, Vernacular architecture, Adobe buildings, Sustainability.

1 INTRODUCTION

Due to the increasing pressure brought by recent global environmental problems, building designers are embracing regionalism and the knowledge of traditional structures, arguing that these structures are energy efficient and highly sustainable.

Adobe building is the oldest traditional structures in the world. Approximately 30% of the world's population lives in buildings made of earthen materials that reflect local traditions. Earth architecture is a type of sustainable architecture [1]. Buildings made with earth are economical, energy saving, environmentally friendly and sustainable. It has several advantages such as easy construction, easy availability, thermal conductivity and low cost construction and maintenance. It has a lower energy and carbon footprint compared to other buildings with complex processes such as concrete, steel or masonry construction. Due to these complex processes, the construction sector produces around 30% of total greenhouse gas emissions [2].

Vernacular architecture is an aspect of cultural expression rooted in a particular place. It refers to something that comes from a particular culture or has its own characteristics. In addition to meeting climatic, physical and ecological requirements, local building materials are also preferred in design for reasons such as creating an architectural identity and integrating into the existing architectural identity [3].

Adobe has been a tried and tested natural construction material for thousands of years, and in combination with modern methods can be used for modern ecological buildings. For a couple of year's earth building techniques have been growing in Iran, USA and all over Europe and Middle East. The reason for this increase is the interest in ecologically friendly construction. At the same time there is an increase in both new building products and technical developments in the production of these sustainable building materials. Adobe is one of the most widely used of all building materials used for different architectural applications [4].

Adobe construction offers economic and environmental benefits especially when used in developing countries where material costs overlap labor costs and where other construction materials and technologies may not be available. As earthen materials are local, long-lasting and economical, and offer environmental benefits, interest in earthen construction is growing and it can be the cornerstone of sustainable cities of the future [5].

In 1980, the definition of 'earthen architecture' appeared for the first time; that required attention not only to materials (mud-brick or adobe) but also "to all architecture, historic or contemporary, that is constructed of earth materials". In parallel, a distinction also seems to have been made between 'monuments' and 'vernacular architecture', which is to say minor structures to be preserved as evidence of a historical culture at risk of disappearance. The latter, while fully included within the UNESCO definition (see Criteria III), nevertheless seemed extraneous to the restoration sphere and became the object of building salvage. In spite of the initial definition of earthen architecture, attention seems to have been focused more on materials and construction techniques than on the architecture itself. The history of the buildings seems to have been moved to the background. As a consequence, the elements testifying to the authenticity of these works were neglected and often subjected to total reconstruction [6].

This study aims to provide information on the introduction of the traditionally used earthen (Adobe) material vernacular architecture in cities and the dissemination of today's earthen architecture techniques in sustainable cities.

2 HISTORY OF ADOBE CITIES

Earth construction techniques have been known for over 9000 years. Mud brick (adobe) houses dating from 8000 to 6000 BC have been discovered in Russian Turkestan. Rammed earth foundations dating from ca. 5000 BC have been discovered in Assyria.Earth was used as the building material in all ancient cultures, notonly for homes, but for religious buildings as well [7].

Many of the oldest buildings in the world have been built with earth; at least one quarter of the world's population lives in earthen dwellings and in more than 180 sites of the UNESCO World Heritage List incorporated earthen elements. As the Lyon declaration1 states, earth has been, is, and will be one of the major materials used by humankind to build its habitat and shape its environment [8].

In the Near Middle East, the earth finds application in the construction of monumental buildings such as the temple cities of the Uruk period (3200-2800 BC) and the sanctuaries, erected in the third millennium BC, made of bricks assembled without mortar. Interesting buildings can be found also in Iran. Historic adobe buildings stand in the cities of Yazd and Isfahan; rammed earthen walls surround the city of Tous; adobe structures characterised also the citadel of Bam (Picture 1), the largest adobe settlement in the world, unfortunately collapsed because of an earthquake in 2003. The Bam Citadel is a fascinating and unique fortress that is divided into several distinct parts, each with its own unique character and history. The fortress offers a glimpse into the intricate design and architecture of ancient Persia all constructed of mud bricks, a traditional building material that is both sustainable and durable (Picture 2), [9,10].

Before the earthquake After the earthquake After the reconstruction

Picture 1. The Bam Citadel [9].

Picture 2. The Bam City [10].

The historical core of the city of Shibam, Yemen, covering about 20,000 m2 and accessible only through a single gateway, was built entirely in adobe (Picture 3). Many houses resemble skyscrapers, and date from the 15th century.

Shibam is one of the architecturally most impressive urban sites in Yemen. Its more than 500 buildings have defied the vagaries of time for hundreds of years. Standing six to eight storeys tall, its mud-constructed houses have reminded many a traveller of the austere modernist architecture of skyscrapers. The city often labelled" Manhattan of the Desert", has been on the world heritage list since 1982 [11]. Shibam is a rare opportunity to investigate the influences of raw earth as it shapes the urban landscape.

Picture 3. The city of Shibam, Yemen Location: Yemen (Shibam) Vernacular, [12]

This adobe city is perfectly suited to the hot, dry desert climate. The roof and window designs of these structures are designed to allow even the slightest breeze into the interior. This keeps the interiors cool even during the hottest hours of the day. One of the most striking features of adobe buildings is their natural insulating properties. Thanks to their high thermal mass, adobe slowly absorbs and stores heat, delaying the reflection of outdoor temperature fluctuations into the interior. This prevents the house from overheating in the summer. In the winter, it maintains indoor temperature, saving energy[12].

Additionally, thanks to their porous structure, adobe walls allow moisture to circulate in a controlled manner. This improves the home's air quality and provides a healthy living environment. Yemen's traditional high-rise buildings are most prominent in the cities of Shibam (Picture 2), Sana'a (Picture 3), and Zabid (Picture 4). Sana'a's buildings, in particular, are notable for their fine craftsmanship and detailed ornamentation. Consequently, all three Yemeni cities are listed on UNESCO's World Heritage List [13].

Picture 4. General view of Sana, Photo: Oleg Znamenskiy [14]

Picture 5. Zabid, urban pattern with decorated historic façade [15]

In 1875 the archaeologist Ephraim George Squier described Earthen Architectures Chan Chan as "the most extensive and populous of all the cities of ancient Peru". It consists of "long lines of massive walls, gigantic chambered pyramids, or huacas, remains of palaces, dwellings, aqueducts, reservoirs, granaries, prisons, furnaces, foundries, and tombs, extending for many miles in every direction"[16].

In 1986, Chan Chan was designated a UNESCO World Heritage Site, recognizing its universal value as a cultural treasure[17].

Picture 6. Chan Chan city with Adobe [17]

The architectural elements of Chan Chan are primarily constructed from adobe, a building material made from clay, water, and straw (Picture 5). This sustainable construction method allowed the Chimú to create vast structures that have endured for centuries. The use of adobe not only showcases the ingenuity of the Chimú people but also reflects their adaptability to the environmental conditions of northern Peru. Visitors will notice the distinctive mud-brick walls, which feature elaborate patterns and designs, enhancing the aesthetic appeal of the ruins. The ability of these structures to withstand the elements, particularly the challenges posed by El Niño, speaks volumes about the architectural mastery of the ancient Chimú civilization [17].

Earth buildings can be found in Africa, Asia, Europe and America. Vernacular architectures, as well as monumental buildings are made using raw earth technology. In America, earthen constructions are both in the North and in the South. In North America (Mexico and Southen United States), earth was used by native populations. The Aztec built their monumental architectures in stones, while vernacular buildings were built in adobe. Monumental and vernacular buildings can be found also in

other countries and, as it is stated by Houben and Guillaud, up to now, in Latin American countries, both earthen brick and rammed earth are still the main building materials [18].

3. SUSTAINABLE VERNACULAR ARCHITECTURE

The concept of 'sustainability' emerged in the early 1970s in response for growing concerns about the impact of development practices on the state of the environment. Although the concept of sustainability was previously defined on the basis of the sustainability of forests and agriculture, it was first officially addressed and defined in 1982 in the World Charter for Nature document [19]. Negative developments for the environment and human beings have brought the concept of sustainability to the agenda and a sustainable development approach in which economic developments are fed by environmental policies has gained importance. Sustainability ensures a harmonious development in line with current needs in meeting and developing the needs of future generations.

The overall definition of elements of a sustainable city is one that facilitates human economic (production and consumption) and social life with the least possible impact on the natural environment. This means that material flows into and out of the city are thought through and managed to minimize destruction of natural systems. The city's water supply comes from sources that are replenished through natural processes or from sources that can be withdrawn without damaging ecosystems. The city's solid waste is recycled as much as possible with food waste converted to fertilizer and other materials separated for reuse as well. Other systems such as sewage treatment, storm water drainage, energy, food, and transportation are designed for efficiency and least possible environmental impact. One of the goals of a sustainable city is to effectively manage material flows into and out of the city [20].

Many researchers have made the claim that unsustainable and identity-less environments tend to be created as the result of a lack of adequate evaluations of vernacular data, especially in the designing of housing and the planning of urban settlements [21]. As a result of the industrial revolution, cities began encroaching onto ever broader swathes of land as they expanded and new lifestyles came into being with the advent of novel modes of production; consequently, problems concerning housing and transportation emerged as major features shaping urban environments in the West. As cities evolved, many important features were lost as the environmental character and identity of urban landscapes suffered in terms of historical continuity. At the same time, the human scale of such environments disappeared, and urban outdoor life deteriorated as well [22].

Sustainable city refers to a vision of an ideal urban structure formed by sustainable land use and urban design principles. Compact urban design with mixed land use: (i) Improve the quality of life by providing social interactions and easier access to a wide range of services; (ii) Minimise energy consumption through green building design technologies; (iii) Reduce greenhouse gas emissions by providing less auto-dependent development, and; (iv) Ease the pressure on environmentally sensitive areas by preventing urban sprawl as well as restoring park and greenway systems [23]. (Jabareen, 2006).

In recent years, cities all over the world have started to struggle with the aforementioned local and global environmental issues. Scholars and practitioners from different disciplines have begun to seek sustainable planning and design solutions to overcome these problems. The goal is the positive development of built environments which refers to "design of cities, buildings, landscapes and infrastructure that generates healthy ecological conditions, increase the life-support services, reverse the impacts of currents systems of development and improve life quality for everyone". The main point: the integration of sustainable development into the current urban development policies and practices is fundamental towards achieving sustainable outcomes for cities [24].

Over the past several years, there has been a significant increase in the development of urban ecosystem sustainability assessment tools in order to provide guidance for the evaluation of the environmental impacts of existing and new urban developments. even though using different assessment themes and sub-themes, they outline the common sustainability principles, such as conservation of native vegetation, reduction of non-renewable energy use, waste reduction, water efficiency, high quality public transport and social safety [25].

Sustainable urban development of cities in the world is perceived as improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden, and thus forming the sustainable city [26].

The concept of sustainable city is a newer concept in the urbanization literature. The concept of sustainable city refers to the ability of urban spaces, the actions within these spaces and the inhabitants of the city to continue their existence as a whole with their environment in a balanced manner and to transfer the values produced within the city to future generations [27].

Vernacular architecture refers to a building, typology, style or form, while traditional architecture refers to a settlement or community that shares similar values, history and location. The loss of vernacular architecture equates to the loss of traditional knowledge, local identities, collective memories, crafts and technology, all of which are underlined in the context of sustainable development [28].

After the technology developed after the Industrial Revolution, nature was not given the opportunity to renew itself and as a result, various environmental problems occurred. In addition, since the beginning of the 20th century, when globalization showed its effect, a period in which everything in the world has developed and changed rapidly and the population has also increased rapidly has started [29].

Sustainability as a terminology was not explicitly present in the discourse of vernacular architecture and traditional built form. Some terms tend to recur, such as 'honesty', 'integrity' and 'respect' in relation to the use of local materials or structural features and limitations; 'wisdom' in relation to the way a settlement integrates with its environment and resources, or the application of craft techniques; 'truthfulness', 'appropriateness', 'appropriateness', 'appropriateness' and 'naturalness' refer to moral judgments about the benefits of tradition and the lifestyles associated with it; 'economy' refers to the efficient use of local and natural resources; and 'rootedness' and 'connection' refer to an authentic relationship with the land and its historical and cultural values. These are some of the recurring words in the historical dialog that are often used today as synonyms for sustainability [30]. (Richards, 2012).

There are four sustainability principles of vernacular tradition. These include 'materials and site appropriateness,' where vernacular materials are produced locally and used efficiently in relation to their surrounding environment; 'climatic responsive,' wherein vernacular forms and materials are by default responsive to climatic condition; 'socio-cultural advantages,' involving the idea that building process strengthens social bonds and lowers cost; and finally 'adaptability,' the assumption borne out by long histories of usage that vernacular architecture is remarkably flexible and expandable [31]. (Alsayyad and Arboleda, 2011).

By filtering and optimizing locally available materials and techniques in eco-system and vernacular earth architecture, it is found that the most basic technique, thermal mass and insulation based on earth and other natural materials, are the most effective solution in sustainability and practical feasibility, and hence should be employed as the key strategy Research and Practice of Contemporary Earthen Architecture. In terms of the emerging, various demands from the governments, clients and dwellers for more diversified and flexible earth-based techniques with vernacular or modern concerns, the huge research domain of earth architecture needs more systematic and sustainable

studies and practices with more parties involved. Research and Practice of Contemporary Earthen Architecture.

5. EVALUATION OF VERNACULAR ARCHITECTURE WITH ADOBE FOR SUSTAINABLE CITIES

The significance of earthen architecture lies in its sustainability, affordability, and capacity to deliver optimal thermal comfort. Earth possesses remarkable thermal mass, enabling it to absorb heat during daylight hours and emit it during nighttime, thereby contributing to the regulation of indoor temperatures. It is naturally abundant in most tropical subsoils [32]. As a result, earthen structures are highly energy efficient and can adapt to different climates. Additionally, using locally sourced materials in earthen construction reduces transportation costs and environmental impact [33]. By amalgamating traditional methodologies with contemporary advancements, practitioners strive to tackle the environmental challenges of the present era.

The use of adobe construction is spread all over the world, especially in countries where the raw material is easily available. Soil is the most important natural building material and is available in most regions of the world. It is often obtained directly from the construction site when excavating foundations or basementsThis happens because this is the simplest and easiest form of construction. However, what occurs over time with scientific and technological developments is that there is a certain abandonment of this technique, especially in more developed countries despite the advantages that this constructive technique offers in terms of sustainable development.

Nowadays, since there is a growing concern with the sustainability of building materials, the preservation of earth buildings should be taken as a focus of preservation of heritage and guarantee economic and environmentally sustainable buildings. In addition to the development of new materials for the rehabilitation of adobe/earthen buildings, there is also a concern with the use of more sustainable materials for construction of new buildings.

The sustainable cities emphasize urban greening, ecological and cultural diversity, and passive solar design. In addition, the approaches of the sustainable city emphasize environmental management and other key environmentally sound policie. In developing countries, shelter needs can only be met by using local building materials and construction techniques.. In industrialized countries, centralized capital combined with careless exploitation of resources and energy-intensive production not only leads to waste, but also pollutes the environment and increases unemployment. In these countries, soil is being revitalized as a building material.

Adobe buildings provide improving indoor climate in moderate to cold climates, people usually spend about 90% of their time in enclosed spaces, so indoor climate is a crucial factor in well-being. Air humidity in contained spaces has a significant impact on the health of inhabitants, and earth can balance indoor humidity like no other building material.

CONCLUSION

Vernacular architecture provides a healthy shelter with adobe for many generations of people, but it still guarantees the principles of sustainable development for cities. Vernacular architecture is a proven model of sustainable architecture, regarding both environmental, economic and social aspects. However, the contemporary building industry shows that buildings designed and constructed by modern technology are still the overwhelming norm. Vernacular architecture is increasingly damaged and gradually lost. Many regions have introduced tighter building standards and zoning regulations (e.g., fire safety, building life expectancy, energy codes), which make vernacular techniques difficult or impossible to apply.

Adobe for sustainable cities are affordability that buildings made with adobe are economical, energy saving, environmentally friendly. It has several advantages such as easy construction, easy availability, thermal conductivity, a significant impact on the health and low cost construction and maintenance. This type of construction ensures responsible use of renewable natural resources, reuse and recycling of materials, contributes to environmental protection and pollution reduction, energy saving and provides a cleaner and healthier living environment. It has a lower energy and carbon footprint compared to other buildings with complex processes such as concrete, steel or masonry construction.

Earthen building possesses remarkable thermal mass, enabling it to absorb heat during daylight hours and emit it during nighttime, thereby contributing to the regulation of indoor temperatures. It increasingly demands energy and cost-efficient buildings that emphasize a healthy and balanced indoor climate. Additionally, using locally sourced materials in earthen construction reduces transportation costs and environmental impact. Adobe architecture for sustainable cities in the world is perceived as improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components. Adobe has been a tried and tested natural construction material for thousands of years, and in combination with modern methods can be used for modern ecological buildings. Sustainable city is made of adobe architecture also economic and possible impact on the natural environment. This means that material flows into and out of the city are thought through and managed to minimize destruction of natural systems. Beyond being a legacy of the past, adobe is the building block of a sustainable future. Adobe brick is not only a legacy of the past, but also a guarantee of sustainable cities. The rediscovery of natural materials offers both environmentally friendly and aesthetically pleasing architectural solutions. Now is the time to bring this time-honored material into the future.

The benefits of vernacular architecture have been recognized throughout history, but its influence waned for a time; today, it has begun to influence sustainable earthen building design for cities. Despite some challenges, the earthen material used in vernacular architecture is gaining traction among current designers.

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An Evalution of Adobe Architecture In Terms of Eco-Comfort In The Context of The Mediterranean Climate and Alanya

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ABSTRACT

This study aims to evaluate the historical development and eco-comfort potential of adobe architecture in the specific context of Alanya, within the framework of the characteristic features of the Mediterranean climate. The Mediterranean climate is characterized by long, hot summers and mild, rainy winters. These climatic conditions have directly influenced the choice of traditional building materials and design approaches in the region. In this context, adobe stands out as a local material due to its ease of production and its success in providing climatic comfort.

Adobe acts as a natural thermal regulator against high temperature fluctuations. Traditional adobe structures in Alanya, with their thick walls and small window openings, prevent excessive heat gain during the day and minimize heat loss at night. Thanks to their high thermal mass, adobe walls store the cool air of the night and prevent daytime heat from penetrating into the interior spaces. These features provide natural indoor comfort without the need for energy consumption, thus increasing the significance of adobe in terms of eco-comfort.

Considering the unique geographical and climatic conditions of Alanya, it is evident that adobe structures also support a lifestyle in harmony with the environment. Traditional Alanya houses, with elements such as sofas positioned according to wind directions, shaded courtyards, and tiered façade designs, represent early examples of passive cooling techniques. Adobe material lies at the heart of these designs, enhancing the climatic adaptability of the structures.

With the modernization process, the widespread adoption of reinforced concrete systems and industrial materials has significantly reduced the use of adobe; however, this transformation has also led to the loss of traditional knowledge based on climatic comfort. Today, in the context of sustainable architecture approaches, the reevaluation of adobe is of great importance both for preserving cultural heritage and for designing low-energy living spaces.

This article aims to comprehensively examine how adobe construction techniques evolved historically in the context of Alanya, what eco-comfort advantages they provided within the Mediterranean climate, and how they can inspire contemporary sustainable building design.

1 INTRODUCTION

The Mediterranean climate is characterized by long and hot summers coupled with mild and rainy winters, reflecting distinct seasonal variations that have historically shaped patterns of settlement and architectural production. In the case of Alanya, these climatic conditions have exerted a decisive

influence on both the selection of building materials and the spatial organization of the built environment. Within this context, adobe emerges as a vernacular building material particularly suited to the environmental and cultural conditions of the region. Its high thermal mass, moisture-regulating properties, and minimal environmental footprint not only illustrate the adaptive wisdom of traditional practices but also underline its potential for addressing contemporary concerns related to sustainability, energy efficiency, and climate responsiveness. Beyond its role as a locally available resource, adobe thus embodies an architectural medium through which ecological design values can be both preserved and reinterpreted.

The present study aims to evaluate adobe architecture from an eco-comfort perspective, situating its inquiry within the characteristic parameters of the Mediterranean climate and the traditional residential fabric of Alanya. Specifically, it investigates the principles of passive comfort strategies, spatial organization, and material performance inherent in traditional adobe structures, while simultaneously emphasizing their potential contributions to sustainable architectural discourse in the present day.

More importantly, this study does not seek to present site-specific empirical findings or fieldwork-based data; rather, it positions itself as an introductory and exploratory research endeavor. By providing a conceptual and theoretical framework, it intends to fill a notable gap in the existing literature concerning the intersection of Mediterranean climatic conditions, vernacular adobe architecture, and eco-comfort strategies. In this respect, the study aspires to function as a preliminary investigation that both informs and inspires subsequent, more detailed research—particularly studies incorporating fieldwork, material testing, and case-based analysis.

Ultimately, this work aims to contribute not only to the preservation and critical reassessment of traditional architectural heritage but also to the advancement of ecological design practices in contemporary architectural thought. By framing adobe architecture within the eco-comfort paradigm, it underscores the broader significance of vernacular knowledge systems in shaping sustainable futures, while offering an initial platform for future scholarly inquiries.

2 AN EVALUATION OF ADOBE ARCHITECTURE IN TERMS OF ECO-COMFORT IN THE CONTEXT OF THE MEDITERRANEAN CLIMATE AND ALANYA

2.1 How Can The Concept Of Eco-Comfort Be Defined?

Eco-comfort refers to an understanding of comfort in the fields of sustainable architecture and environmentally oriented design, which aims to enhance users' quality of life while minimizing environmental impacts. Unlike conventional approaches to comfort, this concept encompasses not only parameters such as thermal, acoustic, and visual comfort but also environmental indicators including energy consumption, natural resource use, and ecological compatibility. Eco-comfort represents a holistic state of comfort achieved through the effective application of passive design strategies (e.g., natural ventilation, maximization of daylight utilization, thermal mass effects) and the use of environmentally friendly materials. This approach seeks to ensure maximum quality of life with minimal carbon emissions and energy consumption throughout the building's life cycle. Particularly in regions with hot and dry summers and mild winters, such as the Mediterranean climate, eco-comfort provides a significant conceptual framework for integrating traditional building techniques with modern design principles. The concept is also addressed in the October 2024 article "A Decision Support System for Monitoring and Managing the Energy Performance and Comfort of Existing Buildings", in the context of system design involving thermal comfort and indoor air quality management.

2.2 Eco-Comfort and Its Methods in the Mediterranean Region

The understanding of achieving eco-comfort in Alanya and, more broadly, in regions characterized by the Mediterranean climate is based on maximizing the benefits of natural conditions while keeping energy consumption to a minimum. This approach draws both from the climate-responsive design principles of traditional building culture and from contemporary practices in sustainable architecture and urban planning.

First and foremost, passive climatic strategies constitute one of the fundamental components of eco-comfort. Orienting buildings in relation to prevailing wind directions and incorporating openings that allow for cross-ventilation enable natural air circulation, thereby reducing the need for mechanical cooling in interior spaces. In Alanya, the orientation of buildings towards the south ensures maximum utilization of solar energy during the winter months, while shading devices such as wide eaves, pergolas, and sun-breaker panels help prevent overheating in summer. Through these methods, eco-comfort is effectively achieved.

2.3 The Concept of Adobe and the Historical and Cultural Background of Adobe Architecture

The Turkish Language Association (TDK) defines *adobe* as "a primitive brick made of a mixture of mud and straw, poured into molds and dried under the sun for use in wall construction" (TDK Contemporary Turkish Dictionary, last accessed 06.09.2022). Concerning the description, classification, properties, production rules, inspection, and testing of adobe blocks, the relevant standard is TS 2514. This standard employs the term *adobe block* instead of *adobe* and defines it as follows: "Adobe blocks are products obtained by mixing clayey and suitably qualified soil with additives such as straw or other plant fibers, reed-type plants, coarse grasses, hemp fibers, leftover straws collected from livestock feed racks, dry heath, pine needles, tree branches, sawdust and shavings, and similar materials, kneading the mixture with water, pouring it into molds to shape it, and drying it in open air, thereby making it usable in construction."

An examination of adobe structures in Anatolia reveals that they are not solely composed of adobe bricks but rather employ various methods of construction.

In addition, the technical and environmental advantages of adobe include low production costs and the use of local materials, high thermal insulation and indoor thermal comfort, as well as recyclability and a low carbon footprint. However, common challenges of adobe structures include their susceptibility to external factors such as moisture and rain, and their limited earthquake resistance. Consequently, the prevalence of rainfall in the Mediterranean climate constitutes a factor that may hinder the development of adobe architecture.

2.3.1 Adobe Structures Around the World

Adobe structures are particularly common in regions with hot and dry climates. In the Middle East and North Africa, countries such as Egypt, Morocco, and Tunisia have traditionally favored adobe for residential and historical buildings, especially in rural areas. Notably, the Kasbahs in Morocco and the Nubian villages in Egypt represent iconic examples of adobe architecture. In the Southwestern United States and Mexico, the use of adobe in Native American traditions is renowned for its environmentally friendly and insulating properties. In Latin America, countries such as Peru and Bolivia employ adobe and rammed earth techniques in both traditional and modern constructions. In Europe, historic adobe farmhouses can be found in rural regions of Spain, France, and the United Kingdom. In particular, in the UK, adobe-like structures known as "cob" are under preservation protection (Patnaik, 2019).

2.3.2 The Use of Adobe in Turkey

Turkey, with its geographical diversity, has seen the development of adobe use in various forms. The primary regions of traditional use include Central Anatolia, Eastern and Southeastern Anatolia, the inner Aegean region, and rural areas of the Mediterranean. In these regions, adobe is commonly employed for the construction of residences, barns, and storage facilities. In historical areas such as Safranbolu, Beypazarı, and Mardin, adobe structures are being restored, thereby preserving the local architectural identity.

Examples:

World:

Ait Ben Haddou Kasbah (Morocco) — Listed as a UNESCO World Heritage site, it represents a magnificent example of adobe architecture.

Fig.1. Ait Ben Haddou Kasbah

Taos Pueblo (New Mexico, USA) — An adobe settlement that has stood for thousands of years.

Fig.2. Taos Pueblo

Turkey:

Safranbolu Village Houses — Preserved examples of Ottoman-era adobe houses.

METU Alker Project — Research on sustainable construction technologies using stabilized adobe materials.

Mardin Stone-Adobe Houses — Structures in which adobe and stone are used together within the Mesopotamian cultural context.

Fig.3. Traditional Mardin Adobe Houses

Adobe is a construction material with thousands of years of experience worldwide and holds significant importance in terms of environmental sustainability. In Turkey, it occupies a unique position where cultural heritage intersects with contemporary sustainable architectural approaches, and its potential for future use is increasing with ongoing technical advancements.

2.4 Traditional Adobe Building Examples in Alanya and Its Surroundings

According to research, adobe structures are not commonly encountered in the Alanya region. This is primarily due to the rainfall characteristic of the Mediterranean climate, which has hindered the use of adobe as a sole building material. Consequently, buildings in this area are predominantly constructed using plaster materials mixed with adobe. This technique has been employed in the region's enduring traditional houses, referred to as "Traditional Alanya Houses."

2.5 Traditional Material Usage and Local Architectural Context

Alanya is a settlement located on the Mediterranean coast and has been influenced by various cultures throughout history. This circumstance has resulted in the coexistence of natural resources provided by the local geography and construction techniques from different periods in the material selection of traditional residential architecture. The primary construction materials used in traditional Alanya houses are stone, timber, and adobe infill.

2.5.1 Use of Stone

In traditional Alanya houses, the use of local limestone and rubble stone is common in the foundations and mostly in the ground floor walls (Aksoy & Sağıroğlu, 2021). Stone provides load-bearing capacity, durability, and protection against moisture. In the foundations of Alanya houses, either the dry masonry technique or the bonding technique with *horasan* mortar was preferred.

2.5.2 Adobe and Timber Frame (Bağdadi) System
In the upper floors of Alanya houses, a timber frame (bağdadi) system with adobe infill was employed (Cimrin, 1996). The advantages of this technique include reducing wall weight, enabling flexible transfer of seismic loads, and ensuring thermal comfort. In practice, the material composed of soil, straw, and lime additives is applied between the bağdadi timber frames. It was also utilized for floor beams, wall plates, bay windows, and balconies. Local wood species such as cedar and pine were preferred.

2.5.3. Mortars and Plaster Materials
Horasan mortar, a water-resistant mortar with brick or tile powder additives, was particularly applied to foundations and walls in contact with moisture (Esin & Yüksek, 2009). Lime plaster and whitewash were preferred for wall surfaces. This practice enhanced indoor comfort by providing both hygiene and light reflection.

2.5.4. Interaction of Local Fabric and Building Material
Traditional Alanya houses clearly demonstrate the relationship between climate and materials through their street patterns adapted to the topography, stone foundations, wooden upper-floor projections, and whitewashed facades. The primary criteria for material selection are local availability, climatic comfort, and durability.

In these traditional houses, the combined use of materials such as stone, adobe, wood, and Horasan mortar ensures structural stability, thermal comfort, and conformity with the local identity. The integration of these materials has created a distinctive architectural fabric that is well adapted to both the geographical conditions and the socio-cultural context of Alanya.

2.6 The Effects of Climate and Residential Planning

In this region, in order to provide cool interiors in summer and mild conditions in winter, houses were generally shaped around a courtyard or a semi-open sofa. The ground floors (usually built of stone) were mostly used as storage, cellars, or animal shelters, while the living spaces were located on the upper floors. This was important both for protection from ground moisture and for maintaining coolness in summer. Oriented toward the landscape and prevailing winds, these houses were generally positioned facing south or southeast.

2.6.1 The Impact of Climate on Façade and Building Elements
The upper floor projections (bays or cumbas) protect the ground floor from sunlight and allow air circulation. Opposing projections over narrow streets create a shading effect, positively influencing the microclimate of the streets. Wooden shutters and lattice screens on the façades block sunlight in summer while allowing light penetration in winter.

Window openings are distributed in a balanced manner on the façade; typically, the ground floor features fewer and smaller windows, while the upper floor has larger ones. Sloped roofs with wide eaves enable rapid drainage of rainwater during the wet winter season. Traditional Turkish roof tiles (alaturka kiremit) reflect heat during hot summer days and allow the roof to breathe.

2.6.2 The Impact of Climate on Material Usage
On the ground floor, stone walls were used to provide resistance against moisture and thermal mass. On the upper floor, a lightweight bağdadi system with wooden frames and adobe infill was applied to prevent overheating in summer and to reduce seismic loads by minimizing structural weight. For plaster and surface finish, white limewash was used to reflect sunlight and keep the interior cool.

Alanya's hot and humid summers and mild winters shaped the design principles of traditional residential architecture in terms of orientation (south-facing and wind-catching), material (balance of stone, adobe, and wood), façade (bay windows, shutters, small ground-floor openings), and spatial organization (sofa and courtyard schemes). These features created a housing culture that was both climate-responsive and ecologically sustainable.

Thanks to natural climate control strategies that support eco-comfort, traditional Alanya houses were able to provide thermal comfort during the hot and humid Mediterranean summers without the need for mechanical systems. Orientation, spatial organization, façade elements, natural materials, and landscaping played a crucial role in ensuring both environmental sustainability and user comfort. These approaches serve as valuable references for contemporary sustainable architecture.

2.7 The Suitability of Adobe Material for the Mediterranean Climate

Adobe, as a building material derived from natural and local resources, has been widely used throughout history in many regions. The Mediterranean climate, characterized by hot and dry summers and mild, rainy winters, makes adobe suitable when combined with proper design and construction techniques.

Adobe possesses high thermal storage capacity (thermal mass). During the day, it absorbs solar heat and gradually releases it in the evening, balancing indoor temperatures in climates with significant diurnal variations, such as the Mediterranean. As a result, the need for mechanical cooling is reduced, providing users with natural eco-comfort.

Its hygroscopic property enables adobe to absorb and release moisture, contributing to humidity regulation and creating a comfortable indoor microclimate during the occasionally humid summer months.

Since adobe is typically produced on-site with locally available soil, its carbon footprint is extremely low. It has historically been widely used in traditional architecture across the Mediterranean basin, including Spain, North Africa, the Middle East, and various regions of Turkey. Local production and low energy consumption make adobe an ecologically appropriate material.

One of adobe's main weaknesses is its vulnerability to rain. In the Mediterranean, sudden and heavy winter rainfall poses a risk to adobe surfaces. Therefore, protective measures are necessary, such as designing roofs with wide eaves, applying protective coatings like lime plaster and limewash, and elevating the foundation with stone or concrete.

2.8 Adobe Architecture in Alanya

The climate of Alanya (hot and dry summers, mild winters) is suitable for the use of adobe, and therefore it was widely employed as an infill material in the upper floor walls of traditional houses. This application was mostly combined with a timber frame (bağdadi) system.

In the traditional houses around Alanya Castle and the Tophane Quarter, stone was preferred for the ground floors, while the upper floors were built with timber frames filled with adobe. For this reason, adobe became an important complementary material in Alanya's housing culture.

Today, however, almost no independent buildings constructed entirely of adobe have survived. Since adobe was mostly used as infill within the bağdadi system, visible examples are rare. Most adobe parts are now either hidden under plaster or have been renewed due to deterioration over time.

In recent years, there has been a renewed interest in natural building materials similar to adobe within the scope of ecological architectural approaches in Alanya and its surroundings. Adobe or rammed earth-like materials are particularly being used in eco-village projects and rural tourism structures. In Alanya, adobe structures were especially common as upper floor infill material in traditional houses; however, independent adobe buildings have rarely survived due to climatic conditions.

Fig.4 Traditional Alanya's House (Kemal Atlı House)

3 CONCLUSION

Although there are studies and surveys on adobe structures in the literature, most of these works primarily focus on the eastern and southeastern regions of Turkey, while existing research and surveys related to the Antalya and Alanya regions remain limited. Moreover, these studies neither examine the existing building examples nor generally analyze adobe constructions from the perspective of eco-comfort. In this study, the relationship between Alanya and adobe material is explored through the concept of eco-comfort, assessing the suitability of the region for adobe architecture.

Due to Alanya's Mediterranean climate and its exposure to rainfall, adobe is not entirely suitable as a standalone building material. However, in the region, it has been used as a material mixed with plaster for wet spaces. Additionally, hybrid solutions in modern architecture can be applied to create alternative architectural perceptions, integrating adobe with other durable materials.

The review of traditional architecture in Alanya indicates that, although adobe possesses significant advantages in terms of thermal mass, moisture regulation, and environmental sustainability, its use as a standalone construction material in the region has been historically limited. The Mediterranean climate of Alanya, characterized by hot, humid summers and occasional intense rainfall, poses challenges to the durability of pure adobe structures.

Consequently, independent buildings constructed entirely from adobe have rarely survived, and adobe has traditionally been employed primarily as an infill material within hybrid construction systems, such as timber frame (bağdadi) techniques combined with stone foundations. This observation underscores the importance of hybrid architectural solutions in Alanya, where the complementary use of stone, timber, and adobe ensures structural stability, climate responsiveness, and longevity. Modern ecological and sustainable design approaches can similarly benefit from integrating adobe as part of composite building systems rather than relying on it as a sole structural material. By adopting hybrid strategies, architects and builders can harness the eco-comfort benefits of adobe—such as passive thermal regulation and low environmental impact—while mitigating its vulnerabilities to moisture and extreme weather conditions. In summary, while Alanya's climatic conditions limit the feasibility of pure adobe constructions, the region is highly suitable for hybrid applications that combine traditional adobe techniques with durable materials like stone and timber. Such approaches provide both continuity with local architectural heritage and the potential for innovative, sustainable housing solutions.

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An Ecofeminist Reading Through Adobe Structures: The Relationship Between Earth, Women, and Production

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ABSTRACT

This study aims to evaluate the production processes of adobe structures from an **ecofeminist perspective**. Ecofeminism argues that the historical forms of domination over both nature and women have evolved in parallel, addressing environmental issues and gender inequality on a shared ground. Within this theoretical framework, adobe structures can be understood as a unique form of production that makes visible the direct and transformative relationship between humans and nature. In particular, women in rural regions of Anatolia have played active roles in adobe production by using natural materials such as earth, water, and straw, becoming key agents in the construction of dwellings. Adobe production is not merely a physical activity, but rather the result of a reciprocal and sustainable relationship with nature. Knowledge and experience related to determining the earth-to-water ratio, planning production in accordance with seasonal cycles, and enhancing insulation were orally transmitted by women from generation to generation. Although often rendered invisible in the patriarchal construction of written history, this transfer of knowledge reveals a creative, intuitive, and productive relationship between women and nature. Instead of exploiting nature, women produced shelters by transforming it. This method of production reflects a sustainable and community-based approach. However, with modernization and urbanization, the rise of industrial construction techniques has significantly reduced both the use of natural materials and the active roles of women in building practices. These processes—based on dominating nature and erasing women's labor—form the core of ecofeminist critique.

The study also offers a spatial reading of adobe architecture. Areas such as **sofa** (semi-open living spaces), **tandır** (traditional ovens), granaries, and cellars are interpreted as spaces where women conducted daily productive activities and integrated into social life. These spaces not only reflect a design approach aligned with climatic conditions but also shaped women's everyday spatial experiences.
In conclusion, adobe architecture embodies not only environmental sustainability but also gendered production relations and alternative forms of knowledge. From an ecofeminist perspective, adobe structures reveal the possibility of a productive, harmonious, and layered way of life in interaction with nature. In this regard, re-evaluating adobe architecture holds great significance for both architectural history and gender studies.

Keywords: Ecofeminism, Adobe architecture, Women, , Sustainability, Traditional building techniques

1 INTRODUCTION

One of the most pressing issues of our time, the environmental crisis, emerges not only as a threat to nature but as a multifaceted problem that affects all layers of human life. This crisis is directly linked to the commodification of nature, the limitless consumption of resources, and the

environmentally exploitative nature of capitalist modes of production. The resulting ecological destruction is not merely an environmental issue; it also points to a problem of social justice and equality. It is precisely at this intersection that ecofeminism intervenes, offering a conceptual framework that seeks to reveal the historical parallel and relationship of domination between nature and women.

The concept of ecofeminism was first introduced in 1973 by French writer and activist Françoise d'Eaubonne **Fig. 1**. D'Eaubonne equated women's reproductive capacity with nature's productivity and criticized the patriarchal-capitalist system for exerting control over both the female body and the natural world.[1] This idea gained greater visibility especially in the 1980s, at the intersection of ecological movements and feminist organizations, and in the 1990s, it acquired a more defined theoretical framework through academic conferences and international environmental policies. The central argument of ecofeminism is that the domination of nature and the oppression of women stem from the same epistemological root: both are outcomes of Western-centric, patriarchal, rationalist systems of knowledge and capitalist modes of production.[2]

Figure 1. Françoise d'Eaubonne (Roger Viollet)

The aim of this study is to bring together ecofeminist thought and architectural practice by analyzing women's relationship with nature—particularly within the context of adobe (kerpiç) construction—and how these relationships are spatially manifested. Adobe, being a construction material derived directly from natural resources such as earth, water, and straw, represents one of the most basic and direct forms of the human–nature relationship. This mode of production is not merely a technical activity; it is also a medium for reciprocal harmony with nature, cyclical knowledge, and the transmission of collective memory. In this context, the role of women in adobe production in rural Anatolia is not only a matter of physical labor but also a form of experiential wisdom passed down through generations.

Women feel the moisture of the soil in their palms, intuitively understand the consistency of the clay, and determine the timing of production in harmony with seasonal cycles. This knowledge is not learned from books but passed on by mothers and grandmothers. In this sense, adobe-making is not just a construction process—it is a bodily and emotional form of communication with nature. This also presents an opportunity to develop a strong critical stance against the patriarchal narratives of architectural history, in which women's labor has often been rendered invisible.

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Accordingly, the study proceeds along three central axes of inquiry: (1) How ecofeminism finds resonance in the field of architecture, (2) how women's knowledge and labor practices in adobe construction intersect with this theoretical framework, and (3) to what extent traditional building practices are actually based on a woman-centered spatial imagination. The methodology of the study is shaped by literature review and theoretical analysis, drawing on fieldwork-based theses and anthropological narratives.

While adobe construction is often seen as a local, sustainable, and nature-aligned alternative to industrial building systems, the historical role of women in this production practice has frequently been overlooked. Yet, women's intuitive relationship with nature not only determines material selection but also shapes spatial organization and even the rhythm of daily life. In this respect, adobe should be regarded not merely as a material, but as a bearer of the woman–nature–space triad.

The case studies of Iraq, Malatya, Mardin, and the award-winning project were deliberately chosen to represent geographical diversity, the visibility of women's involvement, and historical or contemporary relevance. Iraq reflects the Middle Eastern context where women's adobe labor intersects with survival economies; Malatya illustrates the intergenerational continuity of women's experiential knowledge in Anatolia; Mardin highlights seasonal, cyclical practices of adobe maintenance and community solidarity; and the award-winning project demonstrates the recognition and adaptation of women-led adobe practices in contemporary sustainable architecture.

The research is not depending on field data however it is relies primarily on significant sources on literature, including ethnographic studies, anthropological theses, and documented fieldwork reports. Journalistic materials (e.g., Anadolu Agency, Haber49, JinNews) also provided first-hand testimonies of women involved in adobe production. Archival records and scholarly works were triangulated with these accounts to ensure both historical depth and contemporary accuracy.

2. THE RELATIONSHIP BETWEEN ECOFEMINISM AND ARCHITECTURE

Ecofeminism does not regard the association of women with nature merely as an allegorical metaphor but considers it as a holistic capacity rooted in productivity, fertility, nurturance, and the sustainability of life. The equation "Nature = Woman" suggests that nature and women—both revered and exploited throughout history—can be examined within the same epistemological framework. In this context, the possibility of sustaining a non-exploitative, cyclical, and intuitive relationship with nature is viewed as a direct reflection of women's knowledge. This notion of productivity, often associated with women's reproductive abilities, is not only biological but also finds resonance on architectural and spatial levels. A woman's relationship with nature parallels generative processes like childbirth, positioning her as both a user and a creator in the formation of space.

In modern, rationalist architectural history, however, the production of space has mostly been defined through technical knowledge, engineering skills, and planning capabilities—systematically ignoring women's labor, which is rooted in daily life and intuition. Architectural historiography has largely relied on a masculine narrative built around the figure of the "master" builder. Yet traditional building practices that have persisted for centuries in rural Anatolia reveal a different reality outside this central narrative. In constructions that use materials deeply intertwined with nature—such as adobe—women have played active roles not only in the physical labor but also in the knowledge-based aspects of production. This situation necessitates a rethinking of architectural production not solely as a technical process, but also as a social and cultural one.

In adobe-making, for instance, women make decisions based on the type of soil, the consistency of the clay, the amount of straw, and the angle of the sun. This type of knowledge is not written—it is based on experience, observation, and intuitive learning passed down through generations. Adobe construction typically takes place at the beginning of summer, when the wind is minimal, and the sun is intense. Women synchronize this production cycle with nature. Such practical knowledge is also embodied—it resides in a body capable of reading nature's signs. Therefore, adobe construction

is not merely a building process, but a materialization of a relationship with nature.

From an architectural history perspective, interior spatial organization has often been treated as gender-neutral. However, elements commonly found in traditional Anatolian homes—such as the *sofa*, *tandır room*, laundry area, pantry, and granary—emerge directly from women's everyday practices. The woman is not only a user of these spaces but also a shaper of them. Time spent in these spaces reflects a process in which the female body and labor are spatialized and transformed into architectural knowledge. These spaces operate according to the rhythm of women: dough kneaded at sunrise, bread baked by noon, laundry dried in the sun, wheat ground in the afternoon—all define the temporal dimension of architectural space through women's labor. Although in the actual construction process, the act of pouring adobe into molds or erecting the load-bearing structure is typically associated with a male "master" figure, it is women's needs that determine the formal and functional framework of the production. Female wisdom plays a decisive role in a wide range of architectural aspects—from the orientation of the building to the quantity of material used, from the arrangement of spaces to the layout of the inner courtyard. For this reason, the architectural product is shaped not only by the visible, but also by the invisible, the sensed, the felt, and the lived—through women's labor.[3]

The theoretical foundations of this perspective became more pronounced especially with the emergence of new social movements and feminist discourses after 1968. The resistance that broke out in France in 1968, demanding freedom between university students and the administration, quickly evolved into a multi-layered wave that included the women's movement, peace activism, and environmental struggles. The socio-cultural ground laid by these movements became a major turning point for the development of feminist theories. In this context, Françoise d'Eaubonne's coining of the term "ecofeminism" in the 1970s was no coincidence. In the 1980s, the concept resonated in women-centered environmental platforms, and by the 1990s, it had evolved into a foundational theoretical approach through international conferences and academic discourse.[4]

Today, ecofeminism is not only a theory but also presents itself as an alternative mode of production and way of life. In the field of architecture, this approach advocates for a building culture that values women's labor, lives in harmony with nature, and is rooted in local knowledge. Adobe construction, in this regard, is not merely a nostalgic architectural choice—it is an ecofeminist practice of resistance. This resistance lays the groundwork for a new architectural imagination centered on ecological harmony, local identity, and the intuitive knowledge of women.

3. ECOFEMINIST PERSPECTIVES IN ADOBE CONSTRUCTION

Adobe, beyond being a local and natural building material used for thousands of years, is also a mode of production that reveals how gender relations and labor are organized within space. Especially in the context of adobe-making, women's roles have not been limited to physical labor; they have also been key figures in knowledge transmission, seasonal scheduling, social memory, and spatial shaping. Yet historically, this role has often been rendered invisible or reduced to merely "supportive" positions. This section, through examples from different geographies, explores women's role in adobe production from an ecofeminist perspective, questioning how the relationship with nature is diversified through the body, knowledge, and space.

3.1. Iraq – Bricks Carried for Survival

In the Nehravan region east of Baghdad, Iraq, women working in adobe factories carry wet bricks on their shoulders for 8–12 hours daily due to economic hardship. According to Anadolu Agency

[3] Ayşe Tosun Oruç, *Ekofeminizm Bağlamında Kadın Akademisyenlerin Bakış Açısından Kadının Ev İçi Emeği: Kırşehir Ahi Evran Üniversitesi Örneği* (Yüksek Lisans Tezi, Yozgat Bozok Üniversitesi Sosyoloji Anabilim Dalı, 2023), s. 7-8.
[4] Ezgi Kovancı, *İklim Krizi Bağlamında Toplumsal Cinsiyet Tartışması ve Türkiye* (Doktora Tezi, Ankara Üniversitesi Sosyal Bilimler Enstitüsü, 2019), s. 39-40.

reports, many of these women are widows or sole breadwinners for their families. The physical difficulty of the job forces them to wear thick belts, and they often suffer injuries. To resist the scorching sun and the dusty environment, they cover their faces with black veils—an act that highlights how the body's resistance is limited against systemic exploitation. This is an ecofeminist pattern in which the relationship with nature is shaped not through generative knowledge transmission but through the necessity of survival.[5]

"The women doing this job are carrying burdens even men would struggle with. I can't physically handle it, but I have to work."
— Adobe worker, Baghdad

Figure 2. Women carrying bricks

3.2. Malatya (Arapgir), Turkey – The Memory of Silent Masters

In the Arapgir district of Malatya, adobe production is carried out through deeply localized knowledge. Women determine the consistency of the clay with techniques learned from their ancestors and choose sunny, windless days for production. According to field reports by *Haber49*, even though these women are not formally trained as architects or builders, they are the primary users of the spaces and direct the construction process, thereby becoming the carriers of traditional building culture. From an ecofeminist lens, their relationship with nature is experiential, holistic, and sustainable. This method of production embodies both physical and cultural memory, making the woman's spatial agency visible.[6]

"I know the texture of the soil with my hands. I learned it from my mother, and she from hers. If we don't do this, this knowledge will die."
— Female adobe artisan, Arapgir

3.3. Mardin (Kızıltepe), Turkey – Seasonal Knowledge in Women's Memory

In Yaşar (Piremira) village in the Kızıltepe district of Mardin, women re-plaster their adobe homes every autumn in preparation for winter. This is not simply a maintenance task but a collective practice passed down through generations. Using a mixture of straw and clay, they reapply plaster to the outer surfaces of the homes, enhancing thermal insulation and resistance to wind and rain (*JinNews*, 2020).

[5] *Anadolu Ajansı. (2023, Mart 21). Iraklı kadınlar omuzlarında kerpiç taşıyarak ailelerini geçindirmeye çalışıyor.* https://www.aa.com.tr/tr/dunya/irakli-kadinlar-omuzlarinda-kerpic-tasiyarak-ailelerini-gecindirmeye-calisiyor/2852139

[6] Haber49. (2025, Temmuz 7). *Malatya'da asırlık geleneği yaşatan kadınlar: Tarihi yapıların sessiz ustaları*. https://haber49.net/malatyada-asirlik-gelenegi-yasatan-kadinlar-tarihi-yapilarin-sessiz-ustalari

Figure 3. Women replastering their homes

Hamdiye Bozan, who has lived in the same house for over 40 years, renews the plaster every autumn with her children. This process is not only an act of preservation but also a reproduction of memory, labor, and connection with space. Her words reveal that this practice is a tangible expression of the bond between women's labor and time:

"Our adobe houses get damaged by wind and rain. We fix this damage by replastering and applying adobe again... We do this every autumn."

From an ecofeminist perspective, this practice is an example of a woman-led production process in harmony with nature—one that ensures spatial sustainability and strengthens community solidarity. Despite the rise of concrete structures, these women continue to pass down their embodied understanding of adobe's seasonal and bioclimatic advantages:

"I opened my eyes in these homes. They may have their challenges, but they're healthier than concrete homes… Our mothers were raised here, and so are we."
— Ayşe Bozan

Here, women's labor is not just about care and repair—it is also a form of memory transmission and spatial identity construction. This practice in Mardin thus represents both tangible and cultural sustainability and highlights women's productive role through their relationship with nature, space, and community.[7]

3.4. "Women of the Earth Award": International Recognition of Ecofeminist Practices

Launched in 2001 by the France-based Yves Rocher Foundation, the *"Women of the Earth Award"* (*Terre de Femmes*) is an international platform that supports women's projects in harmony with nature. The award recognizes women who promote local production, ecological awareness, and community solidarity. With implementations in over 50 countries, the program plays a key role in making women's generative relationship with the environment visible.

In 2016, Turkish architect Özgül Öztürk won first place in the competition. Through her project, she established the "Anatolian Angel Women's Education and Production Center" in Elazığ, building a collaborative space with adobe. This structure was not only physical but also served as a hub for social and cultural healing.

"A woman's relationship with nature is not just ecological—it is also social."
— Özgül Öztürk, architect

[7] JinNews. (2020, Kasım 1). *Kerpiç evlerde yaşayan kadınlar bu yıl da evlerinin sıvasını yeniledi*. JinNews. https://jinnews.net/TUM-HABERLER/content/view/149968?page=1088

Figure 4. Building constructed from earth by architect Özgül Öztürk in Elazığ

This award stands as a powerful testament to how women's labor is acknowledged on both local and global scales and how ecofeminist thinking intersects with architecture.[8]

Across these diverse examples, one common thread is clear: women's labor is not merely a productive tool but a defining force in the shaping and continuity of space. Though geographies may differ, the experiential, intuitive, and collective relationship women form with nature in adobe-making remains constant. This relationship constructs not only physical structures but also cultural memory and networks of social solidarity. In this respect, adobe becomes both a material and symbolic vessel of spatial production—embodying both the tangible and intangible. Women's active role in this process opens up a realm of knowledge and value that architectural theory has long overlooked.

4. CONCLUSION

Ecofeminism is not merely an approach limited to environmental ethics or gender equality; it also carries transformative potential for architectural theory. The knowledge production processes of architectural history, shaped by modernist and patriarchal codes, have long ignored women's labor and the intuitive relationships formed with nature. Yet, women-centered modes of production observed especially in vernacular architecture present flexible, sustainable spatial organizations that are in harmony with nature—challenging the rigid, technical, and often gender-neutral assumptions of mainstream architectural discourse.

The ecofeminist perspective considers space not as a mere physical shell, but as a dynamic network constructed at the intersection of gender relations, production processes, and cultural memory. Accordingly, women's involvement in adobe production and their spatial interventions—often deemed "invisible work" such as plastering—are in fact central to the shaping of architectural objects.

Throughout architectural history, space has predominantly been constructed through a masculine gaze. The figure of the designer has traditionally been associated with men, while the user has been conceptualized as genderless, neutral, or passive. This framework has positioned women not as active agents in spatial formation but as figures who merely "fit" into space—ignoring or folklorizing their contributions to architectural production. However, from an ecofeminist perspective, especially in local building practices, women are not only users but also experimental and epistemic architects of space. Spaces like *sofa* (central halls), *tandır rooms*, *pantries*, and *granaries* have evolved from women's daily experiences and needs—thus forming what may be called the "social body" of architecture. The binary of "male architect – female space" is therefore increasingly losing its validity, both theoretically and practically. As seen in the examples from Mardin, Malatya, and Iraq, women's collective production practices are directly linked to intuitive spatial knowledge. In this context, space is shaped not only by technical expertise but also by

[8] Akbaş, M. (2020, Şubat 16). *Mimaride özümüze geri dönelim*. Yeni Şafak. https://www.yenisafak.com/hayat/mimaride-ozumuze-geri-donelim-3525799

embodied and ecological relationships.

Historically, women's contributions to the production of space have been seen as part of "daily life" and therefore excluded from architectural historiography. Actions such as preparing adobe plaster, organizing spaces around a *tandır*, repairing walls, or designing food storage units have been categorized as "maintenance" rather than "design," effectively rendering women's labor invisible. Yet, these acts are critical interventions: they ensure the structural integrity of buildings, maintain seasonal harmony, and most importantly, secure the continuity of space. When a woman intuitively adjusts the clay-to-water ratio for plaster, senses which wall is more vulnerable to rain, or prepares insulation before winter, she is not merely practicing a craft—she is enacting an architectural wisdom grounded in her relationship with place, nature, and the body.

Ecofeminist theory intervenes here by repositioning this labor not as "outside design," but as design itself. Donna Haraway's concept of *situated knowledge* captures this well: she describes such intuitive forms of production as types of knowledge excluded from universalist logic but deeply rooted in local realities. The relationship women form with adobe gains meaning within this framework: their knowledge is not derived from formal education but from intergenerational experience; their production is intuitive yet systematic; their spaces are variable yet functional.

Adobe construction is a mode of production grounded in the knowledge, intuition, and memory of the body. The preparation of the material—adjusting soil type, water content, and straw ratio—requires real-time bodily calibration. Thus, adobe is not only a natural material but also a sensory knowledge medium that links the body to nature, time to seasons, and space to culture.

Women's role in this production process is not only physical but also epistemological. In Malatya's Arapgir, women decide the clay's consistency with their hands. In Mardin's Kızıltepe, they re-plaster their homes each autumn. In Iraq, they carry adobe bricks on their shoulders. All these are living practices of sensory knowledge. This knowledge is not written—it circulates through observation, experience, and intergenerational transfer via the body.

Such production also aligns with Donna Haraway's notion of *embodied knowledge*. Architecture is not merely a drawn or calculated process—it is a lived, felt, molded, and enacted ensemble of actions.
Within this framework, international initiatives such as the *"Terre de Femmes Award"* (Women of the Earth) are vital in making women's relationships with nature, their local knowledge, and ecological architectural practices visible. In 2016, architect Özgül Öztürk won this award and founded the *Anatolian Angel Women's Education and Production Center* in Nimri, Elazığ. There, women learned adobe techniques and created their own spaces—establishing a solidarity-based model. This project represents more than just the use of local materials; it exemplifies how women become subjects and transform the practice of architecture itself.

Building on these findings, the study argues that traditional adobe techniques can be adapted to modern eco-friendly architecture while maintaining women's active involvement. This could take the form of community-driven housing projects, workshops training women as master builders, or hybrid models integrating adobe with sustainable technologies such as passive cooling systems. Such approaches not only conserve ecological values but also reaffirm women's central role in shaping architectural futures.

In conclusion, the ecofeminist architectural approach enables not only an ecological but also a just, participatory, and sensorially attuned architectural vision. Adobe structures shaped by women's labor carry both the memory of the past and the sustainability of the future. This knowledge must not merely be preserved—it must be redefined with the theoretical and practical value it deserves within the architectural field.

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Istanbul Terkos Water Reservoirs Protection Problems And Their Refunctıoning On World Examples

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ABSTRACT
Terkos Reservoirs were built within the Terkos waterway system using modern industrial technologies in the late Ottoman period. It attaches great importance to the protection and survival of these structures, which are important for our industrial efficiency. Various protection methods can be applied in order for history to remain alive and reach future generations.
Re-functioning is also among these conservation practices. The aim of preserving and reviving historic buildings should be to preserve the originality and integrity of these buildings while at the same time directly enabling their continuous use by current and future generations. For example, although the conservation and conservation-revival approaches and methods applied to historic buildings in countries such as Germany, Austria, the Netherlands and Belgium and the conservation and conservation-revival approaches and methods in countries such as Italy, Spain and Portugal seem to be fundamentally the same due to the criteria determined by international conservation legislation, the projects that emerge show that these approaches are actually very different when it comes to implementation. Adaptive re-use can transform endangered historic buildings into spaces that meet contemporary needs. Re-use is actually a continuous process and a phenomenon that reflects a constantly evolving society. With each re-use, it can be thought of as a new beginning that adds a brand new meaning to the culture of a historic building. In this research, the protection problems of reservoir examples in Turkey will be discussed through examples of restoration and re-functioning of similar reservoir structures outside of Türkiye.

Keywords: Reservoır, water structures, restoratıon, refunctioning.

1 INTRODUCTION

In the 19th century, the rapid population growth in Istanbul led to significant infrastructure deficiencies, prompting the Ottoman administration to prioritize industrialization with modern solutions. By the second half of the century, Istanbul's water supply problem had become critical due to fires, typhoid outbreaks, and the increasing population. However, the Ottoman Empire, lagging behind technologically and facing financial difficulties, resorted to granting concessions to foreign companies through pioneering individuals as a solution [1].

The Kırkçeşme, Hamidiye, and Halkalı water systems were vital sources supplying water to Istanbul. Over time, however, these systems lost their functionality and became insufficient for the city's needs. The high cost of repairing outdated pipes and addressing water leaks necessitated the use of Terkos Lake as an alternative water source [2].

To address Istanbul's water needs, in 1874, Hariciye Teşrifatçısı Kamil Bey and engineer Ternau Bey were granted a 40 year concession to distribute water from Terkos Lake to Istanbul, Galata, Beyoğlu, and the European shores of the Bosphorus. According to the contract, twelve public fountains would be constructed including those for hospitals, military barracks, schools, fire

stations, and areas designated by the municipality providing free water to the poor. Water would be sold to subscribers at a rate of five coins for twenty five "kıyye", and the concession would remain valid for 40 years from the date of the initial decree [3].

However, the concession holders transferred their rights to a French company known as Dersaadet Anonim Su Şirketi (Istanbul Water Company) or Terkos Su Şirketi (Terkos Water Company). From 1883 to 1926, the company supplied untreated water from Terkos Lake with only basic chlorination. In 1926, it established the first water treatment plant in Kağıthane, providing purified and chlorinated water to the city [4].

2 ARCHITECTURAL AND STRUCTURAL FEATURES OF THE RESERVOIRS

The water supplied by the Dersaadet Water Company from Terkos Lake to Beyoğlu, Galata, and other areas was not sufficiently clean. Since the company needed to provide cleaner water, it sourced water from upstream springs before it reached the lake [5]. On August 21, 1874, an agreement was signed between the Minister of Trade and Public Works, Zihni Pasha, and Paul Letally, director of the Dersaadet Water Company, granting the Terkos Company the concession to supply water to Istanbul. Later, on September 11, 1887, an additional twentythree article agreement and a 16 article specification were signed [6]. Five maps prepared by the Terkos Water Company were attached to these documents (Fig. 1) [7]. Among the facilities constructed by the Terkos Water Company were reservoirs, including: The Feriköy Reservoir (Beyoğlu side), the Edirnekapı Reservoir (Istanbul side), secondary distribution lines between Kağıthane and these reservoirs, six water storage tanks in Beyoğlu and the Bosphorus region with a total capacity of 19,607 m³, a water tower in Bomonti, 221.67 km long distribution network divided into four pressure zones based on terrain. Based on five maps prepared by the Terkos Water Company, the reservoirs are located in Edirnekapı, Feriköy, Şişli, Arnavutköy, Kireçburnu, and Boyacıköy.

Figure 1. Maps showing the reservoirs prepared by the Terkos Water Company [6][7]

The ISKI Bahçeköy Foundation Waters Directorate holds French architectural drawings of these structures. The plans, unsigned and undated, exhibit similarities, suggesting they were prepared by the same individual or team (Fig. 2).

Figure 2. French plans of the reservoirs in the İSKİ Bahçeköy Foundation Water Works Directorate [6] [7]

The reservoirs feature cross-vaulted ceilings supported by brick columns, with a waterproof layer above. The interior walls are plastered, while the exterior consists of rubble stone masonry. The vaults and side walls are also plastered, and the floor is smooth and covered with a plaster layer. The brick columns supporting the vaults rest on inclined stone bases. To prevent water pressure and leakage, the surrounding walls are sloped. To withstand the lateral water pressure, the reservoir features internal buttresses leaning against the walls and arched corner supports on both sides. These buttresses and arched supports, constructed with mortared rubble stone, are plastered up to a certain height from the ground. This load bearing system forms a gallery around the central space, which is divided into aisles by columns. Ventilation chimneys, likely used for water discharge and air circulation, are present on the ceiling. Some chimneys have been sealed or covered with iron lids. A spiral iron staircase, anchored to the side walls, provides access to the lower levels. Corroded iron water pumps, possibly used for drainage, remain inside the reservoir. The mortar used in the stone buttresses, brick columns, and vaults is likely "Horasan mortar", known for its hydraulic properties, making it ideal for water retaining structures like cisterns and baths.

Adjacent to the buildings are structures such as a guardhouse and lodgings within the gardens. These structures are single story, plastered masonry structures with triangular pediments, low arched windows, and masonry walls. Their gable roofs are covered with Marseille style tiles bearing the "Arnaud Etienne 1888" stamp.

3 CONSERVATION STATUS AND REUSE PROPOSALS FOR THE RESERVOIRS

Abandoned structures that lose their function deteriorate rapidly without regular maintenance. Factors such as time, environmental conditions, economic pressures, and vandalism accelerate decay. Adaptive reuse extends the lifespan of historic buildings [8].

When repurposing historic spaces, design integrity must align with the building's original context and new function. This approach enhances the project's value while meeting user demands. Restoration requires expertise to preserve aesthetic and historical significance. Collaborative architectural and interior design projects can revitalize these structures, reinforcing urban memory. Turkey has a significant building stock that complies with this approach to preservation. This will ensure that our building culture and urban memory remain fresh [9].

3.1 Edirnekapı Reservoir

On the island where the "Edirnekapı Reservoir" is located, there are two more historical structures that require preservation. One of these is the building located north of the reservoir, which now serves as a residence. This structure was built alongside the reservoir to provide security and accommodation for the reservoir staff. The other structure on the island is a building constructed in the late 19th century. Today, it is used as the İSKİ Fatih Water, Canal, and Permit Directorate.

It is not known exactly when the "Edirnekapı Reservoir", which is now abandoned, became non functional (Fig. 3). Thanks to the efforts of the İSKİ Fatih Water, Canal, and Permit Directorate officials, some cleaning has been carried out. However, given its architectural, constructional, and technological significance for its era, the structure urgently requires protective measures in its current state.

Figure 3. An external view of the Edirnekapı Reservoir, Photographer Z. E. Ekim, 2018

The ceiling of the structure has collapsed, the plaster has cracks, the joints have opened, and the walls show cracks and darkening (Fig. 4). Corrosion has formed on the stair railings, water inlet pipes, float system, pumps, and metal components in the valve chamber. This corrosion must be removed using chemical and physical methods, followed by the application of anti rust paint and repainting. The machinery, pumps, and other movable and immovable mechanisms in this reservoir, which hold historical value as industrial heritage, should be preserved and displayed as a bridge to the contemporary world.

Figure 4. An external view of the Edirnekapı Reservoir, Photographer Z. E. Ekim, 2018

Believed to have been built in the last quarter of the 19th century as part of the "Terkos System" to meet the water needs of the Historic Peninsula, this structure is one of the few reservoirs that used a pumped water system. As an important piece of the Ottoman industrialization history, this industrial heritage site could become an exemplary project through a carefully executed adaptive reuse plan preserving industrial heritage memory while meeting the needs of modern life [10].
If this site is repurposed as a museum, entry and exit will be through the existing stairwell. A wooden platform will be constructed above ground level, allowing visitors to walk through the structure. To support the platform, metal rings will be installed around the brick piers at their upper levels, and these rings will be interconnected beneath the wooden platform to carry its load. Below the wooden platform, water will remain up to a certain height. Visits to the cistern will be

controlled, limiting the number of people inside the structure. Due to fire risks, a separate exit has been planned, different from the entrance stairwell.

3.2 Feriköy Reservoir

Next to the reservoir, there are also Repair Workshops and residential buildings (Fig. 5). The materials used in the construction of the building include brick, mortar, plaster, stone, iron, wood, and Marseille tiles. To ensure the long term preservation of the structure, non original and low quality additions should be removed, and restoration should be carried out with careful, contemporary interventions. Considering the building's location and Feriköy's current urban development profile, it could be repurposed as a performance or arts center, addressing a notable lack of such facilities in the area. The structure could be transformed into a cultural complex hosting various artistic activities. The absence of detailed records on its original equipment and the presence of a spacious garden provide design flexibility. The building can be perceived as a shell, but any new design must respect its existing features and be developed in line with measured survey and restitution projects [11].

Any new elements added to the structure should harmonize with its original character while preserving its historical qualities. Additionally, the new function assigned to the building should be determined by considering environmental, economic, and social factors. Non-original additions and modifications should remain visually distinguishable for future restoration efforts. The scope of intervention during adaptive reuse must be clearly defined, ensuring that irreversible changes are avoided and that new additions are not confused with original elements [12].

Figure 5. Feriköy Reservoir repair workshops and housing buildings, Photographer Z. E. Ekim, 2016

3.3 Şişli Reservoir

The empty reservoir's roof is currently used as a parking lot. Although the structure is inaccessible, information obtained from the project ledger at the İSKİ Bahçeköy Vakıf Sular Müdürlüğü (İSKİ Bahçeköy Foundation Waters Directorate) indicates that the cistern has a rectangular plan.

One of the most important problems of the reservoir is that it causes collapses and cracks in the roof of the vehicles on it. The waterproofing layer has deteriorated, allowing rainwater to leak through the roof. Therefore, during restoration, repairing the brick vault and renewing the insulation are essential.

Cracks in the ceiling and walls must be filled using injection methods, and all surfaces with material loss should be restored with compatible materials. Original stone, brick, plaster, and

mortar samples should be analyzed in a laboratory to ensure proper restoration. All repairs and reinforcements must adhere to conservation principles. It needs to be cleaned because it is full of garbage (Fig. 6).

Figure 6. An internal and external view of the Şişli reservoir, Photographer Z. E. Ekim, 2018

We live in an era where conditions, values, and societal structures are rapidly transforming, leading to new forms and regulations. Over time, functions may change, but buildings remain. This necessitates repurposing old and even relatively new structures for different uses in the future [13]. The adaptive reuse of historic buildings, like all design projects, requires meticulous planning. While originality is crucial in effective design, it can be particularly constraining in historic structures because the primary priority is preserving authenticity. Therefore, when repurposing historic spaces, interior design factors and façade compatibility with the new function are critical. At the core of architectural design lies addressing human needs and habits creating spatial solutions that accommodate life's demands. Similarly, when adapting historic buildings for new uses, user requirements must harmonize with the structure's preservation.

3.4 Arnavutköy Reservoir

Examining the original plans and sections of the Arnavutköy Reservoir reveals its surroundings at the time, the Zincirlikuyu-Arnavutköy road, the properties of Kamil Pasha, and an abandoned stone quarry. The rectangular plan reservoir measures 29.69 meters along its long side and 21.69 meters along its short side. The structure features a cross vaulted ceiling supported by fifteen handmade brick columns, with perimeter walls also constructed of brick. This load-bearing system creates a central nave divided by columns, surrounded by a gallery. The gallery's roof incorporates six ventilation shafts four with 86 cm diameters and two with 1.56 cm diameters likely used for air circulation, water distribution, and drainage purposes. The original plans show a guardhouse within the compound, which still exists today as a single story masonry structure with plastered rubble walls and a gable roof, accessible via a staircase on its narrow side (Fig. 7). Black patina formations caused by microbial growth from moisture infiltration are visible in several areas of the structure [6].

Figure 7. The picture on the left is the front view of the Arnavutköy reservoir housing building, the picture on the right is the staircase leading down from the chimney to the reservoir, Photographer Z. E. Ekim, 2018

An August 14, 1890 advertisement in La Turquie newspaper listing the Kireçburnu and Arnavutköy reservoirs as addresses for the Istanbul Water Company indicates these facilities handled subscriber transactions. As one of the first structures attempting to address Istanbul's late 19th century water crisis using modern industrial technologies, converting the Arnavutköy Reservoir into a museum under ISKI's management would provide exhibition space for documents related to both this building and the Terkos Water Project including plans, books, records, maps, and photographs [6].

This valuable structure, though no longer functionally operational, has physically endured to the present day and deserves preservation according to universal principles through proper restoration techniques before being adapted for new uses and passed to future generations. Prior to any interventions, thorough spatial analyses must be conducted to identify the building's structural strengths and weaknesses that would affect its transformation.

Industrial buildings, when repurposed and restored with new missions, can generate significant economic benefits for their cities and regions through social, environmental, cultural, and touristic contributions. The adaptive reuse of such structures has created an economic sector termed "industrial tourism" [14]. In our rapidly changing world with growing populations, diminishing resources, escalating demands, and accelerating transformation rates, imagining certain things returning to their original state remains utopian [15]. Individuals socialized in environments bearing markers of the past naturally develop cultural continuity awareness and historical consciousness. The envisioned continuity here aims to carry symbols of the past into new living contexts rather than nostalgically recreating bygone eras [16].

3.5 Boyacıköy Reservoir

The reservoir structure, situated on sloping terrain along the Bosphorus heights, is supported by nine brick piers. The cistern's roof is covered with earthen soil and features three ventilation chimneys (Fig. 8). The rubble stone walls of the reservoir bear the inscription "Co. Des Eaux Constantinople" (Istanbul Water Company).

Figure 8. The picture on the left is the interior view of the Boyacıköy reservoir, the picture on the right is the "Co. Des Eaux Constantinople" inscription on the valve on the outer wall of the reservoir, Photographer Z. E. Ekim, 2018

The site currently houses ISKI's Boyacıköy Social Facilities. Architectural functions inherently establish relationships with their surroundings through considerations of accessibility, utility, orientation, and natural lighting needs [17]. For instance, conference halls and exhibition spaces can be situated underground as they don't require natural light, whereas restaurant spaces should maximize sunlight exposure and capitalize on views. Consequently, the unparalleled Bosphorus vistas offered by the Boyacıköy, Arnavutköy and Kireçburnu Reservoirs present ideal opportunities for converting adjacent areas into dining establishments (Fig. 9).

Figure 9. The picture on the left is a view of the Bogazici reservoir from Boyacıköy, the picture on the right is a view of the Boyacıköy reservoir from the garden, Photographer Z. E. Ekim, 2018

When examining environmental motivations for adaptive reuse through the lens of industrial heritage, these structures demonstrate significant potential for employment generation, social interaction, historical cultural development, and economic growth within their contexts. A prime example of successful industrial repurposing is London's Tate Power Station, transformed into the Tate Modern art museum. To enhance accessibility to this Thames side attraction, architect Norman Foster designed the Millennium Bridge, creating both a physical link and visual dialogue between the structure and its urban context.

The primary objective should be enabling historic structures to adapt to rapidly expanding urban environments while maintaining cultural heritage, thus creating sustainable urban cores. Secondary goals include providing functional diversity for residents and tourists, meeting contemporary needs, establishing vibrant urban centers, and facilitating future investments. While new construction demands substantial capital expenditure, repurposing existing structures requires intensive labor inputs [18]. This economic reality makes adaptive reuse particularly advantageous for technologically developing nations, where retrofitting often proves more cost effective than new construction. Beyond functional conversion, comprehensive planning must address peripheral elements parking areas, transit stops, urban furniture, lighting systems, and landscape interventions to properly integrate repurposed structures with their surroundings. The reservoir sites unique

topographic positions along the Bosphorus ridges offer exceptional opportunities to implement this holistic approach while preserving their industrial character.

3.6 Kireçburnu Reservoir

The site contains a masonry residential building (comprising ground and basement levels) and the reservoir structure. Accessed via a steep staircase, the residential building features rubble stone walls and barrel vaulted flooring in its basement. The structure's segmental-arched windows have brick frames, while its corners are reinforced with alternating brick quoins. The garden area contains four chimneys belonging to the reservoir, whose roof remains earthen covered (Fig. 10). Unlike other service buildings, this residence continued functioning as staff housing until 2017, resulting in non original modifications.

Figure 10. A view of the top of the Kireçburnu reservoir from the garden and the housing building, Photographer Z. E. Ekim, 2018

Late 19th century socioeconomic developments precipitated new architectural needs as living conditions evolved. In this context, every structurally sound but functionally obsolete building now presents adaptive reuse potential. Preserving and transmitting historical, natural, and cultural spaces fundamentally involves integrating heritage with contemporary social life while enhancing living standards through responsive solutions to emerging needs [20]. The urban scale management of industrial heritage conversions requires particular attention.

Structures awaiting repurposing demand thorough preproject analysis to align new functions with their spatial structural characteristics. As material witnesses to their era's technology and architectural practices, these buildings convey multilayered historical messages. Each misstep in their adaptation risks distorting cultural transmission to future generations [21].

4 EXAMPLES OF RESERVOIR STRUCTURE REFUNCTIONING FROM AROUND THE WORLD

The selected European examples are contemporary structures dating back to the 19th century, similar to Turkey's reservoirs. The preservation and adaptive reuse of reservoirs in London and Paris remain crucial. In Paris's 14th arrondissement stands a monument of surprising beauty and simplicity: the underground Montsouris Reservoir. Hydraulic engineer Eugène Belgrand constructed a new aqueduct to bring clean water from the River Vanne in Champagne and built this massive reservoir near the future Parc Montsouris (Fig. 11). These two projects increased Paris's daily water supply from 87,000 cubic meters to 400,000 cubic meters [22].

Figure 11. Montsouris Reservoir, Paris [22]

These structures should not be called cisterns. In Victorian England, they were cathedral like underground reservoirs built to store rainwater. Currently closed to the public for safety reasons, these disused structures in London, Leicestershire, and the Midlands include London's oldest reservoir (built in 1844 to supply clean water to a major naval hospital) with remarkable acoustic properties whispers echo along its curved walls. Another example is the Finsbury Park Reservoir (1868), also known as Hornsey Wood Reservoir, featuring 120 meter long galleries and exceptional acoustics beneath a subway line (Fig. 12). The Leicestershire reservoir (1896), located about two and a half hours north of London, served as both a water storage facility and filtration system [23].

Examining international examples reveals how various civil organizations promote conservation of economic and cultural values. Government support for these institutions and financial backing of such processes prove critical. In Turkey, however, contractor firms typically handle historical conservation projects, which can lead to economic challenges, disputes, and project limitations, sometimes resulting in privatization of world heritage sites. To prevent this, build operate transfer models have begun appearing in public projects, particularly for adaptive reuse.

Figure 12. Hornsey Wood Reservoir, London [23]

Successful adaptive reuse transforms spaces beyond museums or monuments into vibrant living areas hosting cultural events, concerts, exhibitions, libraries, restaurants, and cafes. Globally, such projects favor public, cultural, and artistic uses over private ones. Truly successful conversions integrate industrial structures into urban fabric while generating economic, social, and cultural benefits that gain public acceptance. By revitalizing heritage structures through new functions, we make cultural assets legible, visible, and perceptible effectively bringing history back to life while preserving its original value. The reactivation process allows historical significance to emerge through contemporary interpretation rather than static preservation.

4.1 The Reservoir in Sondermarken, Copenhagen, Denmark

Located beneath Sondermarken Park in Frederiksberg, this underground reservoir has been transformed into an art center. Constructed between 1856 and 1859 to supply drinking water to Copenhagen, it remained in operation until the 1930s. After being decommissioned in 1981, the space was repurposed for modern glass art exhibitions and later became part of the Frederiksberg Museums, focusing on contemporary art. Its cavernous, dimly lit interior reminiscent of catacombs inspires site specific installations that interact with the structure's unique architecture and history (Fig. 13) [24].

Figure 13. The Reservoir in Sondermarken, Copenhagen, Denmark [24]

4.2 Pompeu Fabra University Library, Barcelona

Pompeu Fabra University in Barcelona gained a remarkable new library housed within a forgotten 19th century water reservoir located in the heart of the city. The project, assigned to architects Lluís Clotet Ballús and Ignacio Paricio Ansuátegui, transformed the reservoir into a kaleidoscopic library space. Originally designed in 1874 by architect Josep Fontserè as part of the redevelopment of the former military citadel, the "Dipòsit de les Aigües" (Water Reservoir) featured structural calculations contributed by a young architecture student at the time Antoni Gaudí i Cornet. Rather than employing modern cast iron column technology, the designers opted for a traditional load bearing system capable of supporting both the massive weight of water and the structure's considerable height. Completed in 1876, the reservoir began operation in 1880, primarily regulating water flow to the waterfall in Ciutadella Park and irrigating its gardens.
The structure's impressive 65 meter depth creates a monumental spatial experience. This building served as an exhibition pavilion during the 1888 International Exposition. Over the course of more than a century, it was repurposed as a hospital center, municipal storage facility, film set, fire station, and judicial archive before being transferred to Pompeu Fabra University in 1992. In 1993, the architectural duo Clotet and Paricio undertook its transformation into a library while meticulously respecting the original structure preserving the load bearing system and designing all modern additions as removable elements. The vaulted arches create a "kaleidoscopic effect" that lends dynamic visual character to the interior space. Five strategically placed skylights were incorporated into the roof geometry. Two prefabricated concrete elements (one serving as flooring, the other as structural support) were suspended three meters above the main floor, forming an intermediate level that functions like built in furniture while expanding usable space. The necessary installations of the building were hidden in this way, and different reading areas were created (Fig. 14).

Figure 14. Pompeu Fabra University Library, Barcelona [25]

The renovations were carried out respecting the building's original structure, and the interior was intervened with removable elements. Modern interventions that do not disrupt the historical fabric are important in terms of Gaudí's early engineering contributions and the integration of industrial heritage with the academic function [25].

CONCLUSION

When repurposing a historically significant structure with an appropriate new function and making it publicly accessible, it's crucial to consider and implement necessary adjustments to the surrounding facilities particularly those in close proximity to the building. This approach ensures the structure's harmony with its environment while preserving its historical qualities in collective memory and guaranteeing its sustainability. People living in historic environments naturally form strong, continuous social bonds through their interactions. Historic areas hold significant value in strengthening and maintaining community relationships through their spatial context and sustainability impact.

However, dense urbanization, growing population needs, new settlement areas, commercial pressures, and legal loopholes threaten these historic sites they either disappear or get repurposed for commercial uses that contradict their original character. Cities are living, dynamic entities. Beyond education, work, and housing needs, urban dwellers require spaces for socialization, culture, art, and sports. In this context, alongside new projects, defunct cultural heritage sites can transform into important recreational areas under local government leadership to serve community needs.

Consequently, adaptive reuse has emerged globally as a highly favorable planning strategy. Worldwide, across Europe and in our country, reuse projects prioritize public benefit by converting significant heritage structures into public spaces serving urban communities. The question of how to utilize industrial heritage sites that have lost their original function represents a critical issue. While industrial heritage has followed different trajectories across nations, it fundamentally reflects industrialization's legacy and era specific imprints on urban identity and memory.
The emergence of industrial building reuse stems from their forms, locations, and functional obsolescence processes. In this context, the new functions given to these structures and the resulting transformed spaces hold architectural, cultural, economic, and historical significance at urban, national, and global scales. The adaptive forms shaped by new purposes maintain dialogue between past and present while addressing contemporary urban needs, creating a sustainable model where heritage conservation and modern functionality coexist productively. This approach not only preserves material history but also revitalizes urban memory through meaningful contemporary use.

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Development Of Traditional Earthen Wind Catchers in Contemporary Constructions (Case Study: Yazd, Iran)

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ABSTRACT

One of the unique features of earthen architecture in hot regions, especially in Yazd city, is the use of wind catchers. Using these earthen elements in historical buildings for natural ventilation and cooling, making them a recognized architectural symbol of the city. These structures, especially in the past, helped to ventilate buildings by using natural air flow. Although by introduction of new ventilation methods, wind catchers have lost their original function, new constructions have tried to preserve and expand this architectural element by restoring, renovating and reusing them. Using new materials, new technologies and advanced tools has sometimes improved the performance and efficiency of wind catchers.

In recent decades, a significant number of wind catchers have been built in Yazd city. These ones differ from the original earthen models in four aspects including, ventilation method, structure, material and usage. In This article, newly built wind catchers in the city of Yazd have been examined from these four main aspects by using a survey research approach and theoretical and basic research studies through library resources and interviews with professional earthen specialists. The criteria for selecting the samples in this article were factors such as accessibility, availability of sufficient information, distribution in different parts of the city, diversity in style and construction methods. Examining these structures allows to analyze the evolution that has occurred in using wind catchers in contemporary architecture and the way of adaption of historical identity with modern needs.

The results argue that most of newly built or renovated wind catchers have undergone changes in one or more areas of ventilation, structure, materials, and use. Improvements and optimizations were least frequent in the mechanical or air conditioning features, the most important function of this symbol of Yazd earthen architecture. Investing in and developing wind catchers will help reuse this unique earthen heritage, leading to sustainable buildings.

Keywords: Wind catcher, contemporary constructions, sustainable building, earthen heritage

INTRODUCTION

Wind catchers, which were used in the past as a way to ventilate buildings in hot and arid regions, have been gradually forgotten due to the invention of modern air conditioning systems and technological building advancements. In contemporary architecture, this vernacular element is rarely incorporated, and when it is, its form and function are often adapted to meet present-day design standards. Nevertheless, a number of historic buildings have undergone restoration efforts to preserve or reactivate their original windcatchers, while some contemporary projects have reinterpreted and reconstructed them with modern materials and methods. The present study focuses on selected

examples of windcatchers in the city of Yazd that have been either restored or newly constructed in recent decades. These cases have been chosen based on notable aspects such as enhanced performance, innovative construction techniques, environmental responsiveness, the use of contemporary materials, and the adaptive reuse of this traditional architectural feature.

Windcatcher: A Vernacular Approach to Passive Cooling

The central plateau of Iran—particularly the historic city of Yazd—is home to numerous earthen structures, including the iconic windcatchers (badgirs). In Persian, the term badgir literally means "a structure for capturing wind" and specifically refers to architectural forms that channel outdoor air into indoor spaces. In English, the term is commonly translated as "windcatcher" or "wind tower." In traditional Iranian architecture, windcatchers functioned as passive air conditioning systems, designed to cool interior spaces and provide natural ventilation. These earthen structures helped mitigate the intense summer heat by capturing and directing airflow from the outside into the buildings.

Although many contemporary windcatchers, especially those in newer urban developments, have lost their original functional purpose, they are still employed as symbolic or decorative architectural elements. However, in certain architectural projects, windcatchers continue to serve both ornamental and functional roles—contributing to passive ventilation strategies and reducing energy consumption. In addition to preserving the historical identity, wind catchers also enhance the aesthetic aspects of the building.

Figure 1. The Historic Fabric of Yazd – A Section of the Shah Abolqasem Neighborhood Skyline (Source: Authors)

Contemporary Windcatchers

In recent decades, a considerable number of windcatchers have been either newly constructed or restored across the city of Yazd. Many of these have emerged as part of restoration initiatives and cultural heritage preservation projects. Some are built using a variety of materials, such as brick, stone, and even metal, in projects located in a new content of city.

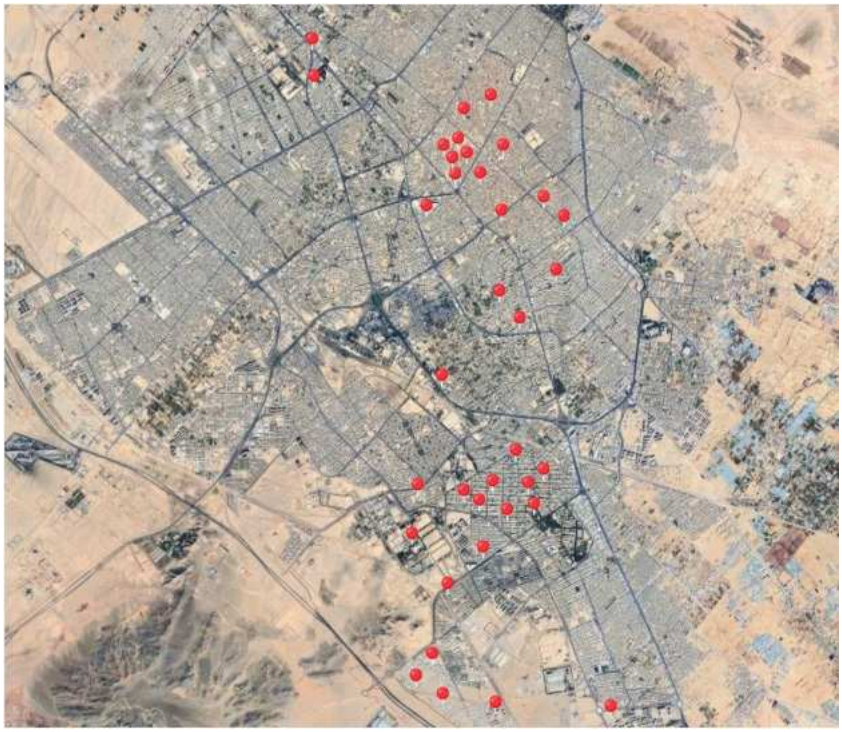

Figure 2. Aerial View of Yazd – Source: Google Maps, 02 February 2025

General Classification of Selected Cases

The selection criteria for the windcatchers examined in this article included factors such as accessibility, availability of sufficient documentation, geographical distribution across different parts of the city, diversity in style, and variation in construction techniques. Furthermore, priority has been given to those windcatchers that have undergone restoration processes, as well as those incorporated into contemporary public or residential buildings with functions differing from the original purpose of windcatchers.

In this study, the examined windcatchers are broadly categorized into two main groups: modified (or "upgraded") and unmodified windcatchers. Although the term upgrade typically carries a positive connotation, in the context of this article it does not necessarily imply improvement or enhancement. Instead, it refers to any change that has occurred in the design, structure, or performance of the windcatchers.

These modifications may include the use of modern materials, alterations in ventilation system functionality, adaptation to contemporary needs, or integration with new technologies. In other words, modified windcatchers are those that, over time and through the evolution of architectural practices, have undergone structural or functional transformations—regardless of whether these changes have resulted in increased efficiency or architectural value.

This classification enables a more nuanced understanding of how windcatchers have evolved in the context of modern architecture and provides a framework for analyzing their continuity or departure from traditional typologies.

Figure 3. Selected Windcatchers Studied – Source: Author

In contrast, unmodified windcatchers refer to those that have largely retained their traditional form, preserving their original function without undergoing major changes in design or materials. These windcatchers are typically constructed entirely from traditional and locally sourced materials such as brick, gypsum, and wood, and they continue to operate using historical methods of passive ventilation and cooling.

These structures serve as valuable references for understanding the authentic typology of windcatchers, as they maintain a direct link with their vernacular origins.

Table 1. Overview of Studied Windcatchers

Upgraded	Location	Name	No.	Upgraded	Location	Name	No.
-	Amir Chakhmaq Sq.	Shesh-Baadgiri Cistern	2	-	Basij Blvd.	Rostam Giv Cistern	1
-	Emam St.	Yazd Cultural Heritage Office	4	-	Iranshahr St.	Golchinan Cistern	3
✓	Sahel Ibn Ali	Kazem Rasoolian House	6	-	Sahel Ibn Ali	Mortaz Historic House	5
-	Sahel Ibn Ali	Mehdi Rasoolian House	8	-	Golchinan	Poostforoush Historic House	7
-	Golchinan	Shafi'pour Historic House	10	-	Gazorgah	Hojjat Historic House	9
✓	Vaght o Saat	Shokoohi Historic House	12	-	Fahadan	Heyrani Historic House	11
✓	Sahel Ibn Ali	Kermani Historic House	14	-	Darvazeh Ghasabha	Daryaei Historic House	13
-	Gazorgah	Gorji Historic House	16	✓	Sahel Ibn Ali	Lariha Historic House	15
-	Shah Abolghasem	Mahmoudi Historic House	18	-	Tall District	Morshed Historic House	17
✓	Sahel Ibn Ali	Rasoolian Timcheh	20	-	Golchinan	Rasoolian Cultural Center	19
✓	Paknejad Blvd.	Parad Residential Complex	22	✓	Mollasadra 19	Deniz Residential Complex	21
✓	Safaieh - Taravat Blvd.	Twin Tower Complex	24	✓	Safaieh – Kooye Asaatid	House No. 1 (Dr. Farahza)	23
✓	Safaieh - Majd Al-Olama 9	House No. 4	26	✓	Safaieh - Vesal 2	House No. 7	25

✓	Safaieh - Gendarmerie 4	House No. 6	28	✓	Safaieh - Nirang & Ladan Junction	House No. 9	27
✓	University Blvd.	Yazd University Mosque	30	✓	Mehrawaran - .Imam Hadi Sq	House No. 13	29
✓	Daneshjoo Blvd.	Ghadir Cultural Center	32	✓	Shesh-Baadgiri District	House No. 15	31
✓	Daneshjoo Blvd.	Yazd Department of Culture & Islamic Guidance	34	✓	Shahid Beheshti Blvd.	Dr. Sartipzadeh's Clinic	33
✓	Juy-e Horhor District	Ava Hotel & Restaurant	36	✓	Shahid Ghani Blvd.	Hayat Tayyebeh School	35
✓	Azadi Square	Azadi Square Landmark	38	✓	Iranshahr St.	Iranshahr Shopping Center	37
✓	Hakimian Crossroad	Hakimian Underpass	40	✓	Safaieh - Imam Hassan Sq.	Safaieh Hotel – Main Building	39

In this study, a total of 40 windcatchers from various locations throughout the city were examined. Of these, 36%—equivalent to 15 cases—had undergone no significant modification or enhancement and were either constructed or restored using traditional methods. In contrast, 64%—a total of 25 windcatchers—showed various degrees of change in their design or structure during construction or restoration. These modifications may include the use of new materials, structural alterations, or other architectural interventions. The adjacent pie chart clearly illustrates the distribution of these two categories, highlighting that the majority of the windcatchers studied fall under the 'modified' classification

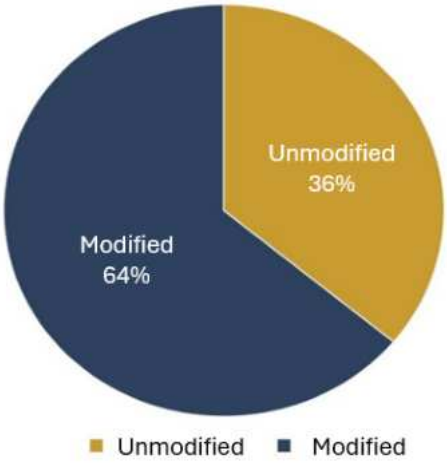

Figure 1. Classification of Modified and Unmodified Windcatchers

Modified and Enhanced Windcatchers

Based on the findings, a set of criteria was developed to categorize the modified windcatchers, which are briefly outlined below:

Structural Criteria: This category assesses changes in the physical structure and design of the windcatchers, including alterations in height, form, and the number or configuration of air openings.

Functional Criteria: This includes evaluation of the windcatcher's performance in natural ventilation and cooling, as well as changes in its use within both traditional and contemporary buildings. It also encompasses cases where the windcatcher has been completely repurposed—for instance, where evolving spatial needs have rendered the original ventilation function obsolete, and the structure has been adapted into a decorative element or integrated into other architectural functions.

Material Criteria: This criterion addresses the incorporation of new construction materials—such as metal, glass, or concrete—in contrast to traditional materials like brick and gypsum. These material shifts often reflect aesthetic or technical responses to contemporary architectural trends.

Mechanical and HVAC Criteria: This involves analyzing the integration of mechanical ventilation systems or hybrid systems combining traditional passive cooling with modern technologies—such as

the addition of fans or mechanical air circulation devices to enhance or supplement the natural airflow provided by the windcatcher.

It is important to note that the majority of windcatchers in the 'modified' group meet two or more of these criteria, indicating a multidimensional transformation.

Table 2. Classification of Modified Windcatchers Based on the Defined Criteria – Source: Authors

Areas of Enhancement				Name
Mechanical	Material	Occupancy	Structural	
✓	-	-	-	Kazem Rasoulian Historic House
✓	-	-	-	Shokoohi Historic House
✓	-	-	-	Kermani Historic House
✓	-	-	-	Lariha Historic House
-	-	-	✓	Rasoulian Timcheh
-	✓	✓	✓	Parad Residential Complex
-	✓	✓	✓	Deniz Residential Complex
-	✓	✓	✓	Twin Tower Residential Complex
✓	✓	-	✓	House No. 1 – Dr. Farahza's Modern House
-	✓	-	✓	House No. 4
-	✓	-	✓	House No. 6
-	✓	-	✓	House No. 7
-	✓	-	✓	House No. 9
-	✓	✓	✓	House No. 13
-	-	-	✓	House No. 14
-	✓	✓	✓	Dr. Sartipzadeh's Clinic
-	✓	-	✓	Yazd University Mosque
-	✓	✓	✓	Hayat-e-Tayebeh School
-	✓	-	✓	Ghadir Cultural Center
-	✓	✓	✓	Iranshahr Commercial Complex
-	✓	✓	✓	Yazd Department of Culture & Islamic Guidance
-	✓	✓	✓	Safaieh Hotel – Main Building
-	✓	✓	✓	Ava Hotel Restaurant
✓	✓	✓	✓	Hakimian Underpass
-	✓	✓	✓	Azadi Square Landmark

Selected Case Studies

- **House No. 1 – Dr. Farahza's Modern Residence**

The architectural design of this residence follows a pattern inspired by traditional houses, incorporating evaporative cooling systems in the Howzkhaneh (central pool room) and a windcatcher (badgir). Natural airflow strikes moisture-laden perforated bricks, leading to a decrease in air temperature. This cool air is then directed to the lower levels of the house, primarily cooling the basement via the Howzkhaneh.

This case demonstrates both structural and material upgrades.

Figures 4, 5, 6. House No. 1 – Dr. Farahza's Residence – Source: Authors

- **Kazem Rasoulian Historic House (Currently the Faculty of Art and Architecture, Yazd University)**

This historic house, left uninhabited for several years, was donated to Yazd University in 1999 (1378 SH) and repurposed as the Faculty of Art and Architecture. Following restoration, it officially began operating in January 2001 (Dey 1379 SH). The windcatcher of this house is relatively low in height and connected to a sealed space located above the sardab (basement chamber), which lies underground.

In today's conditions—characterized by warm and polluted air—this windcatcher is used in exhaust mode rather than for direct cooling. The system draws the cooler, humid air from the sardab upward through the windcatcher, contributing to a more pleasant indoor environment.

Recent climate analyses suggest that the windcatcher no longer suffices for cooling interior spaces through traditional methods; therefore, the extraction-based approach is seen as a logical and effective adaptation for reviving the windcatcher's function.

This case has undergone mechanical enhancement.

Figures 7, 8, 9. Kazem Rasoulian House (Faculty of Art and Architecture, Yazd) – Ayatollahi, 2007

- **Hayat-e-Tayyebeh Educational Complex**

Located at the intersection of Shahid Ghandi and Shahid Samei Boulevards, the Hayat-e-Tayyebeh Educational Complex originally incorporated windcatchers designed to function similarly to traditional

ones but constructed with modern materials. However, it appears that due to poor execution, these windcatchers failed to meet the intended performance requirements. Currently, their ventilation shafts

have been blocked, and they now serve solely as decorative architectural elements within the urban landscape.

This case has undergone structural, occupancy, and material modifications.

Figures 10, 11, 12. Hayat-e-Tayyebeh School – Source: Authors

- **Safaieh Hotel**

The windcatchers of the Safaieh Hotel have been modified not only in terms of materials but also in form and structure compared to their traditional counterparts. The materials used include brick, cement, metal mesh, steel, and a decorative Sim-Gel coating.

This case illustrates upgrades in structure, occupancy, and materials.

Figures 13, 14, 15. Safaieh Hotel – Source: Authors

- **Timcheh-ye-Rasoulian**

Due to the construction of tall and modern buildings in its surroundings, the windcatcher of the Rasoulian Caravanserai lost its effectiveness in ventilation as well as its symbolic presence within the urban landscape. Based on the recommendation of restoration consultants, the windcatcher was

completely demolished and reconstructed to restore its ventilation function and urban identity. The materials used in the reconstruction include adobe, brick, gypsum, and steel.

This case reflects an upgrade in structure.

Figures 16, 17, 18, 19, 20. Timcheh-ye-Rasoulian – Source: Authors

- **Mosque of Yazd University**

This windcatcher was designed as a water-assisted cooling system and simultaneously serves as a symbolic minaret for the mosque. Two out of the three openings of the windcatcher use cotton and straw curtains (similar to evaporative cooler pads) to moisten the incoming air, thereby lowering its temperature. The third opening allows airflow without evaporative cooling, similar to traditional windcatchers. Tests have shown that the evaporative cooling method yields better thermal performance compared to other techniques.

This case exhibits structural and material upgrades.

Figures 21, 22, 23. University Mosque of Yazd – Source: Authors

CONCLUSION

The conducted analysis reveals that during restoration and reconstruction processes, traditional forms and earthen materials—such as adobe and clay—are still widely used in wind catchers.

Based on the findings of this research, it can be concluded that most upgrades observed in windcatchers constructed in recent decades pertain to materials and structural aspects. These

modifications have been primarily aimed at improving the performance and structural durability of windcatchers, which are both necessary and beneficial from an engineering perspective. However, less attention has been paid to mechanical enhancements of windcatchers. Structural and mechanical improvement of wind catchers, considering nowadays need of buildings to optimize resource consumption and find sustainable solutions for energy crisis, can turn these earthen element into an efficient and effective option in contemporary architecture.

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Regenerative Approach to Saudi Arabia's Earthen Architectural Heritage

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ABSTRACT

This study explores the harnessing of Fourth Industrial Revolution (4IR) technologies in the conservation and regeneration of Saudi Arabia's earthen architectural heritage, aligning with the Kingdom's Vision 2030. The research adopts a regenerative approach to ensure that Saudi earthen heritage sites are revitalized as integral components of cognitive destinations.
Qualitative methods, including expert interviews and focus groups with key stakeholders in heritage management and technology, were employed to examine the applications of 4IR technologies. These technologies were assessed for their potential to enhance each phase of Saudi earthen heritage regeneration within the framework of cognitive destinations.
The findings indicate that 4IR technologies significantly support the regenerative phases of earthen architectural heritage conservation, structured around four key phases—Understanding, Valuing, Caring, and Enjoying—to ensure that heritage sites are revived as living assets within cognitive destinations.
This research highlights the transformative potential of integrating 4IR technologies into the regenerative conservation of Saudi Arabia's earthen architectural heritage, contributing to the realization of Vision 2030 goals. While these technologies offer promising advancements, their full potential is still emerging, and their practical implementation faces notable challenges at this early stage of the transformative era.

Keywords: Fourth Industrial Revolution, Regenerative Approach, Cognitive destinations

1 INTRODUCTION

Saudi Arabia is undergoing a significant cultural transformation aligned with Vision 2030, placing increased emphasis on the regeneration its architectural heritage. This study focuses on adopting a regenerative approach to the conservation of the Kingdom's earthen architectural heritage—recognizing these sites as dynamic cultural assets rather than static historical artifacts.

The regenerative approach moves beyond sustainablity, aiming to revive, adapt, and integrate heritage into contemporary cultural and environmental contexts. This perspective views heritage as a living system—one that interacts with and evolves alongside modern social and cultural dynamics.

This research investigates how regenerative methodologies can be effectively applied to earthen architectural heritage in Saudi Arabia. The study also examines the potential role of Fourth Industrial Revolution (4IR) technologies in supporting innovative conservation strategies.

Anchored in the broader objectives of Vision 2030, this work seeks to provide a forward-thinking framework for regenerating Saudi Arabia's earthen architectural heritage while promoting its continued relevance for future generations.

2 PROBLEM ANALYSİS

The basic livable needs have been changing dramatically since the current Fourth Industrial Revolution emerged, namely the Cyber-Physical System (Schwab, 2017). Moreover, when global phenomena worsened remarkably, such as climate change, demographic shift, digital transformation, etc. These issues have been making people rethink how to look in a holistic manner to the cosmos and to live as a part of the world. In fact, scientists called this regenerative approach, is a concept beyond sustainability, and chose it to be the ideal approach in all sectors (Fullerton, 2015).

Today, Saudi heritage sector is still viewed independently as a component despite all conservation approaches. In reality, the majority of people, concerned by the foregoing issue, restore the most important heritage site with minimal infrastructure as a landmark to be proud of, not for adaptive reusing as a part of the destination ecosystem. In fact, this is more degenerative, because it costs money, space, etc. as an accumulated problem (Jwear, 2023). Additionally, this still has been a threat for a long time, because the cultural identity of the destination will disappear if they don't develop the heritage area as a livable place relay on The current era.

Saudi Arabia has a wealth of cultural heritage, located in new cognitive destination projects, which need to be integrated to revive heritage (Neom, 2023), but there is no research about it.

As depicted in Figure 1, to revive heritage through regenerative approach, you need to understand the heritage cycle and value it in order to expand the meaning of capital to include heritage form of capital (Cultivating Culture, 2013).

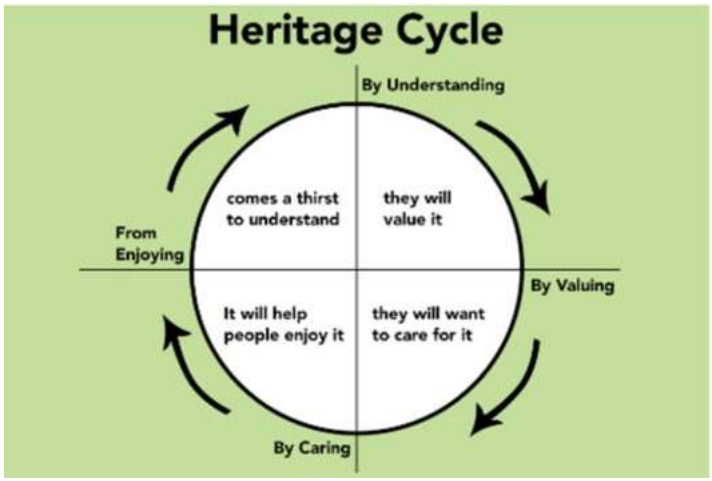

Figure 1: Heritage Cycle

Regarding the regenerative approach as shown in figure 2, the sustainable phase is the initial phase to increase regenerative value in the universe. Moreover, heritage is a driver of sustainability (ICCROM, 2015), and there is a lot of research on it. However, there is no research on how heritage can go beyond sustainability, and this is the problem of the research.

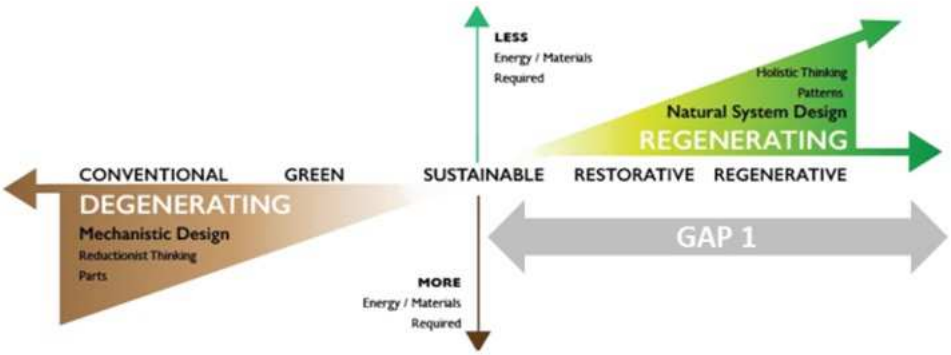

Figure 2: Regenerative Approach

3 RESEARCH DESIGN

3.1 Research Question

How can the regenerative approach be applied to revive Saudi Arabia's earthen architectural heritage through the integration of Fourth Industrial Revolution (4IR) technologies?

3.2 Research Aim

To examine the application of the regenerative approach in Saudi Arabia's earthen architectural heritage sites located within emerging cognitive destinations, with the aim of reviving heritage as an integral component of the destination's ecosystem.

3.3 Research Gap

Despite progress in conservation, two key gaps remain. First, current efforts focus on sustaining rather than regenerating earthen architectural heritage, lacking models that restore and integrate it as a living system (Angelica Isa Adaniya, 2022). Second, the role of Fourth Industrial Revolution (4IR) technologies—such as AI, IoT, and 3D scanning—in enabling regenerative heritage practices is still underexplored (PWC, 2023). These gaps limit the potential to position earthen heritage as an evolving cultural asset aligned with contemporary needs and Vision 2030 goals.

3.4 Research Methodology and Methods

This study adopts a qualitative research methodology to investigate the integration of Fourth Industrial Revolution (4IR) technologies in the regenerative conservation of Saudi Arabia's earthen architectural heritage. A grounded theory approach is employed to allow data-driven insights to emerge directly from expert contributions, enabling the formulation of a context-specific regenerative framework.

The theoretical foundation is based on the heritage value chain and the transformative potential of 4IR technologies. Grounded theory enables the systematic coding and analysis of data collected through semi-structured interviews and focus groups, with the aim of identifying recurring patterns, challenges, and enablers relevant to regeneration. This iterative process allows for the development of a Regenerative Heritage Framework tailored to Saudi Arabia's earthen heritage context.

Data collection involved 20 expert interviews and one focus group of 8 participants, targeting specialists in heritage conservation, digital innovation, and reneraative development. The interviews and group discussions explored participants' perceptions of integrating 4IR tools—such as AI, IoT,

and 3D scanning—into heritage regeneration strategies. All sessions were recorded, transcribed, and analyzed using grounded theory coding.

This approach provides a robust and flexible structure to explore complex intersections between heritage, technology, and regeneration—offering strategic insights for reviving earthen architectural heritage.

4 FINDINGS

The Regenerative Saudi Earthen Architectural Heritage Approach presents a value chain that addresses the regeneration of Saudi earthen architectural heritage sites. This approach is centered around four key phases: understanding, valuing, caring for, and enjoying earthen architectural heritage places, each of which plays a vital role in ensuring the preservation and adaptation of heritage assets in line with contemporary needs. In addition to this, the integration of Fourth Industrial Revolution (4IR) technologies across all phases further enhances the efficiency, precision, and accessibility of the heritage regeneration process. The following findings explore how each phase of the regenerative framework, along with advanced technologies, contributes to reviving Saudi earthen architectural heritage sites and transforming them into cognitive destinations, fostering a deeper connection between the past, present, and future.

4.1 Regenerative Saudi Earthen Architectural Heritage Approach

As illustrated in Figure 3, the Regenerative Saudi Earthen Architectural Heritage Approach is a comprehensive framework that addresses the regeneration of Saudi Arabia's earthen architectural heritage, ensuring that heritage sites integrate with cognitive destinations. The value chain revolves around four interconnected phases: understanding, valuing, caring for, and enjoying earthen architectural heritage places. These phases collectively form the foundation for regenerating earthen architectural heritage. The findings in each phase reflect a regenerative approach that emphasizes reviving Saudi earthen architectural heritage in cognitive destinations.

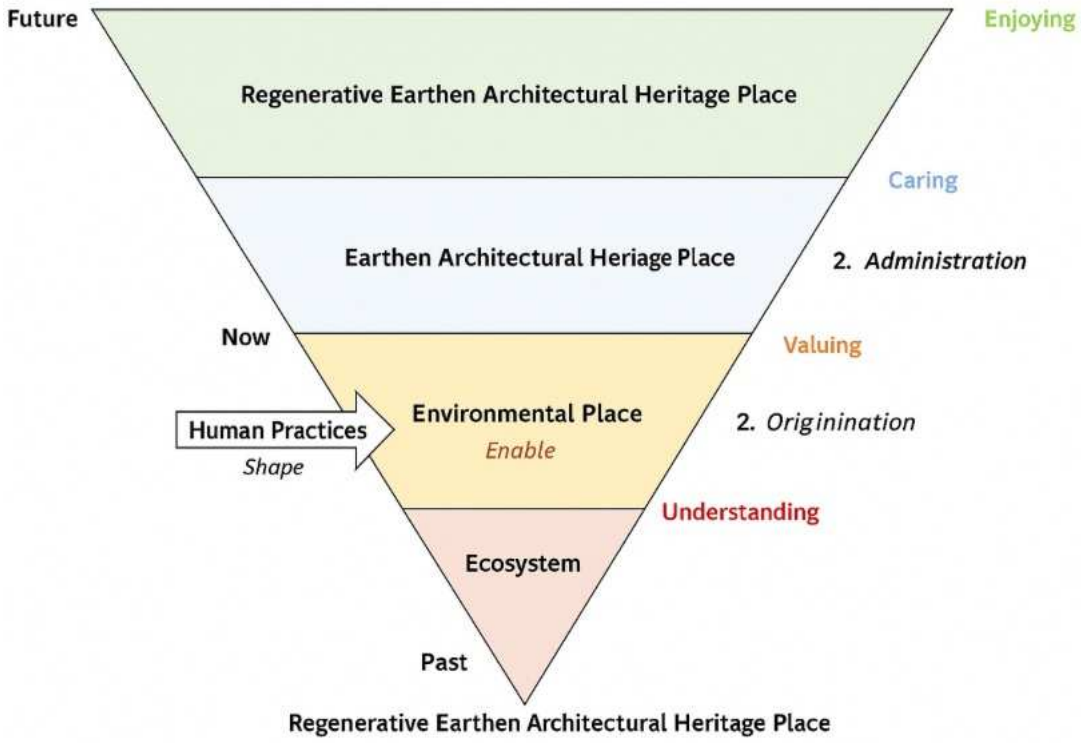

Figure 3: Regenerative Saudi Earthen Architectural Heritage Approach

4.1.1 Understanding Phase
The first phase is foundational in the regeneration process. It focuses on comprehensively exploring the cultural and environmental context of Saudi earthen architectural heritage sites. This phase provides crucial insights into the origins of heritage and the relationship between humans and their environments, which informs decisions on how to regenerate these sites.
4.1.2 Valuing Phase
The second phase focuses on documenting and evaluating earthen architectural heritage sites. This phase plays a crucial role in assessing and conserving the values of Saudi earthen architectural heritage sites throughout the regeneration process.
4.1.3 Caring Phase
The third phase addresses the practical aspects of conservation, involving both preventive and interventive measures to restore and adaptively reuse Saudi earthen architectural heritage sites. This phase guarantees the conservation and adaptation of Saudi earthen architectural heritage sites to generate heritage value in the future.
4.1.4 Enjoying Phase
The last phase focuses on ensuring that Saudi earthen architectural heritage sites are accessible and engaging for both the public and the scientific community. This phase is critical for the regeneration of Saudi earthen architectural heritage sites.

4.2 Harnessing 4IR Technologies for Regenerative Saudi Earthen Architectural Heritage

As shown in Table 1, the Regenerative Saudi Earthen Architectural Heritage Approach integrates key Fourth Industrial Revolution (4IR) technologies across all phases of the value chain, ensuring that heritage sites are effectively regenerated in innovative ways.

4.2.1 Understanding Phase
n the Understanding phase, technologies like AI, Big Data, IoT, and drones are used to characterize heritage assets, conduct exploratory missions, and aggregate data from various sources. These technologies help create a comprehensive database of heritage sites, allowing for efficient registration and information sharing among stakeholders through cloud computing platforms.

4.2.2 Valuing Phase
In the Valuing phase, the emphasis is on the documentation and assessment of the sites. AI and 3D scanning play a crucial role in evaluating the structural integrity and authenticity of Saudi earthen architectural heritage sites, while blockchain ensures the secure storage and authenticity of documentation data. These technologies enable the detailed recording of heritage sites, helping prioritize conservation efforts based on accurate assessments.

4.2.3 Caring Phase
The Caring phase involves both preventive and interventive conservation measures. IoT sensors are deployed to monitor environmental conditions in real time, providing early warnings about risks such as structural shifts or weather-related damage. 3D printing is used for restoring damaged architectural elements with precision, while AI aids in predicting potential structural failures and automating maintenance tasks. This phase ensures continuous monitoring and proactive care of heritage sites using advanced technologies.

4.2.4 Enjoying Phase
In the Enjoying phase, technologies like VR and AR enhance public engagement by offering immersive experiences of Saudi earthen architectural heritage sites. Cloud computing further facilitates the sharing of heritage data and virtual access for educational and research purposes. These technologies make earthen architectural heritage sites more accessible to the public and the scientific community, fostering deeper cultural engagement.

Table 1: 4IR Technologies for Regenerative Saudi Earthen Architectural Heritage

Value Chain	Applications	Technologies
Understanding Phase	Characterizing the heritage assets within the surrounding environment.	AI, Big Data, IoT, Drones
	Exploratory missions to discover the heritage assets.	Drones, IoT, IoT
	Registering information of heritage assets.	Big Data, AI, IoT, Drones
	heritage data hub among all stakeholders.	Cloud Computing, Big Data, Blockchain, Drones
Valuing Phase	Digital documentation of heritage assets	IoT, 3D Imaging/Scanning, Robotics, Cloud Computing
	High-fidelity evaluation.	Blockchain, Digital Twins, 3D Scanning, AI
	Continuous real-time monitoring.	Big Data, AI, IoT, Digital Twins
Caring Phase	Early risk detection and preventive interventions using real-time data.	IoT, Big Data, Robotics
	Biotechnological restoration and precise replication of heritage elements.	3D Printing/Bioprinting, Biotechnology
	Restoration of heritage sites with precision through 3D printing.	3D Printing, AI, 3D Scanning
Enjoying Phase	Public engagement through immersive AR/VR experiences	AR/VR, 3D Scanning
	Public engagement through heritage gamification.	AR/VR, 3D Scanning
	Collaboration with scientific communities through virtual labs and digital heritage simulations.	Digital Twins, Cloud Computing, AR/VR

In conclusion, the findings from the Regenerative Saudi Earthen Architectural Heritage Approach illustrate how the effective application of this framework—supported by 4IR technologies—ensures the regeneration of Saudi Arabia's earthen architectural heritage. By utilizing technologies such as AI, Big Data, IoT, drones, 3D scanning, blockchain, and immersive tools like VR and AR, each phase—understanding, valuing, caring for, and enjoying—is enhanced. This regenerative approach not only preserves earthen architectural heritage but also ensures its adaptation and relevance within contemporary society.

5 CONCLUSİONS

This research explored the application of regenerative thinking and Fourth Industrial Revolution (4IR) technologies in the revitalization of Saudi Arabia's earthen architectural heritage. Grounded in Vision 2030, the study aimed to develop a framework that moves beyond traditional preservation toward active regeneration.

The findings revealed that 4IR technologies significantly enhance each phase of the regenerative process—understanding, valuing, caring for, and enjoying heritage. These technologies offer tools for comprehensive analysis, precise documentation, proactive conservation, and interactive engagement. Their integration creates new possibilities for making earthen architectural heritage more resilient, accessible, and meaningful in a changing world.

By identifying gaps in existing sustainability-focused models, this research contributes a new theoretical and practical approach that connects heritage conservation with digital innovation. It

provides a replicable framework for heritage practitioners, policy makers, and planners in Saudi Arabia and beyond.

6 ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the Saudi Heritage Commission for its support and continuous efforts in regenerating the Kingdom's cultural heritage. I am also deeply thankful to all the participants and experts who generously shared their time and insights during this study. Their contributions were essential to the development and depth of this research.

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Traces of Adobe Architectural Heritage in Anatolia: Gemiş Village Pınar Mosque

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ABSTRACT

The building, also known as Old Pınarlar Mosque, is located in the Gemiş neighborhood within the borders of Çardak district of Denizli province. Although the construction date of the mosque is not clearly known, it is possible that it was built in 1931 according to the date written on the signboard in the stoa. According to some sources, this date is the repair date of the building. It is possible to see mosques built in the 18th-19th century with similar architectural features in the districts of Denizli.

The building was constructed in wooden frame construction system and adobe material was also integrated. The plan scheme consists of a semi-open and closed space. It is possible to see wooden carriers in both spaces.

Registered in 1995, the building was damaged in the earthquake that occurred in 2019. After the earthquake, collapses have occurred on the walls. Within the scope of this study, architectural assessments will be made by examining the authentic architectural features of the building.

Gemiş Village Pınar Mosque is one of the few architectural heritages in Denizli, which is distinguished from other buildings of the same function with its adobe material, ornamentation and motifs. Today the building is in a dilapidated state. This mosque, which is under risk, is in danger of collapse and extinction. Conservation and repair works should be carried out on the building.

Keywords: Adobe architecture, Adobe mosques, Architectural heritage of Denizli

1 INTRODUCTION

Gemiş neighborhood is affiliated with Çardak district of Denizli province. Located east of Denizli city center, Çardak has been within the borders of many states such as the Roman, Byzantine, Seljuk, and Ottoman empires in the past [1]. The Gemiş neighborhood also contains buildings from different periods. In addition, the settlement has a coastline on Acıgöl. Acıgöl is a lake that hosts natural life and bird watching activities. The lake and Gemiş are home to many bird species such as flamingos and storks during certain periods of the year.

In the Gemiş neighborhood, it is possible to encounter many different architectural elements such as troglodyte habitats, water cistern, and structures built of adobe, wood, or stone 'Figure 1-3'.

Figure 1. Adobe house, 12.07.2025.

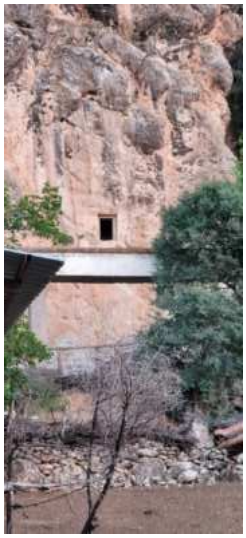

Figure 2. Troglodyte habitat, 12.07.2025.

Figure 3. Adobe house, 12.07.2025.

The Gemiş Village Pınar Mosque is one of the buildings in the region that features an adobe construction system. The building sustained severe damage in the 2019 earthquake [2]. One of the facade walls has collapsed, and the other walls and structural elements have been damaged. The mosque is no longer usable. The reinforced concrete mosque built in previous years is located on the same parcel as the Gemiş Village Pınar Mosque. Today, this mosque is in use, while the Gemiş Village Pınar Mosque has not been restored and no urgent conservation measures have been taken 'Figure 4-7'. On the other side of the structure, there is another structure located close to the authentic mosque.

Figure 4. Gemiş Village Pınar Mosque and Gemiş Pınar Mosque, 12.07.2025.

Figure 5. Gemiş Village Pınar Mosque and Gemiş Pınar Mosque, 12.07.2025.

Figure 6. Gemiş Village Pınar Mosque, 12.07.2025.

Figure 7. Gemiş Village Pınar Mosque, 12.07.2025.

2 ARCHITECTURAL FEATURES OF THE GEMİŞ VILLAGE PINAR MOSQUE

Although the construction date of the mosque is not clearly known, it is possible that it was built in 1931 according to the date written on the signboard on the facade. According to some sources, this date is the repair date of the building. It is possible to see mosques dating back to the 18th and 19th centuries built with a similar construction system in Denizli and its surroundings. [3] Currently, the mosque does not have a minaret.

The construction system can be seen in places due to damage caused by the earthquake 'Figure 8'. This system consists of rubble and adobe fill between wooden beams. Rubble stone filling continues up to a certain level. Then, adobe blocks were used as filling material in some places. Earth plaster can be seen on the walls.

The interior of the mosque is accessed through a narrow entrance area that extends along the approximately 10-meter-long facade and is bordered by walls at the corners. In the middle of this entrance area, which could be called a stoa, there are two wooden pillars that support the wooden roof and taper upward. These pillars are connected to the wooden beams under the eaves by means of carved wooden brackets.

Access to the interior is provided by a door made using the kündekari technique 'Figure 9'. There are different geometric shapes on the door. Since the floor coverings are not in place, the wooden beams and connection details on the floor and gallery level are visible. Horizontal wooden timbers have been placed on top of vertical wooden timbers placed on the ground 'Figure 10'. These timbers, which are circular and rectangular cross-sectioned wooden floor beams, must have wooden cladding. The interior height is approximately 4.00 m. There is a gathering-place approximately 2.50 m above the floor 'Figure 11-12'. This space is accessed via a wooden staircase. The gathering-place has a beam system similar to that on the ground floor. Some of the wooden beams in this space extend into the gallery space. The beams rest on columns that extend from the floor to the roof at a height of approximately 2.50 m above the floor.

One of the wooden pillars supporting the roof inside the building, located near the ceiling center 'Figure 13-14', is not in its authentic place. There is only one rectangular cross-section load-bearing pillar dividing the interior space, excluding this pillar. The other visible pillars support the gallery. Four of these are adjacent to the walls. Three of these load-bearing pillars adjacent to the entrance facade are circular in cross-section. The pillars are approximately 20 cm in size at eye level and taper towards the top.

There is a wooden dome hidden in the roof space [4].

Figure 8. Construction system details, 12.07.2025.

Figure 9. Entrance door, 12.07.2025.

Figure 10. Construction system details, 12.07.2025.

Figure 11. Gathering-place, 12.07.2025.

Figure 12. Gathering-place, 12.07.2025.

Figure 13. Ceiling detail, 12.07.2025.

Figure 14. Ceiling detail, 12.07.2025.

The circular window element on the floor contains colored glass (Figure 15). It is likely that this structural element was located on a rectangular window and is now positioned on the wall, which is in a state of collapse. The windows on the other sides are rectangular in shape and have wooden railings (Figure 16). The window openings narrow from the interior to the exterior (Figure 17). The wall thicknesses measured from these gaps are approximately 75 cm on the southeast facade and 65 cm on the entrance facade.
The mihrab section is painted green, yellow, blue, and light pink, and there are inscriptions around it 'Figure 18'. In an area close to the mihrab, but not adjacent to it, there are inscriptions extending from the roof to the floor.
The pulpit on the right side of the mihrab is green and white and is in good condition (Figure 19). The circular railing is noteworthy. The halpace on the left side of the mihrab is made of wood 'Figure 20'.

Figure 15. The circular window element, 12.07.2025.

Figure 16. Window, 12.07.2025.

Figure 17. Window, 12.07.2025.

Figure 18. Mihrab, 12.07.2025.

Figure 19. Pulpit, 12.07.2025.

Figure 20. Halpace, 12.07.2025.

There are two horns on the rear facade under the eaves, on the south-east facade where the mihrab is located, on the pulpit side 'Figure 21'. Since these horns resemble goat horns and goats are raised in the neighborhood, it is likely that they are goat horns. One of these horns is placed at each corner of the structure and on both sides, and there is a circular hollow next to the one on the southeast facade 'Figure 22'.
In Turkish mythology, horns play an important role in the cult of horned animals such as bulls, deer, mountain goats, and rams. According to Turkish beliefs about death, the soul is carried to God by a heavenly animal. In the context of symbolizing divinity, horns are symbols of power, fertility, abundance, kingship, and protection in Turkish mythology. During the Göktürk period, it was frequently used as a seal. [5] It is also known that horns were used in Anatolia in accordance with the belief in the evil eye [6].

Figure 21. Horns, 12.07.2025.

Figure 22. Southeastern facade, 12.07.2025.

3 CONSERVATION ISSUES

The mosque was not in use even before the earthquake in 2019. In addition to this, it is likely that regular maintenance and repairs were not carried out. The structure, which was already neglected, has been further damaged by the earthquake 'Figure 23-24'. One wall has collapsed, and there are cracks in the other walls. Cracks can also be seen in some wooden beams. Damage to the load-bearing system has put the structure at risk of collapse.
The plaster on the walls is crumbling in places. There are also gaps in the decorations and inscriptions on the walls.

The stairs leading to the gathering-place are unusable. There is no flooring on the ground floor except for the door entrance and in the gathering-place. Floor beams are missing in some areas. The

authentic roof covering has been replaced with sheet metal. This covering is unable to protect the building from weather conditions.

Figure 23. Demolished facade, 12.07.2025.

Figure 24. Demolished facade, 12.07.2025.

There are deficiencies in the structural elements that make up the building. This situation raises the possibility that these structural elements may have been removed without permission due to the lack of maintenance of the building.
With the exception of the window opening on the front facade, which is thought to have been added later, the authenticity of the building remains largely intact.
After the earthquake, local authorities wanted to carry out restoration work on the building, but later decided against it.
The building is vulnerable to damage caused by natural and human factors. No emergency or temporary protective measures have been taken.
The new mosque built next to it is taller than the Gemiş Village Pınar Mosque and also has a larger area. This new structure, which rivals the historic mosque in size, negatively affects the visibility of the Gemiş Village Pınar Mosque. The fact that the two structures were built close to each other may also cause some structural problems.

4 EVALUATION AND CONCLUSION

Denizli is a remarkable settlement with its architectural heritage dating back to different periods. Mosques built using the adobe construction system, which is widely used throughout the province, are of great importance. These mosques are notable not only for their construction systems but also for their ornamentation and decoration.
Gemiş neighborhood; Acıgöl is a stopping point for bird species and a bird watching area. It is a neighborhood that needs to be protected and studied due to its adobe texture, troglodyte habitat, and other heritage elements. Although there are academic studies on Gemiş, it is a neighborhood that needs more detailed research.
The Gemiş Village Pınar Mosque is a structure located in a rural area and is no longer in use today. Adobe structures can be preserved through regular maintenance and repairs. In addition, the earthquake resistance of such structures has been the subject of research, and it is known that their sustainability can be ensured through regular maintenance and repairs.
The Gemiş Village Pınar Mosque is at risk due to the severe damage it sustained in the 2019 earthquake. No repairs have been carried out, and no protective measures have been taken. The mosque is vulnerable to natural disasters and human intervention.
A new mosque has been built right next to the structure. The reason for building the new mosque may be the need for a larger mosque than the Gemiş Village Pınar Mosque. The fact that this mosque is used for worship has made the Gemiş Village Pınar Mosque a structure that is not considered urgent to preserve or repair in the eyes of the local community and administration.
Icomos' charter entitled "Principles for the Analysis, Conservation, and Structural Restoration of Architectural Heritage" states that the conservation, reinforcement, and restoration of architectural

heritage requires an interdisciplinary approach, that the value of architectural heritage lies not only in its appearance, and that it is important to preserve it as a unique example of the construction technology of its period with all its components. [7]

The Gemiş Village Pınar Mosque is an important structure that must be preserved due to its authenticity and heritage value. The structure has not lost its integrity. It is a rare example of the architectural features of mosques from a particular period. Urgent conservation measures must be taken for the structure. This structure, whose construction system has been exposed after the earthquake, should be documented, and conservation and restoration work should be carried out.

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Anachronism or Prospect for İnnovation? Reassessing Heritage Sustainability in Earthen Architecture of Kasbahs and Ksour in Morocco

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ABSTRACT

The global imperative for sustainable development necessitates a critical examination of diverse architectural traditions, particularly vernacular forms often overlooked in mainstream discourse. Studying the sustainability inherent in vernacular architecture, such as the earthen Kasbahs and Ksour of southern Morocco, offers invaluable lessons in climate adaptation, resource efficiency, and socio-cultural resilience, challenging contemporary building paradigms that are often reliant on high-energy materials and technologies. This study addresses the pressing need to evaluate whether such a methodology for examining the sustainability of traditional building practices represents mere historical relics (anachronisms) or holds tangible potential for future sustainable innovation.

The primary objective of this research is to comprehensively reassess the sustainability dimensions of traditional earthen architecture in the Kasbahs and Ksour of southern Morocco. It seeks to identify and analyze the inherent environmental, socio-cultural, and economic sustainability principles embedded within their design, construction, and maintenance, evaluating their relevance and adaptability in the face of modern challenges like climate change and urbanization.

Employing a qualitative methodology, the study combines architectural analysis, fieldwork (including interviews with local communities and artisans), and comparative assessment of traditional techniques against contemporary sustainability benchmarks. Case studies of selected Kasbahs and Ksour, such as Ksar Taourirt, Ksar Aït Ben Haddou, Kasbah Taourirt, and Kasbah Tifoultoute provide empirical data on construction methods, material sourcing (rammed earth, adobe), passive design strategies, and long-term durability and maintenance practices.

The aimed conclusions are inherent to our research title's question. While facing challenges related to maintenance skills transfer and adaptation to contemporary living standards, these architectures demonstrate significant innovation potential. They offer a valuable repository of knowledge for developing hybrid approaches that integrate traditional wisdom with modern techniques, fostering culturally relevant and environmentally responsible architectural solutions for the future. Re-evaluating this heritage is not just an act of preservation but a vital step towards resilient and sustainable built environments.

Keywords: heritage sustainability, earthen architecture, Kasbahs and Ksour, Morocco, Innovation

1 INTRODUCTION

Sustainable development demands innovative yet context-sensitive architectural strategies that minimize environmental impact while respecting cultural heritage. Vernacular earthen architecture, such as Kasbahs (fortified dwellings) and Ksour (fortified villages) in Morocco, provides rich lessons in climate adaptation and resource efficiency. These traditional forms evolved over centuries to thrive in hot, arid conditions with scarce rainfall, using local earth materials and passive cooling techniques instead of modern high-energy systems.

Among the most illustrative examples of vernacular sustainability are the Kasbahs and Ksour in Morocco. These earthen fortresses and collective settlements have stood for centuries, embodying responses to harsh climatic conditions and complex social dynamics. Constructed predominantly with earth-based materials such as adobe and rammed earth, they exemplify ecological appropriateness, socio-cultural embeddedness, and economic efficiency [1]. Yet, in modern times, they are often perceived as outdated structures, vulnerable to decay, and incapable of meeting contemporary living standards [2]. Yet in mainstream practice they are often dismissed as outdated or irrelevant, raising the question: are these buildings anachronisms of a bygone era or living models for future sustainable innovation?

The importance of this question lies in its broader implications. If vernacular architecture can be reassessed not as heritage frozen in time but as a living repository of sustainable principles, then it becomes possible to integrate its lessons into contemporary design practice. This is particularly relevant in Morocco, where rapid urbanization and modernization coexist with pressing environmental challenges. The future of Moroccan cities and rural settlements may depend on striking a balance between embracing modern technologies and reviving traditional architecture.

This study pursues three interrelated objectives. First, it seeks to analyze the environmental, socio-cultural, and economic sustainability dimensions of Kasbahs and Ksour. Second, it examines their current condition, challenges, and resilience in the face of contemporary pressures, including climate change and rural depopulation. Third, it evaluates the potential for hybrid approaches that combine vernacular techniques with modern innovations, thereby contributing to a broader agenda of sustainable architectural development.

This research reassesses the sustainability dimensions of the Moroccan earthen heritage of Kasbahs and Ksour. We examine the environmental performance of these structures (thermal comfort, material use, life cycle), their socio-cultural roles (community identity, traditional skills) and economic aspects (use of local labor, tourism potential). We also analyze whether and how such features can be harnessed today, considering pressures like climate change, rural depopulation and urban growth. Our qualitative methodology combines literature review, architectural analysis and fieldwork.

The paper is organized as follows. The next section reviews relevant literature on vernacular architecture and sustainability concepts. We then outline the methodology adopted. The core sections present case studies of several exemplary earthen sites – the Ksar of Aït Ben Haddou, Kasbah Taourirt in Ouarzazate, and Kasbah Tifoultoute – analysing and discussing their design, construction, and traditional maintenance. We discuss how these factors impart resilience and efficiency, as well as the contemporary challenges they face. Finally, we synthesize the findings, arguing that these heritage buildings offer a genuine prospect for innovation, and outline strategies to integrate their know-how into future sustainable architecture.

2 LITERATURE REVIEW

Vernacular architecture refers to building traditions that have organically developed in a region, using local materials and artisanal techniques [3]. In Morocco, earthen vernacular architecture has a

long history: in the arid south one finds Kasbahs, Ksour and Igoudar (collective granaries) as the dominant rural typologies [4]. These structures often feature rammed earth or adobe walls and evolved to meet harsh climatic conditions. As noted by Hassan Fathy (1973), vernacular architecture is a practical and culturally appropriate solution for rural housing. He championed the use of local, indigenous materials like mud brick and traditional building techniques as a sustainable alternative to costly Western modernism. This approach provides climatically suitable homes while empowering communities by involving them in the construction process [5]. Similarly, vernacular settlements are oriented and configured to optimize passive climate control, with narrow, shaded streets and small windows reducing solar gain [6].

The relevance of vernacular forms for modern sustainability has been widely recognized in the literature. The classic Brundtland definition of sustainable development emphasizes intergenerational equity [7]. Architecture scholars have summarized sustainable design as involving "life-cycle thinking" and an "economy of resources" (focus on reduction, reuse, and recycling) [8]. Traditional earthen buildings exemplify these principles: for example, when an old Ksar is flooded or abandoned, inhabitants historically rebuild it using soil recycled from the ruins, embodying a resource cycle and ending the old village's "life cycle" [9]. In other words, traditional communities inherently practiced early "life-cycle design" long before the term existed [10].

Vernacular design has been linked to bioclimatic and biophilic principles embodying deep integration of nature and microclimate considerations [11]. The compact, courtyard-based layouts create cool communal spaces. In addition, the social organization of Ksour is part of their sustainability. As stated by Maha Salman (2019), sustainability in vernacular architecture is not only a technical matter but also tied to identity, continuity, and cultural resilience, which may seem like anachronisms but are in fact resources for innovation [12].

Thus, a growing body of research argues that studying vernacular earthen architecture can inform today's sustainability. For example, Mora-Ruiz et al. (2025) note that earthen construction uses far less energy than conventional materials [13]. Furthermore, earthen walls excel in thermal mass, storing heat, and hygrothermal comfort: they naturally moderate indoor temperature swing. Thus, earthen vernacular provides a plausible solution in the climate crisis context.

However, researchers also acknowledge challenges. Traditional earth constructions typically have low inherent strength and vulnerability to moisture. They require regular maintenance – for example, re-plastering with mud after rains – to remain durable. Gil-Piqueras and Rodríguez-Navarro (2021) emphasize that Moroccan Ksour require constant maintenance [14]. Social changes (rural migration, modern housing preferences) have caused abandonment and deterioration of many sites [2]. Engaging this heritage can also foster local development as promoting vernacular sites contributes to a sustainable rural economy, tourism, and human development [15].

3 METHODOLOGY

This study follows a qualitative case-study approach, inspired by recent field research on Moroccan Kasbahs and Ksour. We combined three main methods: Architectural and urban analysis of built forms through site visits and plans; Fieldwork and Comparative assessment against modern sustainability criteria. We also evaluated each site's sustainability features by comparing them to contemporary benchmarks. For environmental performance, we noted passive climate-control elements. For socio-cultural aspects, we considered the site's role in community life and its contribution to local identity or tourism. This holistic, qualitative methodology allows us to recontextualize the earthen heritage on sustainability grounds and identify both its strengths and limitations as seen by contemporary standards.

4 CASE STUDIES OF KASBAHS AND KSOUR

4.1 Ksar Aït Ben Haddou

Ksar Aït Ben Haddou is a fortified village on the Ouarzazate–Marrakesh route, 30 kilometers distance to Ouarzazate. It is a UNESCO World Heritage Site since 1987. It exemplifies southern Moroccan Kasbah-type architecture: a cluster of earthen houses enclosed by massive defensive walls and towers, perched on a hillside. The core material is rammed earth, mixed with straw. These materials were locally sourced and easily workable. Traditional builders took advantage of the desert climate: the mud-brick walls are typically 0.8–1.5 meters thick, providing excellent thermal inertia. Figure 1 shows the Ksar's south façade, illustrating its rammed-earth walls and square corner towers (all built in the 17th–18th centuries).

Figure 1. Ksar Ait Ben Haddou, Morocco (Author, 2025)

The layout of Aït Benhaddou also embodies passive design. Houses are densely packed, with narrow, winding alleys mostly covered by the overhanging upper floors. This creates deep shade and limits direct sun penetration. In each house, openings are kept small and oriented away from the harsh afternoon sun. Aït Benhaddou's streets and façades are arranged to funnel any breeze through the settlement. The village even includes a communal agadir (granary) crowning the hill, which doubles as a cooling loft for grain storage at night. Together, these strategies kept indoor temperatures moderate before modern cooling was available.

Socio-culturally, Aït Benhaddou was a hub of community life and trade on the desert caravan route. It has cultural significance as a heritage and film set. This draws tourism, which now supports local guides and artisans, an economic role quite different from its original function. However, tourism also poses threats that heavy visitation can risk commodification and authenticity loss of sites like Aït Benhaddou. Economically, Aït Benhaddou's revival is tied to its heritage value. Local artisans demonstrate earth construction techniques, reinforcing cultural continuity. The Ksar Aït Ben Haddou illustrates how an earth-built site remains sustainable in design, and how active heritage management can adapt it to modern uses without losing ecological qualities.

4.2 Kasbah Taourirt (Ouarzazate City)

The Kasbah of Taourirt lies at the heart of Ouarzazate town. Though sometimes called Ksar Taourirt in heritage contexts, it is essentially a large earthen fortress built in the late 19th–early 20th century. The structure consists of multiple contiguous dwellings, towers, and granaries enclosed in fortified walls. As seen in Figure 2, Kasbah Taourirt's façades are an expanse of reddish mud-brick, punctuated by square towers. Like Aït Benhaddou, it uses thick rammed-earth walls. The material's thermal capacity again provides insulation.

Figure 2. Photos of Kasbah Taourirt in Ouarzazate. (Author, 2025)

The spatial organization emphasizes security and communal life. Entry is through a single monumental gate, beyond which a few wide open courtyards provide daylight. Interior passages are narrow and segmented. The dense mass of rooms stores heat during the day during winters; only the late-evening opening of doors and windows allows the accumulated warmth to dissipate. Traditional palm-beam roofs and adobe ceilings provide modest insulation as well. No active heating or cooling was needed historically.

Taourirt's heritage value is officially recognized. Like many earthen sites, it required extensive conservation. Restoration agencies have used a combination of earth re-plastering and subtle reinforcement. In modern times, parts of Kasbah Taourirt have been repurposed for cultural events, linking past architecture with present community functions. The Kasbah is a focal point of the old city, reminding residents of their heritage.

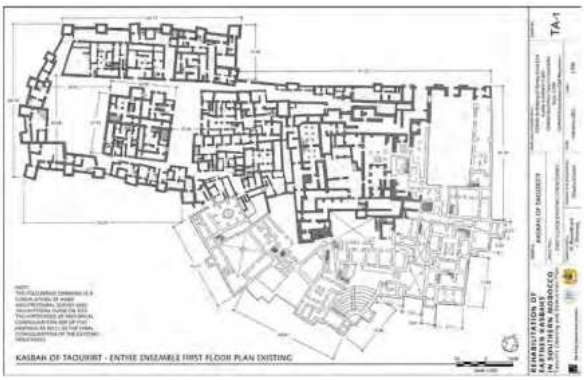

Figure 3. Kasbah Taourirt, Architectural Plans. Dessin Claudia Cancino, 2012. Source: CERKAS, 2016

Environmentally, Kasbah Taourirt typifies sustainable features of earthen design. Its materials were all local (clay soil from nearby, palm trunks, straw), so the embodied energy is minimal. A comparative assessment would note that the carbon footprint of constructing this Kasbah was very small in relation to an equivalent concrete building. The building also provides cooling.

Culturally, the Kasbah embodies community resilience: its existence arose from traditional forms of local governance and defense. Ongoing use for tourism and education also generates income and jobs (guides, craftspeople) tied to conserving traditional skills. In these ways, Kasbah Taourirt continues to be both a heritage icon and a model of resource-efficient, climate-appropriate building within a growing city.

Figure 4. Interior of the Kasbah Taourirt. (Author, 2025)

4.3 Kasbah Tifoultoute

Kasbah Tifoultoute is another example of Moroccan rammed-earth architecture. Located a few kilometers west of Ouarzazate on the Draa Valley, it dates to the 17th–18th centuries. The Kasbah

is famed for its decorative façade and corner towers. The walls are constructed of large adobe bricks and thick mudcourses, giving the structure solidity over time.

Figure. 5. Kasbah Tifoultoute. (Author, 2025)

From an environmental viewpoint, Tifoultoute shares the same passive qualities: heavy earthen walls and small high windows keep interiors temperate. Architecturally, it includes internal courtyards and terraces that funnel breeze through the building, as in other traditional dwellings.

Socially and economically, Kasbah Tifoultoute today caters mainly to tourism (tours, guesthouse). Preservation efforts emphasize using traditional mud plaster and palm beams to train new artisans, thus keeping skills alive. In summary, Tifoultoute's design leverages earth construction for sustainable living, and its adaptive reuse for tourism shows one pathway of innovation: heritage as livelihood.

Figure 6. Interiors of Kasbah Tifoultoute (Author, 2025)

5 DISCUSSION

The case studies reveal common threads. Environmentally, all these earthen structures achieve what modern architects call bioclimatic efficiency. Their material selection offers a stark contrast to high-tech alternatives: rammed earth and adobe are low-tech yet high-performance. They have minimal embodied energy – indeed, manufacturing one cubic meter of concrete releases roughly 100 times more CO_2 than harvesting the same volume of earth. Life-cycle analyses consistently find that earthen construction greatly reduces carbon footprint. The Moroccan examples confirm that their thermal performance is likewise robust. Thick earth walls are excellent thermal masses. They slowly absorb midday heat and release it at night, evening out extremes. Small windows and shaded alleys minimize unwanted solar gain. These passive measures achieve comfort without air-conditioning.

However, these systems come with constraints. All cases require continuous maintenance. Without it, the buildings deteriorate in a few decades. Heavy rains can erode unplastered walls, and high winds or seismic events can cause collapse if not patched. Social change has amplified these vulnerabilities. During the 20th century, migration and new economies led many descendants of Kasbahs and Ksour to seek a modern shelter. After Moroccan independence and migration to cities, returning families built houses with foreign materials like concrete and cement, considered of higher status. As a result, traditional houses were often left to nomads or fell into ruin, and the craft of maintaining rammed earth faded.

Despite these issues, the heritage buildings retain clear socio-cultural value. They are physical embodiments of local identity and collective memory. Interviewed villagers emphasize that living in the old quarters was a communal affair: children played in the courtyards and communal spaces, ceremonies gathered families in the plaza, and knowledge of earth-building was passed from elders. This bonds social cohesion and promotes resilience to environmental stress – in that sense, these sites symbolize identity and culture as well as resilience to environmental hazards.

The tangible ruins themselves also drive tourism, which brings economic benefits that in turn fund preservation, as seen at Ksar Aït Ben Haddou, Kasbah Taourirt, and Kasbah Tifoultoute. In contrast, many modern concrete houses are perceived as generic and inadaptable to climatic conditions.

Thus, the answer to our title question emerges: these sites are neither completely obsolete nor ready-made blueprints. They require adaptation, but contain innovation potential. For instance, current research suggests that hybrid strategies as conservation challenges must be recognized. More than just structural maintenance, there is a need for skills transfer. The older generation of maâlems (master masons) is dwindling. Architects, urbanists, policy-makers, and educators can resolve these problems by promoting vernacular architecture.

At the community level, linking heritage with sustainable development is important. Engaging locals as stakeholders in adaptive reuse (guesthouses, cultural centers, museums) ensures that the architecture remains economically viable while retaining its traditional essence.

In summary, the evidence indicates that southern Moroccan Kasbahs and Ksour are more of an inspiration than anachronism. They illustrate core sustainability principles – local material efficiency, climatic harmony, and community-centric planning – that are central to resilient architecture. With thoughtful innovation, these traditional forms can inform new green buildings that are both culturally relevant and environmentally sound. Re-evaluating this heritage, therefore, transcends pure preservation; it is an essential step in creating sustainable built environments attuned to local realities

6 CONCLUSION

Traditional earthen architecture in Morocco's Kasbahs and Ksour embodies a rich legacy of sustainable design. As shown in the case studies, these buildings use only local, natural materials and employ passive climate strategies that minimize energy use while providing thermal comfort. They also fostered strong community structures, with shared granaries and courtyard living that supported social resilience. Although modernization and environmental stresses have led to deterioration in many sites (demonstrating the challenge of maintenance), the core sustainability lessons of these structures remain highly relevant.

Our analysis concludes that these earthen heritage sites should not be dismissed as mere historical artifacts. Rather, they represent a valuable knowledge base: an innovative opportunity to blend ancient knowledge and know-how with modern architecture and engineering.

By integrating traditional earthen techniques with new materials and technologies, architects can create structures that are both innovative and rooted in local identity. In this way, preserving Morocco's Kasbahs and Ksour becomes a contribution to sustainability, not just an exercise in cultural nostalgia. The phrase "innovating without inventing" captures this ethos: often, the most efficient solutions are already embodied in our mere existence. Reconsidering and reusing that heritage wisely may help us build more resilient, climate-adapted communities for the centuries ahead.

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Urban Planning Potential, Thermal Performance, and Construction Techniques of an Earth Dome: Study of an Experimental Prototype in Tunisia

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ABSTRAC T

In a context of ecological and social transition, this research analyzes an experimental prototype of an earth dome built in Tunisia, with a focus on its construction techniques, thermal performance, and architectural and urban potential. The structure was built using the Superadobe method, employing polypropylene bags filled with locally sourced, moistened, and stabilized earth, laid in superimposed circular courses, mechanically compacted, and reinforced with barbed wire between each layer to ensure cohesion and seismic resistance.

The building adopts a hemispherical form that optimizes load distribution and provides structural stability without the need for an additional supporting framework. On the thermal level, temperature measurements taken at fixed daily intervals enabled comparison between indoor and outdoor conditions and assessment of the dome's thermal damping capacity.

The results show a strong ability to naturally regulate temperature variations, limiting daytime overheating and maintaining comfortable night-time temperatures despite significant external climatic shifts. From an architectural perspective, the compact, circular interior spatiality enhances energy efficiency while reconnecting with vernacular logics adapted to arid climates.

At the urban scale, this construction method opens up perspectives for modular, self-sufficient housing models based on local resources, offering viable solutions for resilient planning projects in Mediterranean and Saharan contexts. This study thus highlights the relevance of combining revisited traditional construction techniques, environmental performance, and territorial integration to address current sustainability challenges.

Key Words: earthen architecture, eco-dome, thermal performance, urban resilience, crisis urbanism.

INTRODUCTION

In light of the global challenges posed by climate change, accelerated urbanization, and the scarcity of natural resources, Mediterranean cities face increasing pressure to transition toward more sustainable, resilient, and locally rooted development models. The building sector alone accounts for nearly 39% of global energy-related carbon dioxide emissions [1], making it a critical area for rethinking both construction practices and urban planning strategies. In arid and semi-arid regions, these challenges are amplified by climatic constraints, resource limitations, and the need to develop spatial solutions that are both environmentally responsible and socially inclusive.

Among the approaches gaining renewed interest, earth-based construction techniques offer a promising avenue for reducing environmental impact while drawing on local materials and know-how. These methods are not only energy-efficient and cost-effective, but they also enhance thermal comfort and contribute to circular economies rooted in place-based practices [2], [3]. Their relevance lies in their capacity to provide adaptive, low-carbon alternatives to conventional building systems, particularly in the face of growing urban vulnerabilities [4], [5].

The theoretical framework of situated urbanism, developed by scholars such as Viganò, Charbonneau, Amin, and Thrift [6][9], invites us to rethink the production of urban space beyond standardized planning models. Situated urbanism promotes a context-specific, bottom-up, and socially engaged approach to urban development that recognizes the importance of materiality, local dynamics, and community-based knowledge. It aligns with contemporary discourses on resilient urbanism and climate-adaptive design, which consider cities as socio-ecological systems requiring flexible and participatory planning strategies [10], [11].

In this context, earth-based construction is not only relevant from a material or technical perspective; it also serves as a vector for rethinking urban development in a more integrated and ecological manner. While much research has focused on the architectural or environmental benefits of these techniques, fewer studies have examined their potential to inform urban planning strategies, particularly in regions facing climate stress, informal urban growth, or resource constraints.

This study aims to assess, through an experimental prototype built in Sousse (Tunisia), the thermal and technical performance of an earth dome, while exploring its potential contribution to situated urban development in Mediterranean contexts. By bridging material experimentation with spatial analysis, this research seeks to support more sustainable and resilient urban trajectories rooted in local realities.

2 METHODS

The methodological approach adopted in this action-research is twofold: it combines a structural analysis of the prototype with an in situ evaluation of its thermal performance. These methods are designed to integrate the material, technical, and environmental dimensions of the project, in relation to its territorial context.

2.1 Structural approach

Figure 1. General view of the main façade of the large superadobe dome, showing its overall volume and architectural proportions.

Figure 2. Curved profile of the dome and junction between the large and small superadobe structures.

The structural approach is based on the Superadobe technique, a sustainable construction method that utilizes raw earth contained within polypropylene bags to create self-supporting structures. This method combines ease of implementation, the use of locally available materials, and mechanical properties well suited to seismic and climatic conditions [12], [13].
The choice of a hemispherical form addresses stability requirements and ensures uniform compression stress distribution, thereby minimizing the need for additional frameworks [14]. To enhance structural performance and safety, mechanical reinforcements using metal bars have been incorporated within the layered assembly [15]. Furthermore, the design integrates two interlocking volumes (Figure 2), creating a compact functional space (Figure 1) that meets the requirements of a small autonomous dwelling [16]. The construction phase was carried out through assisted self-construction, supported by the association Ecomen 3000, which promotes ecological and participatory building practices. This phase was also conducted in collaboration with builder-trainer Laurent Libre, a specialist in earth dome construction and author of *Construire un dôme en terre crue* [17], [18].

2.2 Thermal Approach

The second phase of the experiment focused on assessing the dome's thermal performance through manual temperature readings taken using a standard digital thermometer, with an accuracy of ±0.5 °C. Measurements were conducted on site at six fixed times throughout the day: twice in the morning (7:00 am and 10:00 am), twice in the afternoon (1:00 pm and 4:00 pm), and twice in the evening (7:00 pm and 10:00 pm), in order to capture the full daily thermal cycle.

Temperature readings were taken at several key locations inside the dome, particularly at the center of the volume (approximately one meter above ground) and near the inner surfaces of the walls. Additional measurements were recorded outside the structure, in a shaded area, to compare indoor and outdoor thermal conditions. Although punctual, this regular monitoring method provides reliable data on the thermal damping effect of the raw earth envelope, accounting for the diurnal temperature variations characteristic of the semi-arid Mediterranean climate.

3 RESULTS AND DISCUSSIONS

3.1 Structural Approach: Construction Process and Performance Findings

The construction phase enabled the tangible realization of a prototype based on the outlined methodological approach. The first step involved preparing the earth-gravel-cement mixture, in

carefully measured proportions: the raw earth, moistened to reach an optimal consistency, was stabilized with a hydraulic binder at approximately 10%, then enriched with 30% fine gravel to improve the mechanical strength and durability of the earth used (Figure 5). It is important to emphasize that these percentages are not universal and must be adjusted according to the specific characteristics of the locally available soil (Figure 4), which directly affect the mixture's performance. This material was tested by producing samples (Figure 3), which were left to cure for 24 hours to assess their cohesion and ability to withstand mechanical stresses without cracking.

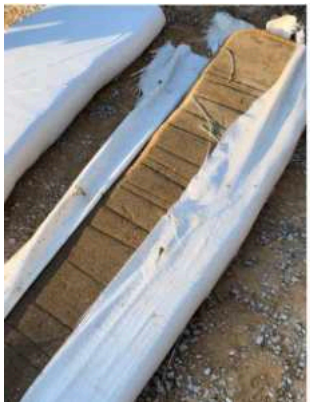

Figure 3

Figure 4

Figure 5

Figure 3. Laboratory test on an earth-based mixture, placed in a polypropylene bag for 24 hours to assess material behavior.

Figure 4. Sedimentation test of local soil in a glass jar, revealing distinct stratification layers and allowing identification of its components.

Figure 5. Completed superadobe wall segment with dried polypropylene bags, showing surface texture after construction.

Once the material was validated, construction began with the installation of an innovative foundation composed of two staggered layers of used tires filled with compacted coarse gravel (Figure 6). This technique provides a stable and durable base while promoting recycling and reducing the environmental impacts associated with traditional materials. The stacking of polypropylene bags filled with the prepared mixture was then carried out in concentric circular layers, following the hemispherical shape characteristic of the superadobe technique. Each layer was carefully placed and mechanically compacted to ensure uniform density and good cohesion between the courses. To reinforce structural strength, particularly stability against seismic forces, 12 mm diameter metal rods were inserted horizontally at regular intervals between each layer, acting as an internal mesh.

The final structure consists of two interlocking domes, forming a compact living space: the first dome, 5 meters in diameter (corresponding to an interior surface area of 19.62 m²), houses the main bedroom, while the second, 3.5 meters in diameter (9.61 m²), contains the kitchenette and bathroom. These two volumes are connected by a curved junction, seamlessly integrated into the organic continuity of the dome's overall hemispherical shape (Figure 7). This smooth transition ensures not only aesthetic coherence but also structural continuity, enhancing the overall stability of the building while maintaining the even distribution of compressive forces characteristic of the form.

Figure 6

Figure 7

Figure 6. Tire-based foundation structure with superadobe earthbags being placed during construction.

Figure 7. First two staggered layers of superadobe earthbags placed above the tire foundation.

The average wall thickness, approximately 45 cm, provides the entire structure with high thermal inertia, thereby contributing to indoor comfort by moderating temperature variations. Situated in an olive grove in the governorate of Sousse, in the central-east region of Tunisia, the building exclusively uses local materials, thus limiting the carbon footprint related to transportation and promoting constructive autonomy. The construction was carried out by self-building, under technical assistance, as part of a pedagogical approach aimed at transmitting the skills related to this ancestral technique adapted to contemporary challenges.

These results demonstrate the technical, environmental, and social relevance of the adopted structural approach, opening promising perspectives for the dissemination of this type of sustainable and resilient architecture in similar climatic and territorial contexts.

3.2 Results and Thermal Discussion

The thermal readings manually recorded during the experimental phase highlighted the remarkable thermal regulation capacity of the superadobe dome. Over the measurement period (from July 1 to July 30, 2025), outdoor temperatures recorded in the shade ranged from 24 °C at night to 43 °C during the day, with peak values occasionally reaching 45 °C. Inside the dome, the average temperature measured at the center of the space (approximately one meter above the floor) was 30.2 °C, with moderate fluctuations ranging from 27.5 °C in the morning to 32.8 °C in the late afternoon.

This thermal attenuation—ranging from 10 to 12 °C during periods of intense daytime heat—demonstrates the effectiveness of the earthen envelope in buffering exterior variations. It reflects the thermal inertia of the material, which can absorb, store, and gradually release heat, thereby contributing to interior climate stability.

The 45 cm-thick walls played a key role in thermal lag, estimated at approximately 10 hours, meaning that peaks in exterior heat were perceived with a significant time delay indoors. This behavior aligns

with findings by Ciancio et al. [19], who demonstrated that earthen walls can significantly delay heat transmission, thereby improving passive thermal comfort. This phenomenon is particularly suitable in semi-arid Mediterranean climates where daily temperature ranges are high.

The lived experience inside the dome supports these empirical findings: despite extreme outdoor temperatures, thermal sensation indoors remained generally comfortable throughout the day without any active cooling devices. This performance confirms the relevance of such passive housing forms in arid and semi-arid regions. It also supports Schmid's conclusions [20], which emphasize the thermal advantages of compact, curved volumes that minimize thermal exchanges and optimize energy efficiency.

3.3 Discussion and Correlation between Structural Approach, Thermal Performance, and Situated Urbanism

The combined analysis of structural and thermal data reveals a significant synergy between the superadobe construction design and its passive climatic behavior. The wall thickness, the composition of the earth-gravel-cement mixture, and the hemispherical form not only ensure the mechanical stability of the structure but also form the basis of effective thermal inertia, capable of moderating the sharp temperature fluctuations characteristic of the Mediterranean semi-arid climate.

This natural integration of material, shape, and thermal performance illustrates the relevance of bioclimatic design deeply rooted in local resources and traditional know-how. It supports the idea that energy efficiency in passive housing is inseparable from its structural qualities, particularly when relying on natural materials with high thermal capacity.

Beyond these technical aspects, the project is embedded within a framework of situated urbanism that goes beyond mere architectural concerns to fully engage with the territorial reality of Sousse. The use of local materials, the reuse of waste (tires), and the guided self-building process contribute to a contextualized approach that values social ties, ancestral practices, and reduced environmental footprint.

Thus, this experiment exemplifies a model of housing integrated into the Mediterranean intra-urban landscape, aligned with territorial dynamics of resilience and sustainability. It opens perspectives for ecological urbanism where the relationship between structure, environment, and society becomes a lever for innovation in urban planning.

In sum, the complementarity of structural and thermal approaches, enriched by the consideration of situated urbanism, makes this prototype a tangible example of how renewed vernacular architecture can help address contemporary challenges related to climate and urban development.

4 CONCLUSION AND RESEARCH PERSPECTIVES

This experimental study of the Superadobe dome prototype confirms the relevance of an integrated approach combining adapted vernacular techniques, passive thermal performance, and structural resilience within the semi-arid Mediterranean context. The project demonstrates how situated urbanism—based on the use of local materials, the valorization of ancestral know-how, and a guided self-building process—can sustainably address current climatic, social, and urban challenges.

Beyond thermal and mechanical performance, this type of housing shows notable capacity to withstand various crises. Its structural robustness, reinforced against seismic hazards, along with its passive thermal envelope, provides a safer and more comfortable living environment during major disruptions such as the COVID-19 pandemic, where confinement and housing quality were critical. Furthermore, the modularity and inclusion of adaptable spaces contribute to the flexibility needed to respond to future crises, whose nature and severity remain uncertain.

Future research perspectives focus primarily on integrating these prototypes at a broader urban scale, especially in peripheral and informal settlements where living conditions are often precarious and lack resilience. The dissemination of these techniques could offer vulnerable populations more sustainable, economical, and ecologically responsible alternatives while strengthening social cohesion through accompanied self-construction.

However, certain challenges remain and require further investigation. The earth material's sensitivity to moisture variations may pose long-term durability issues, particularly under extreme or changing climatic conditions. Additionally, current regulations and the lack of standardization for superadobe techniques still limit large-scale deployment. Finally, social acceptance of these atypical architectural forms necessitates ongoing efforts in awareness and cultural appropriation, which must be integrated into future projects.

Therefore, the alliance of technical research, social engagement, and supportive urban policies is essential to overcome these barriers. Developing ecological and inclusive urbanism that incorporates resilience to crises and sustainable housing performance represents a major challenge for contemporary and future Mediterranean cities.

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El Haouz Earthen Architecture in the Context of Post-Earthquake Reconstruction: Questioning the Continuity and Discontinuity of its Technical Resilience and its Genius Loci

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ABSTRACT

The Haouz region of Morocco, historically shaped by a sophisticated vernacular tradition of earthen construction, has long demonstrated an intrinsic capacity for resilience, adapting to environmental, socio-economic, and cultural transformations while embodying a distinctive Genius Loci. The recent seismic event, followed by large-scale emergency reconstruction initiatives privileging reinforced concrete technologies, raises critical concerns regarding the continuity of historically rooted spatial practices and technical knowledge systems.

This article interrogates the extent to which contemporary reconstruction efforts constitute a disruption within the natural, historically evolved processes of spatial fabric. Grounded in an interdisciplinary, field-based methodology—encompassing architectural surveys, material analysis, and ethnographic engagement with local craftspeople and communities—the study foregrounds the immediate structural impacts of seismic destruction and post-disaster interventions on the vernacular built environment. Particular attention is paid to the concept of **disruption,** understood here as the abrupt severance of traditional building practices and spatial configurations, and the imposition of an imported culture of building. This disruption challenges the notion of reconstruction as a mere act of technical remediation, revealing it instead as a profound reconfiguration of territorial identities and memory landscapes.

This study examines the sustainability of resilience in the post-earthquake reconstruction process, and investigates the historical continuity of *genius loci* through the dynamic processes of knowledge transmission, communal building practices, and spatial adaptation. The findings demonstrate the potential for reconciling the demands of contemporary safety standards with the imperative to preserve the historical spatial fabric of El Haouz's living heritage.

Keywords: Earthen Architecture, Morocco, Al Haouz, Post-Earthquake Reconstruction, Disruption

1 INTRODUCTION

Located at the foothills of the High Atlas, the Haouz region of Morocco has, over centuries, formed a distinctive cultural landscape shaped by a refined vernacular tradition of earthen construction. This built heritage, the product of communal knowledge and careful adaptation to environmental constraints, embodies a **Genius Loci** deeply rooted in local lifestyles, spatial practices, and social organization [1]. It reflects intrinsic resilience, where architectural forms, construction techniques, and uses have continuously adjusted to climatic, economic, and cultural changes [2,3].

The earthquake of September 8, 2023, abruptly disrupted this historical continuity, causing massive destruction and prompting rapid mobilization of public authorities and various actors through emergency reconstruction programs. While these interventions address the legitimate imperatives of safety and habitability, most rely on standardized reinforced concrete technologies — often at odds with traditional construction logics, social interaction codes, and local environmental specificities [4,5].

This raises a central question: does post-seismic reconstruction in Haouz represent the continuation of a historical process of adaptation, or, constrained by urgency and budget, does it signify a profound rupture in the evolution of spatial and social fabric? This question encourages viewing reconstruction not merely as a technical act aimed at restoring structures or replacing housing, but as a cultural and territorial phenomenon, carrying potential identity and landscape recompositions [6,8].

To address this, the article adopts an interdisciplinary approach, combining architectural surveys, material analyses, and ethnographic investigations with local artisans and residents. Through multiple case studies of affected villages, it compares pre- and post-disaster conditions to examine how reconstruction dynamics transform vernacular architecture and redefine resilience — understood here not only as the capacity to overcome a shock, but also to preserve and transmit a living heritage adapted to its context [9,10].

In this perspective, the analysis of cases in the Haouz region invites a more complex reading of the initial issue. It is no longer only about identifying visible changes induced by reconstruction, but also about questioning underlying — often silent — factors that contribute to the recomposition of local dynamics. These elements may, in turn, reinforce certain dimensions of what might be called socio-psycho-spatial rupture, prompting a more nuanced redefinition of the notion of rupture in post-disaster processes.

2. CONCEPTUAL FRAMEWORK: BETWEEN BUILT MEMORY, TRANSFORMATION, AND RESILIENCE

To analyze post-seismic reconstruction dynamics in the Haouz region, it is essential to adopt a conceptual framework linking the material, cultural, and social dimensions of vernacular architecture. Far from mere construction forms, the earthen dwellings of Haouz embody complex configurations shaped by history, climate, local resources, and collective practices. Their alteration - or even disappearance - following the September 2023 earthquake raises fundamental questions about the nature of the transformations at play: are we witnessing a sudden rupture or a deep, structured mutation?

Addressing this issue requires four key notions: vernacular architecture as a living heritage carrying its own **genius loci**; resilience, understood as the capacity of spatial and social forms to adapt; rupture, as a technical, spatial, and identity discontinuity; and finally, theories of continuity/discontinuity in cultural landscapes [1,2,4,5].

Earthen vernacular architecture in Morocco, as elsewhere, is closely linked to the soil, locally available mineral resources, and the social organization of communities. It is neither a rural aesthetic nor an obsolete technique: it embodies territorial intelligence, the result of intergenerational transmission of refined and contextually adapted know-how [2,11]. In Haouz, where raw earth and local stone have long been the main materials for domestic, agricultural, and religious buildings, this construction mode has shaped a perceptible **Genius Loci** [4], evident in the way space responds to climatic constraints, agricultural rhythms, and collective practices (fig. 1). This genius of place manifests both in spatial organization - hierarchical and centered on the courtyard - and in wall materials, whose textures reveal a direct relationship between humans, their environment, and their habitat.

Figure.1. Agoudar of Douar Taounghasst Imindounit (in Ruins). One of the oldest buildings in the douar.

Legend:
1: A foundation base of locally quarried stone
2: A system of horizontal stiffeners (beams) in large-caliber local stone, separating rows of rammed-earth (pisé) made from local soil
3: Lintels of solid local timber
4: A parapet protection system, made of finely cut local stone

However, this intangible heritage is increasingly fragile. The know-how of the *maâllems***,** transmitted orally and through practice, is eroding due to a lack of succession and institutional support [12]. This loss is evident in some villages, where the precision of stonework (Fig. 2) and mastery of earthen construction no longer meet previous standards. The decline of this skill base threatens the **Genius Loci**, compromising the faithful reproduction of an architecture that intertwined materiality, memory, and community cohesion.

Figure.2. Close-up of a wall in a dwelling that withstood the earthquake, Douar Taounghasst Imindounit.

The crack that appeared after the earthquake reflects two levels of construction quality and provides tangible evidence of a gap in the transmission of building heritage between generations of *maâllems.*

Resilience, a central concept in social sciences and architecture, refers not only to the technical capacity to recover after a shock but also to a territory's ability to preserve symbolic, social, and cultural continuities [10,9]. As Pierre Nora notes regarding collective memory, rupture is not limited to material destruction: it also reflects the loss of anchoring, the erasure of a framework of meaning that connected inhabitants to their living space [13].

This tension between continuity and erasure is common in post-seismic contexts. In L'Aquila, Italy, after the 2009 earthquake, rapid relocation into standardized housing disrupted neighborhood routines and shifted the heart of community life to the periphery, showing how reconstruction can uproot as much as it repairs [14].

In Haouz, the dynamic is similar but carries another dimension: it is not only urban organization that is affected, but the intimate relationship with vernacular skills and the rural **genius loci**. The gradual replacement of earth with reinforced concrete does more than change materials; it silently

transforms social interaction, courtyard use, spatial hierarchies reflecting social hierarchies, and the balance between housing and productive activities. Rupture is thus both spatial and mnemonic, undermining the living continuity of built culture.

Moreover, Haouz was already experiencing "fragility" before the earthquake: photographs taken days after the disaster show a composite architectural fabric, where reinforced concrete buildings were already interspersed with earthen structures (Fig. 3). Far from marginal, this trend introduced distortions in the vernacular landscape, initiating a progressive rupture that the earthquake only accelerated and amplified.

Figure.3. Panoramic view of a Douar in EL HAOUZ (Tasskourt-Assif Lmal).

The photograph illustrates the hybrid construction modes already present in the region's architectural landscape. This hybridity is further compounded by provisional dwellings in plastic tents, arranged according to a new logic, foreign to the traditional patterns of settlement and anchoring (guided instead by accessibility, land optimization, and safety).

Rather than strictly opposing rupture and continuity, the built landscapes of Haouz appear as dynamic entities, shaped by successive layers of evolution, reinterpretation, and sometimes deliberate discontinuities. Continuity does not equate to stasis, nor does transformation necessarily signify rupture. As noted by Ingold [1] and Johnson [2], constant interactions among nature, culture, and history produce hybrid landscapes where memory, adaptation, and innovation coexist. From this perspective, the "breach" - material, social, and cultural - was beginning to emerge well before the earthquake.

Post-disaster examples allow analysis of how these discontinuities intensified and spread across time and space, providing a concrete measure of rupture while highlighting processes of resilience and vernacular reappropriation. Understanding Haouz's landscapes as the product of evolving strata provides the framework for examining the earthquake's impacts in the field. To this end, a methodological approach combining direct observation, architectural surveys, and spatial analysis will be employed to document post-disaster transformations and quantify discontinuities, while revealing dynamics of continuity and cultural reinvention.

3. DISCUSSION: MATERIALIZATION AND PERCEPTION OF POST-SEISMIC RUPTURE

3.1 Comparative Survey: Morphological and Organizational Rupture

Comparative analysis between traditional rammed-earth structures and reinforced concrete reconstructions highlights a clear rupture in morphology and spatial organization. Traditional houses, with walls at least 60 cm thick, timber and/or stone bonding, and earthen-and-wood roofs, integrate harmoniously into the village fabric (Fig. 4).

Figure 4. A typical house under construction just before the earthquake (Tasskourt-Assif Lmal).

Legend:
1. A stable and secondary entrance hall
2. Living spaces (work and rest)
3. Open-air hall (patio or **Houch**)

In contrast, new constructions, systematically built in reinforced concrete following a standard plan (Fig. 5), alter proportions, openings, and the orientation of interior spaces, producing both aesthetic and functional rupture. This transformation reflects a "modernization" dynamic which, although driven by state directives, changes the identity defining characteristics of vernacular dwellings (Fig. 6).

Figure.5. Rehabilitation program plan.

The single-prototype, single-orientation design poorly suits the uneven terrain, disrupting accessibility, intimacy, and socio-spatial hierarchy.

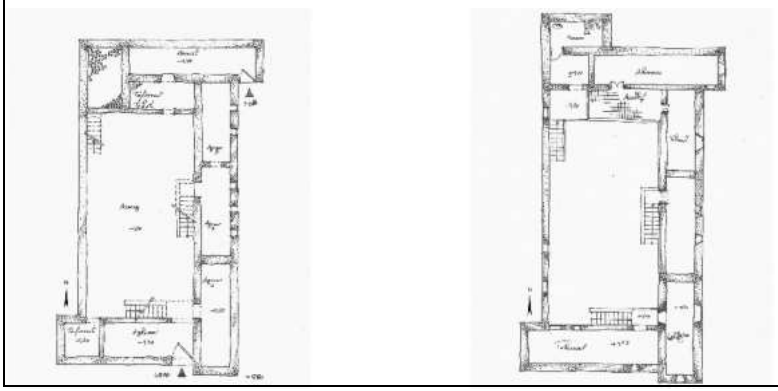

Figure.6. Survey and restitution in plan. Douar Taounghasst Imindounit.

The original plan organizes spaces by function and intimacy, adapted to topography and external accessibility.

Nevertheless, beneficiaries acknowledge certain advantages: these buildings provide better seismic resistance, enhancing the sense of safety, and offer significant health benefits compared to traditional earthen and stone constructions, notably by reducing the presence of harmful insects or vectors that can inhabit untreated earth or stone walls [6,9].

3.2 Construction Techniques: Material Continuity and Discontinuity

Comparative photographs of traditional and recent construction techniques illustrate a shift from local to industrialized materials. Traditional methods, such as rammed earth and adobe, remain well-suited to local climatic and geological conditions, providing good thermal and acoustic performance. However, their seismic vulnerability is widely noted in the literature, particularly by Moroccan engineering researchers [4,7], and confirmed by current seismic regulations in Morocco.

Field observations suggest that the observed fragility does not result solely from the materials used, but also from the quality of their implementation (Fig. 7).

Figure 7. Reinforced concrete structure with rammed-earth infill, Douar Taounghasst Imindounit.

Legend:
1. Main pseudo-beam
2. Load-bearing pseudo-column
3. Rammed-earth wall
4. Column base without footing

Two examples illustrate this finding: a concrete structure with earth infill that failed in the earthquake despite using a supposedly superior material, and two vernacular houses, one poorly executed and demolished, the other carefully built and more resilient. These cases show that durability and resilience depend not only on material [12] but also on skill and construction rigor (Fig. 8).

Figure.8. Two neighboring vernacular houses, Douar Taounghasst Imindounit

3.3 Material Analysis: Ecology and Aesthetics

The analysis of materials and site placement reveals ecological, spatial, and aesthetic rupture. Traditional dwellings, built with local earth and stone, were anchored in the topography, optimized orientation, and incorporated modest but identity-rich ornamental details (Fig. 9), enhancing

passive comfort, landscape coherence, and socio-spatial morphology. In contrast, standardized reinforced concrete reconstructions, imposed through typical plans, disregard the site and prioritize minimal functionality over climatic performance and architectural expression [2,4,5].

Figure.9. Examples of stone ornamentation on the main door and painted decorations on the living-room wall, Douar Taounghasst– Imindounit.

3.4 Resident Survey: Social Acceptance of Rupture

The survey reveals strong acceptance of new constructions, valued for their safety and modernity despite breaking with vernacular architecture (only 10% were satisfied with their old homes; 90% no longer wish to live in rammed earth and stone; 80% prefer the new houses for their stability and perceived safety; 50% are aware of the smaller sizes of future homes, 3–6 times smaller; 30% regret the loss of patios; 100% desire modern amenities [9] (Fig. 10)). This adherence reflects an adaptation strategy where safety and comfort outweigh the preservation of heritage and traditional socio-spatial codes, even when construction quality, typology, size, or form of housing is deficient (Fig. 11).

Figure 10. Construction site of a post-earthquake housing unit, Douar Taounghasst–Imindounit.

Figure 11. Due to budget and site constraints, secondary works were undertaken before completing the main structure: a party wall remains unplastered, and the terrace, "accessible by ladder," lacks waterproofing, Douar Taounghasst - Imindounit.

3.5 Summary: An Accepted but Questioned Discontinuity

Discontinuity and rupture, often invoked, appear less as a radical break than as an acceleration of a transformative trajectory [15], a gradual reconfiguration, and a transformed continuity [1]. This perspective encourages moving beyond the opposition between tradition and modernity, viewing

post-seismic reconstruction as a laboratory for experimenting with new modes of dwelling at the intersection of technical, social, and cultural logics, towards a probable new local Genius Loci.

5. ACKNOWLEDGEMENTS

The author gratefully acknowledges Mr. Rachid Ait Haj Fars for his invaluable assistance in conducting interviews with local residents and facilitating access to field sites despite challenging topography, which greatly contributed to the empirical analysis in this study.

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Analysis of Clay Building Materials in the Construction Technologies of Roman Baths in Anatolia

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ABSTRACT

Roman baths are architectural complexes notable for their specialized design, construction techniques, and integrated functional systems. This study examines the use of clay-based building materials in the structural, heating, and water infrastructure systems of Roman bath buildings in Anatolia. Initially, clay was used in the production of structural bricks incorporated into architectural elements such as foundations, walls, and arches within the load-bearing systems of baths. These bricks were fired at high temperatures and engineered to meet the mechanical requirements of structural elements. Secondly, clay materials played a critical role in the *hypocaust,* the underground heating system, which was one of the most significant Roman innovations in bath architecture. In this system, hot air generated in underground furnaces circulated beneath the floors via *pilae* (fired clay supports), typically circular or square in shape. Research indicates that these bricks were specifically designed to withstand intense heat and thermal stress while effectively retaining heat over time. Additionally, in-wall components such as *tegulae mammatae* (lugged tiles), *tubuli* (box flue tiles), spacer pins and spacer tubes were crafted from clay and embedded into the walls to faciliate the circulation of hot air throughout interior spaces. Finally, clay was also used in water infrastructure, representing another significant technological advancement. In early examples, terracotta pipes (*künks*) were installed beneath bath structures to supply fresh water and discharge wastewater. Analytical studies indicate that these pipes were produced using potter's wheels, reflecting a high level of craftsmanship and long-term durability.
In conclusion, clay-based building materials were fundamental to the construction and technological development of Roman baths in Anatolia, appreciated for their durability, thermal performance, moisture resistance, and ease of production.

Keywords: clay building materials, bricks, terracotta pipes, hypocaust system, Anatolian baths.

1 INTRODUCTION

Since prehistoric times, uninterrupted traditions of bathing have constituted an integral component of Anatolia's cultural landscape. Archaeological excavations in palace settlements such as Hattusa, Aslantepe, and Zincirli reveal the existence of sophisticated bathing practices, along with developed water supply and drainage systems, dating back to the Bronze and Iron Ages. During the Greek and Hellenistic periods, bathtubs and pools were incorporated into gymnasium complexes to serve the hygienic needs of athletes.

With the peace and economic prosperity ensured by the Roman imperial system, bath structures of various scales were constructed even in the smallest mountain settlements. In particular, the small-scale baths found in regions such as Lycia, Pamphylia, Pisidia, and Mountainous Cilicia stand out

as examples of the "Pompeian type" plan scheme, adapted to local conditions. These baths typically consist of an apodyterium**,** frigidarium**,** tepidarium, and caldarium**.** Service units such as water tanks and ash pits are situated on one side of the complex, while on the other are athletic facilities, including the colonnaded palaestra [1][2][3]. Notable examples of this type can be observed in sites such as Oenoanda, Patara, Arykanda, and Anemurium.

One of the most distinctive architectural contributions that Anatolia offered to the ancient world is the bath-gymnasium complex, which embodies a unique social and architectural synthesis. During the Roman Imperial period, these complexes became indispensable components of urban life. Characterized by high-vaulted halls, naturally illuminated interiors, and marble-lined swimming pools, they were constructed as monumental edifices that reflected Anatolia's multi-layered cultural heritage. This building typology represents a synthesis of the open courtyard plan characteristic of Greek gymnasiums and the monumental, vaulted architecture of Roman baths. Notable examples such as the Imperial Bath-Gymnasium at Sardis and the Vedius Baths at Ephesus illustrate a hybrid layout, in which these two architectural traditions coexist side by side. One of the earliest examples of this synthesis is the Vergilius Capito Baths in Miletus, dated to the first half of the 1st century CE. The symmetrical and axial planning principles observed in this example were continued in later large-scale bath-gymnasium complexes [4][1][5]. Major Anatolian examples—such as the Sardis Bath-Gymnasium, the Harbor Baths at Ephesus, the Caracalla Baths in Ankyra (Çankırıkapı), and the Great Bath-Gymnasium of Magnesia—are comparable to the imperial baths of Italy in terms of their scale and architectural grandeur [1] the monumental Roman baths gradually lost their original functions, smaller and more economical urban baths continued to be utilized by Christian-Byzantine communities and later by Islamic societies that began settling in Anatolia from the 8th century onward. These structures provided the architectural and cultural groundwork for the development of the traditional Turkish bath and are regarded as a continuation of the ancient bathing tradition [1].

This research explores the characteristics of clay-based construction materials utilized in the development of structural, thermal, and hydraulic systems within Roman-era baths in Anatolia. It focuses on fired clay bricks employed in the construction of foundations, walls, and arches; pilae columns supporting the hypocaust flooring; earthenware components such as *tegulae mammatae* (lugged tiles), *tubuli* (box flue tiles), spacer pin and spacer tube that were enabled hot air circulation within wall cavities; and terracotta conduits (*künks*) designed for water conveyance and drainage. The study's findings demonstrate that these materials were deliberately manufactured to meet specific functional demands, owing to their mechanical durability, thermal efficiency, and ease of production.

2 ROMAN BATHS

In Roman society, bathing was a daily ritual closely linked to hygiene, health, leisure, and social life. By the late Republic, it had become a routine practice after midday meals and rest [2]. Thermae provided therapeutic environments through clean water, steam, oils, and massage, enhanced by architectural grandeur—marble, mosaics, sculptures, and domes [2]. Baths were also perceived as spaces of healing, with the sequential use of hot, warm, and cold rooms endorsed by ancient physicians. As multifunctional public institutions, they hosted cultural activities, dining, and social gatherings [2][6]. Compared to other public venues, baths were more inclusive, accessible to various social groups, though slaves participated only as attendants [7]. Low fees encouraged public use, and emperors used baths for political gain [2]. Their expansion was supported by technological innovations such as Roman concrete, which lowered costs and facilitated widespread construction, making baths both profitable and accessible [2].

2.1 Architecture of Roman Baths

Roman baths represent remarkable architectural achievements that significantly influenced and shaped the evolution of Roman architecture. Their spatial organization was primarily designed in accordance with the sequential order of bathing spaces typical of the Roman bathing tradition. The principal functional components of these complexes included the apodyterium (changing room), frigidarium (cold room), tepidarium (warm room), caldarium (hot room), and the palaestra (exercise area).
Roman baths featured both symmetrical and asymmetrical plans, reflecting diverse spatial and architectural approaches. Asymmetrical layouts, common in smaller bath (*balnea)*, followed the bathing sequence—apodyterium, frigidarium, tepidarium, and caldarium. In contrast, symmetrical plans characterized large Imperial Baths (*thermae*), which often included additional facilities such as libraries, meeting rooms, colonnades, and gardens, underscoring their cultural role [1]. These plans were organized along a central axis, typically anchored by the frigidarium with its *piscina*, flanked by apodyterium and tepidarium. The caldarium, usually placed to the south or southeast for solar heating, was surrounded by heated chambers. Frigidarium and caldarium were typically vaulted—cross vaults were most common, though barrel and domed roofs also appeared [8].

2.2 Heating System of Roman Baths

The bath complex is arranged as a progression of rooms with gradually increasing temperatures, beginning with the cold room and advancing through warm to hot rooms. This design distinctly separates heated spaces from unheated ones. The heating mechanism employed is known as the "hypocaust," which literally means "heated from below." Its primary function was to warm the floors and surfaces on which bathers stood and moved [9][2]. The baths were heated by a furnace known as the praefurnium**,** typically constructed from refractory firebricks measuring approximately 0.50 x 0.50 m. The furnace connected to the bath's underfloor space via two short walls, which directed hot gases and enhanced draft efficiency [10][2].

Hot air and gases produced by the same furnace heating the hypocaust circulated within this cavity and were vented through openings below the eaves, allowing reuse of the heat while enabling visitors to lean comfortably against the walls. The walls were heated by utilizing the cavity behind the exterior plaster (stucco). These hollow wall cavities were formed using terra cotta tiles called *tegulae mammatae**,** tubuli*, terrocotta stakes and terrocotta connector iron nails (Fig. 1) [2].

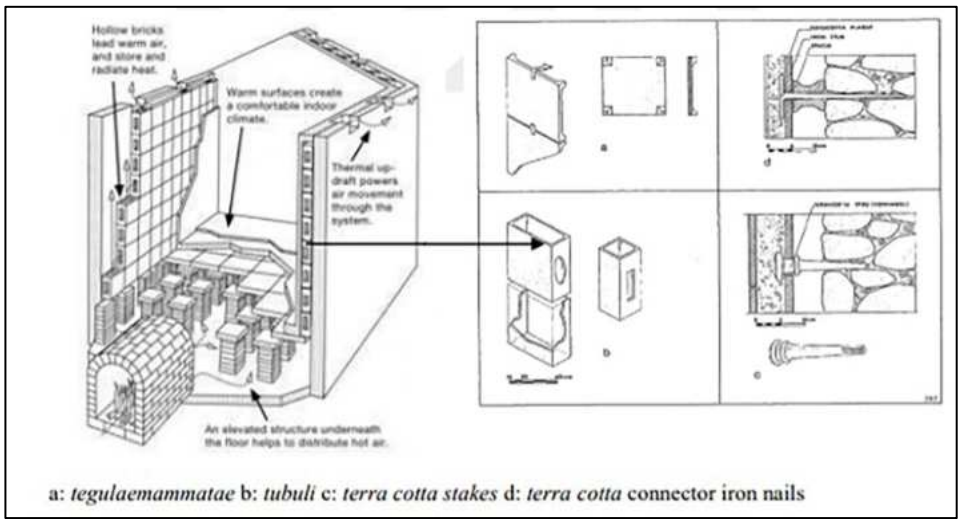

Figure 1. Wall heating system of Roman Baths [2]

2.3 Water Supply System in Roman Baths

Water infrastructure was vital to public health in the Roman period [11]. Small and medium-sized baths relied on wells, rooftop tanks, or cisterns and were designed to operate with minimal water. In contrast, large imperial baths depended on aqueducts for a continuous supply [12]. As Yegül [2] notes, aqueducts marked a major technological advance, allowing baths to be built even in arid regions. Water was first collected in a *castellum* at the city's highest point and then distributed via three channels: to homes, public buildings (including baths), and administrative centers [13]. Despite aqueduct access, cisterns remained essential for bath operations. Inside the baths, water circulation was mainly achieved through terracotta pipes terminating in taps [14].

3 ROMAN BATHS IN ANATOLIA

Archaeological studies indicate that numerous Roman baths were constructed in Anatolia during the Roman period. The region's fertile lands and strategic location attracted Roman interest, ultimately leading to its invasion in 190 BCE. Following the bequest of Attalos III, the Kingdom of Pergamon was incorporated into the Roman realm in 133 BCE, becoming Rome's first province in Asia. Under the rule of Julius Caesar (63–44 BCE), Roman colonization intensified throughout Anatolia, fully integrating the region into the Roman Empire. This era witnessed a significant increase in construction activity, including the establishment of numerous bath complexes [15].

3.1 Architectural Characteristics of Roman Baths in Anatolia

The plan types of Roman Baths in Anatolia were classified by Yegül, who highlighted the emergence of a new form the bath-gymnasium complex. This hybrid type combined features of the Greek gymnasium with those of the Roman bath, incorporating spacious rooms designed to meet the community's needs for education, physical exercise, bathing, and leisure. While grand, symmetrical, and axial layouts were prevalent, examples of asymmetrical plans also exist [2]. In contrast to the curvilinear layouts commonly found in Roman baths, Anatolia examples typically featured linear and orthogonal plans. Curved forms were generally limited to niches and small circular rooms. Although Anatolian bath architecture was influenced by the symmetrical thermae of Rome, no examples have been found with a centrally located caldarium flanked by multiple apses. Yegül identifies three main types of symmetrical plans in Anatolian bath architecture: (a) the Double Row Layout, observed in examples such as the Port Bath-Gymnasium in Ephesus, and the Caracalla Bath-Gymnasium in Ancyra; (b) U-Shaped Halls with Reverse Circulation, as seen in the East Bath-Gymnasium of Ephesus; and (c) the axial alignment of bath structures and palaestra, exemplified by the Bath-Gymnasium complex at Sardis [2][8] Anatolia also offers examples of asymmetrical planning, such as the South Gate Baths at Perge [1][8].
The heating and water supply systems of Roma Baths in Anatolia shared common features. However, differences arose due to variations in local materials and craftsmanship. This localized approach was both more practical and cost-effective, as transporting architectural plans and structural descriptions was considerably easier than relocating building materials or skilled labor. In essence, while Anatolian builders replicated the forms and techniques of Roman models, they adapted them using locally available resources [16].

3.2 Materials of Roman Baths in Anatolia

The primary construction materials used in baths include stone, brick, mortar, and plaster. The economic and structural properties of locally sourced materials—including their load-bearing capacities, durability, and hierarchical associations with other material types—were carefully considered in construction practices [1].

3.2.1 The specific uses of clay-based building materials

In the Roman baths of Anatolia, fired clay bricks were employed as primary load-bearing elements. These bricks were used either independently or in conjunction with stone in the alternating wall masonry technique. They were particularly common in vertical structural components such as foundations and walls, as well as in transitional and roofing elements like arches, vaults, and domes. Bricks were favored due to their ease and cost-effectiveness of production in regions where suitable clay was locally available. Additional advantages included their lower unit weight compared to stone and concrete, standardized dimensions that facilitated handling and construction, and the possibility of constructing thinner walls. When manufactured using appropriate techniques, these bricks demonstrated high compressive strength, low water absorption, resistance to frost, and durability against environmental factors [17] [18]. Examples of the stone-and-brick alternating wall technique (*opus mixtum*) have been identified in the Roman baths of Parion and Smintheion (Fig. 2) [19] [20].

Figure 2. The use of stone-and-brick alternating wall structures in the Roman Baths of Parion and Smintheion [19] [20]

Clay-based building materials were widely utilized in Roman bath heating systems due to their high thermal resistance and heat retention capacity. Among these, *pilae* (brick supports) used in hypocaust systems were manufactured in various sizes and shapes to suit different structural needs. At the Roman baths in Parion, the hypocaust system incorporated square, rectangular, and circular bricks, as well as fired clay pipes, particularly in the central areas of the structure. These elements demonstrate how clay-based materials were specifically engineered to optimize heat distribution in different structural zones. In contrast, at the Smintheion Roman Baths, the *pilae* are also made of square or round clay bricks; however, a distinct construction method is evident. Unlike other examples, the floor of the structure is supported by tuff stone pillars. The use of tuff in this context was likely intentional, offering both protection against moisture damage and enhanced fire resistance (Fig. 3) [19] [20].

Figure 3. Heating system in the Roman Baths of Parion and Smintheion [19][20]

In wall heating systems, a variety of solutions involving clay-based materials were employed. At the Parion Roman Baths, examples from the Late Roman period reveal the use of hollow terracotta spacer tubes—shaped like spools or cylinders—embedded within the walls to facilitate the circulation of hot air. These elements were engineered to endure high temperatures and thermal stress, ensuring effective and sustained heat retention (Fig. 4)[19].

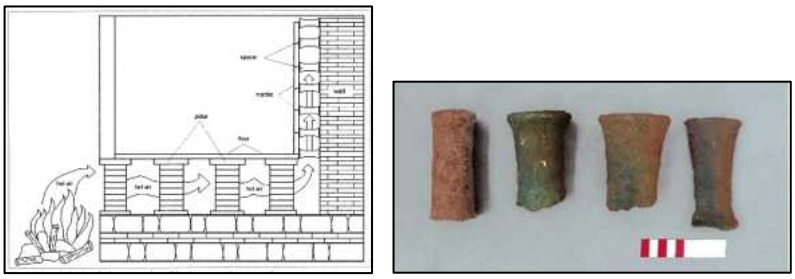

Figure 4. Spacer tube system [21] and hollow terracotta spacer tubes in the Parion Roman Baths [19]

The walls of the heating system in the Smintheion Roman Baths incorporate a *tegulae mammatae* system. In this technique, flat fired clay tiles featuring raised nipple-like projections were used to construct a hollow wall layer, enabling the circulation of hot air and gases rising from the hypocaust. These protrusions served to create an air cavity—typically between 8 and 12 cm—between the structural wall and the interior marble cladding, thus facilitating efficient heat transfer while preventing damage to the surface materials (Fig. 5)[20].

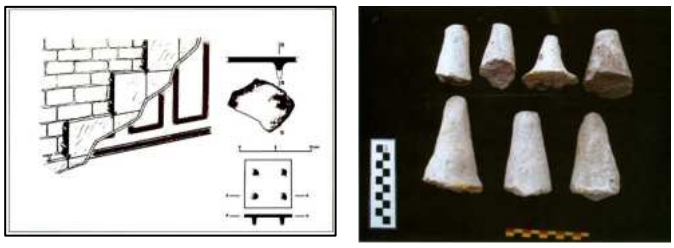

Figure 5. Tegulae mammatae system and *Tegulae Mammatae* tiles on the late-phase walls of the Smintheion Roman Baths [20]

In addition to standard heating components, spacer pin systems with terracotta wall nails were also used in some Roman baths structures in Anatolia. For instance, in the Roman Baths at Gürsu (Antalya), ball-headed terracotta nails were discovered embedded within the rubble masonry of the *tepidarium* and *caldarium* sections. Residual mortar traces on these nails suggest that they were originally fixed into the walls to support a layer of covering plates. This arrangement would have created a ventilated cavity, allowing the circulation of hot air along the wall surfaces and thereby contributing to the overall efficiency of the heating system (Fig. 6)[23].

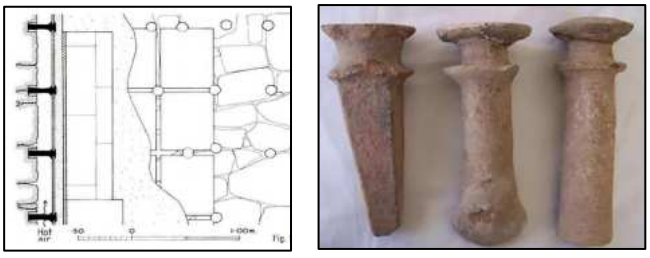

Figure 6. Spacer pin system [22] and ball-headed terracotta nails in the Roman Baths at Gürsu (Antalya) [23]

Clay-based materials were also used in the water distribution and drainage systems of Anatolian baths dating back to the Roman period. Findings from various archaeological excavation sites reveal the use of terracotta pipes in this area. For example, in the Roman Baths in Ankara, which dates back to the Caracalla period, baked clay pipes connected to the water reservoir have been

found [24]. Studies reveal that these pipes were produced on ceramic wheels and that clay was preferred due to its ease of shaping and resistance to water and moisture (Fig. 7)[25].

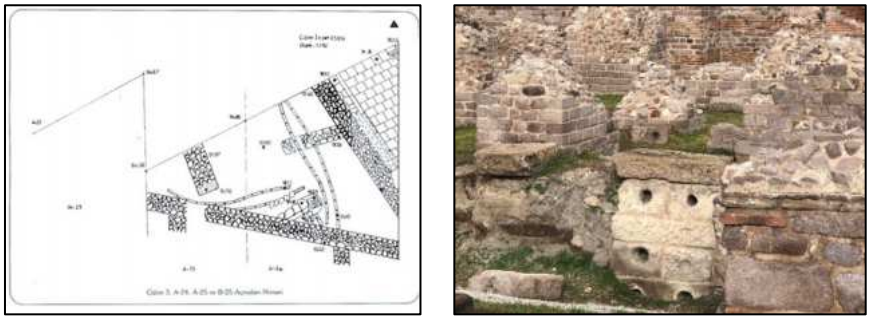

Figure 7. Plan of the excavated area [24] and the found terra-cotta pipes [25]

In the mortar and plaster materials used for binding, protective, and decorative purposes in baths in Anatolia, lime was employed as the primary binder, with aggregates such as sand and, in some cases, crushed brick fragments also incorporated [25].

CONCLUSION

This study has examined the use of clay-based materials in the construction technologies of Roman baths in Anatolia, with a focus on structural, heating, and water systems. Fired clay bricks were extensively used in load-bearing components such as walls, arches, and foundations, demonstrating considerable strength and durability. In heating systems, clay-based *pilae* supported the hypocaust floors, while *tegulae mammatae* (lugged tiles), *tubuli* (box flue tiles), spacer pins, and spacer tubes facilitated the circulation of hot air within the walls, enabling the system to endure intense heat and thermal stress. Clay was also utilized in the production of wheel-thrown terracotta pipes (*künks*), valued for their resistance to water and moisture resistance, which enabled effective water supply and drainage. These findings highlight the versatility of clay in meeting diverse technological needs and support the preservation of Roman baths as key elements of Anatolia's architectural heritage.

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Restoration And Static Strengthening Techniques of Malatya Arslantepe Excavation House After the Earthquake

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ABSTRACT

Arslantepe excavation house was built as a small depot by French archaeologist Francois Delaporte in the 1930's to preserve excavation tools.
In 1961, when the Italy, Roma La Sapiaenza Univetcity team continued their excavations, the depot building built by the French was expanded and started to be used as an excavation house. In later years, the retaining walls around the roof were added and reinforced, and it has survived to the present day.
The structure was built of stone up to the basement level and adobe brick above the basement level. The outer walls of the structure were built with double rows of adobe brick approximately 50 cm thick. However, the inner partition walls were manufactured in lath and mortar. The upper cover consists of poplar rafters, wooden cladding and approximately 10 cm thick soil on the wood. A high roof used as a depot was placed on the earth roof. The area where the building is located is positioned on the roadside and has a height starting from 50 cm and reaching 1.5 m from the sloped road code. The slope was tolerated with a retaining wall between the road and the building and the retaining wall was filled. A section of the retaining wall was manufactured as a dry stone wall; in other sections, a retaining wall was created by the municipality using reinforced concrete in order to prevent the wall from damaging the road during the asphalting works of the road passing next to the excavation area in previous years.
After the earthquakes centered in Pazarcık Mw7.7 and Elbistan Mw7.6 on February 6th, 2023, deformations occurred on the roof of the structure and cracks occurred on some of its walls. The retaining wall, which was made as a dry stone wall, was demolished.
The restoration and reinforcement project prepared in 2025 was implemented after the approval of the Ministry of Culture Board. In our article, the reinforcement and restoration works of this adobe building group will be explained.

Keywords: Kerpic, restoration, earthquake, reinforcement, earth building restoration

1. INTRODUCTION

Malatya's Arslantepe Mound is one of Anatolia's oldest settlements, and the excavation house used during archaeological excavations is also significant in terms of cultural heritage. The 2023 Pazarcık (Mw 7.7) and Elbistan (Mw 7.6) earthquakes caused damage to various sections of the structure. This article will discuss the restoration and structural reinforcement work carried out on the traditional adobe-built sections of the structure.

2. HISTORY OF THE ARSLANTEPE EXCAVATION HOUSE

The Arslantepe Excavation House is located within the Orduzu neighborhood of the Battalgazi district of Malatya, a first-degree archaeological site, and was built on public land. The foundations of today's excavation house were laid in the 1930s when French archaeologist François Delaporte built a small storage area to preserve excavation tools. This modest structure was expanded over time and turned into an important center hosting archaeological research.

With the involvement of an Italian archaeological team in the excavations in 1961, the existing French structure was expanded and converted into a dig house containing accommodation and work areas. The core of the house was created in 1964 under the leadership of Salvatore Puglisi, and then, between 1970 and 1978, additions were made to various directions (north, south, and west), giving the structure its current form. During these periods, the kitchen was extended to the north, and bedrooms, work areas, and other living spaces were added.

Three smaller adobe houses, not attached to the main structure but overlooking the same courtyard, were constructed between 1979 and 1980. These new buildings were constructed using local techniques in traditional adobe architecture and provided additional logistical support to the excavation team.

The dig house holds a significant place not only for its architectural features but also in the social memory of the local people. For the local people, this house was not only an archaeological site; it also served as a meeting place where they experienced their first work, provided social security, and celebrated various events.

The Arslantepe excavation house is also a place where four generations of Italian archaeologists, as well as leading figures in archaeology in Türkiye such as Robert and Linda Braidwood, have stayed and left their mark. During the 2021 UNESCO and ICOMOS evaluation process for the region's World Heritage List, the excavation house was particularly emphasized as a "place of memory and history."

The 2023 Kahramanmaraş-centered earthquakes caused significant structural damage to the main building, particularly placing the adobe sections at risk. Although the structure's demolition was considered due to the limited number of experts in adobe architecture, the decision was made to preserve it due to its archaeological and cultural significance. As part of this effort, three previously added small adobe structures were restored in 2023, and restoration work began on the main structure in 2024. The Arslantepe Excavation House's importance in terms of cultural heritage is valuable not only for its functional past, but also for its harmonious relationship with local architecture and scientific continuity. During an on-site survey conducted in 2019 during the World Heritage nomination process, the ICOMOS Turkish National Committee determined that the structure dates back over half a century, integrates with the site and its surroundings, and possesses both historical and ethnographic qualities.

The excavation house's construction, using materials and at a scale compatible with traditional rural architecture, was considered a sustainable example, emphasizing its aesthetic integrity with the surrounding natural landscape. It was also observed that the excavation house and storage areas were adequate for scientific working conditions, and the arrangement of research materials was exemplary. Therefore, ICOMOS considers the preservation and preservation of the existing structure crucial for maintaining Arslantepe's historical continuity and serving as a model for similar excavation sites.

3. POST-EARTHQUAKE STRUCTURAL DAMAGE AND REASONS FOR INTERVENTION

Two major earthquakes, centered in Kahramanmaraş and intensely impacting the Pazarcık (Mw 7.7) and Elbistan (Mw 7.6) regions, occurred on February 6, 2023, causing significant damage throughout Malatya province. The Arslantepe Excavation House was also directly affected by these earthquakes; the structure exhibited various structural deteriorations, particularly in its adobe-built sections.

The main damage observed can be summarized as follows:

- Deformations occurred on the roof system, with stiffness losses observed, particularly in the poplar (poplar) beams, and collapses in the soil cover.

- Cracks appeared in the exterior walls (double-layered adobe walls), and separation began in some areas.

- Failures were observed in the mortar and lath joints of the interior partition walls (Baghdadi style).
- The dry stone retaining wall has completely collapsed, which has put the environmental stability of the structure at risk due to the sloping ground level. The structure's foundation and adobe bricks, due to their inherent poor elasticity and energy absorption, exhibit serious structural vulnerabilities in such tremors. Furthermore, the structure's sloping location and the dysfunction of its retaining wall have increased the risk of secondary damage.

Preliminary investigations concluded that the restoration of the excavation house is essential not only for the preservation of its cultural and historical value but also for the holistic sustainability of Arslantepe Mound, which has been proposed for inscription on the UNESCO World Heritage List. Preserving and strengthening the structure in situ, rather than demolishing it, was adopted in accordance with both scientific and ethical restoration principles.

Accordingly, a comprehensive restoration and static reinforcement project, prepared in 2025, was submitted to the Malatya Regional Conservation Board of the Ministry of Culture of the Republic of Turkey.

4. STATIC ASSESSMENT AND INTERVENTION METHODS

The post-earthquake intervention process for the Arslantepe Excavation House was shaped in accordance with the "Static Analysis and Intervention Report" prepared in 2025. The structure was constructed on a timber frame system with adobe infill and has an L-shaped plan. Load-bearing walls were approximately 50–55 cm thick, while interior partitions were constructed with thinner sections of 15–20 cm. According to finite element analysis conducted with SAP2000 V23.3.1 software, the structure has very short periods (Tx: 0.10 s, Ty: 0.09 s), indicating that it was highly exposed to peak acceleration effects during the earthquake.

Due to the lack of a ground survey report, the analysis was conducted based on data from the Turkey Earthquake Hazard Map (TDTH) and assuming a "ZD" class soil. During the February 6, 2023 earthquakes, according to data obtained from accelerometer stations in the region, it was determined that the area where the structure is located was exposed to short-term but high intensity accelerations, especially at the beginning of the earthquake.

As a result of the analyses:

• The in-plane performance of the walls was found to be close to the limit values,

• They were found to be inadequate against out-of-plane movements.

• The target performance of the structure was determined to be at the "Controlled Damage" level.

5. RESTORATION AND STRENGTHENING TECHNIQUES

Based on the damage assessments and analyses, the main intervention and strengthening techniques implemented are as follows:

5.1. Foundation and Structural System Strengthening

A 25x35 cm reinforced concrete bond beam was laid below ±0.00 level around the foundation of the structure. Steel angles (profile belt system) were placed on the bond beam, extending from both the exterior and interior. This system was designed to work as a single unit, passing through the wall using rods.

5.2. Wall and Crack Repairs

Cracks in the adobe walls were repaired using injection and suturing methods, depending on their depth. Stainless steel spiral reinforcement was used, particularly in cracks exceeding 1 cm, and the voids were filled with natural hydraulic lime (NHL 5.0) mortar.

5.3. TRM (Textile Reinforced Mortar) Reinforcement

To increase the out-of-plane strength of the masonry walls, the TRM method was used, using carbon or basalt mesh reinforcement and natural hydraulic lime-based mortar. This system is both protective and removable.

5.4. Roof Structure Repair

Poplar rafters and purlins deformed during the earthquake were removed and replaced with original techniques and materials; the bracing and siding systems were completed. Usable roof tiles were removed and replaced, and any missing ones were replaced.

5.5. Surface Repair and Aesthetic Integrity

Exterior surfaces were coated with mud plaster and whitewash in accordance with local architecture; steel profiles were painted in natural earth and white tones with oven-baked paint to blend in with the building's texture. Historical inscriptions on the interior plasters were preserved, and intervention on the interior surfaces was avoided.

These practices represent a sustainable restoration approach, preserving not only the structure's physical security but also its cultural identity and aesthetic values.

6. ADDITIONAL EVALUATIONS AND DISCUSSION

6.1. Research Question and Method

The main research question in this study was developed as follows:

"What structural and environmental factors can explain the resistance of adobe brick during earthquakes despite its low elasticity and energy absorption capacity, and what intervention methods can improve this performance?"

As a method, field observations and post-earthquake damage analysis, static and dynamic performance evaluations using the finite element method, ground assumptions using TDTH data, and examination of the performance contributions of the applied restoration and reinforcement techniques (TRM, injection, steel belts, foundation lines, etc.) were evaluated together (Gün, Özkaya, & Aydın, 2025).

6.2. Unexpected Behavior of Adobe Bricks

Considering the known weaknesses of adobe bricks (low elasticity, low energy absorption capacity), the reasons why the structure did not collapse completely are as follows:

• Mass and rigidity due to the wall thickness (50–55 cm);

• The contribution of wooden elements (poplar beams, lath-and-mortar walls) to energy dissipation;

• The additional weight and binding effect of the earth roof;

• The harmonious combination of local construction traditions (double-row adobe walls + lath-and-mortar interior walls).

These findings demonstrate that the strength of adobe buildings can be explained not only by the material properties but also by the integrated operation of construction techniques and components (UNESCO & ICOMOS, 2021).

6.3. Literature References

Main sources used for the seismic performance of adobe:
• TBDY (2018) – Turkish Building Earthquake Code,
• TYDRYK (2017) – Guide for the Management of Earthquake Risks of Historical Structures,
• UNESCO & ICOMOS (2021) – Arslantepe Mound World Heritage Nomination Report,
• Gün, Özkaya, & Aydın (2025) – Arslantepe Excavation House Static Analysis and Intervention Report.

In addition, methods such as Textile Reinforced Mortar (TRM), proposed in recent years, are prominent in the literature for improving the weak seismic performance of adobe.

6.4. Turkey Earthquake Hazard Map (TDTH) and Scale Limitations

Since no ground survey was conducted, the Turkey Earthquake Hazard Map (TDTH) was used in the analyses. However, the TDTH was prepared at a scale of 1:475,000 and therefore only indicates regional seismic hazard and does not provide the necessary geotechnical details at the parcel or building scale. Therefore, the results obtained in this study should be considered to have limited reliability at the field scale and should be supported by detailed geotechnical investigations in the future (TBDY, 2018; TYDRYK, 2017).

7. CONCLUSION

The structural and architectural characteristics of the Arslantepe Excavation House emphasize its role in both scientific and social memory. The reinforcement and restoration practices were carried out in accordance with national and international conservation principles and supported by original materials and techniques. This structure, as a successful example of sustainable post-earthquake restoration and in-situ preservation, serves as a model for similar historical structures.

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Enhancement of Mechanical Properties of Cement-Stabilized Soil Blocks through Stabilizer-Assisted Methods

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ABSTRACT

The increasing emphasis on sustainability in the construction industry has accelerated the search for eco-friendly, low-emission building materials. In this context, Cement Stabilized Earth Blocks (CSEBs) have gained prominence due to their minimal environmental impact, affordability, and reliance on locally sourced materials. Unlike traditional fired bricks, CSEBs offer a lower energy production route, thereby contributing to a significant reduction in carbon emissions associated with building practices. However, issues related to the standardization of mechanical strength and moisture resistance in connection with material composition remain unresolved in the existing literature. Achieving consistent structural performance and durability continues to pose a challenge for the broader application of these materials. This research aims to improve both the structural and physical properties of CSEBs by developing novel mix formulations, guided by an extensive review of current literature and experimental trials. In addition to conventional cement-based stabilization, the study investigates the effectiveness of various alternative binders and additives to produce optimized compositions. The modified CSEB samples will be tested for key performance metrics such as compressive strength and water absorption. Specimens will be cast as 5×5×5 cm cubes, with compressive strength measured on the 7th and 14th day. Water absorption will be evaluated using a one-day immersion test followed by oven drying at 105 °C for 24 hours. Furthermore, the study will systematically assess the influence of water-to-binder ratio, soil-to-binder ratio, and compaction techniques on the long-term durability and structural stability of the blocks, using standard procedures commonly applied in civil engineering practice.

Keywords: Compressive Strength, Cement Stabilized Earth Blocks (CSEB), Rammed Earthen Construction, Sustainable Construction Materials

1 INTRODUCTION

In recent years, research on Cement-Stabilized Rammed Earth Blocks (CSEBs) has emphasized the influence of various stabilizing agents such as cement and lime on the mechanical strength and durability of these materials [1]. It has been reported that adding 6-12% cement can improve compressive strength to the range of 2–5 MPa, along with significant enhancement of physical properties. Moreover, the degree of compaction has been found to play an equally critical role as stabilization itself, with optimal compaction increasing strength by up to 30% [2]. Experimental studies conducted with Jordanian soils have demonstrated that a mixture of sodium silicate and lime can achieve strength levels comparable to those obtained with 8% cement addition [3]. In Turkey, the seismic behavior of stabilized rammed earth walls was investigated, and the results revealed that such walls exhibit higher energy dissipation capacity under cyclic lateral loads compared to brick and autoclaved aerated concrete wall systems [4]. Long-term durability

assessments comparing various stabilizers under laboratory and environmental exposure showed that a mixture of cement and resin resulted in minimal volumetric deformation [5]. In Saudi Arabia, cement-stabilized calcareous soils were found to offer superior water resistance compared to lime-stabilized variants [6]. Traditional stabilized earthen construction methods, such as the use of alker, have historically contributed to sustainable architecture in Turkey [7–8]. Moreover, experimental studies employing alternative stabilizers such as pozzolanic additives or fiber-reinforced mixes inspired by traditional mortars like Horasan have achieved notable improvements in strength without the use of cement [9–11]. In this context, the search for novel stabilizer combinations not only enables the utilization of local material resources but also aligns with global efforts to reduce the carbon footprint of construction practices [12]. Due to their affordability and minimal environmental impact, rammed earth construction techniques are increasingly gaining interest in the architectural field, especially in the context of sustainable and vernacular building design [13]. In rural housing projects, the use of CSEBs facilitates community-based construction models and supports local employment. In countries like Turkey, which are prone to seismic risks, it is of utmost importance to adapt these building systems to comply with modern engineering standards. This study aims to improve both the mechanical and physical performance of cement-stabilized rammed earth blocks by developing new material formulations based on a comprehensive literature review and experimental findings. Going beyond traditional cement based stabilization methods, this research explores alternative binders and admixtures to identify and evaluate optimized mixtures for sustainable and structurally sound earthen construction.

2 MATERIALS AND METHOD

In this study, locally available soil, Portland cement, lime, and fine aggregates were utilized as primary components. The physical characteristics of the selected soil particularly its grain size distribution were determined to ensure its suitability for stabilization. Various stabilizer combinations were tested systematically. A comprehensive mixture table was prepared based on a detailed review of previous studies in the literature, which served as a reference for the experimental formulations. The proportions of soil, lime, sand, and fine aggregate were altered in each mixture to allow for comparative evaluation of their physical properties. Experimental tests, including water absorption and compressive strength, were conducted on the samples, and the results were compared with findings from existing studies. It is important to note that no mechanical pressing device was employed during the sample preparation phase. Instead, manual compaction techniques drawn from traditional construction methods were used to shape the specimens.

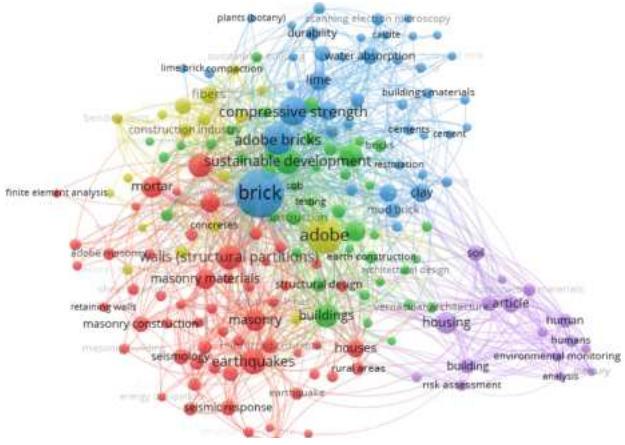

Figure 1. Data analysis of studies on earth-based materials indexed in the Scopus database.

This study employs a bibliometric co-word analysis approach to explore the positioning of brick and its associated technical terms such as compressive strength, durability, water absorption, and fiber reinforcement within the existing body of literature on construction materials. The research

methodology was structured in four key stages: data collection, keyword filtering, analysis, and visualization. The cluster of terms frequently co-occurring with "brick," including "compressive strength" and "durability," constitutes a central theme within the applied engineering literature and closely aligns with the broader topic of sustainable building materials. The analysis demonstrates that while brick is a traditional material, it is now being revisited through the lens of contemporary engineering techniques. Particularly, there is an emerging focus on its performance, environmental resilience, and structural safety. Increasing environmental concerns in recent years have driven the construction industry toward more sustainable materials with lower carbon footprints. In this context, traditional building elements such as brick and rammed earth have regained significance due to their environmental compatibility and integration with vernacular architecture. Modern research not only considers these materials in terms of structural performance but also emphasizes aspects such as energy efficiency and lifecycle sustainability. This study aims to identify thematic clusters in the international literature related to "brick" and "rammed earth" and to map their scientific trajectories through keyword-based visualizations (Figure 1).

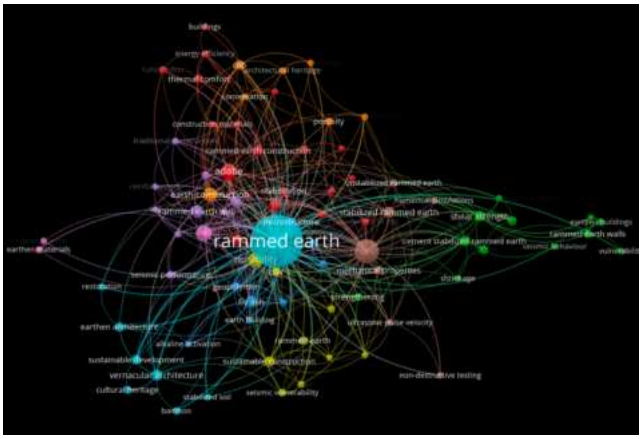

Figure 2. Data analysis of studies on rammed earth materials conducted within the Scopus database.

The bibliometric analysis reveals that both brick and rammed earth construction materials occupy a multidisciplinary space in the literature, encompassing technical, environmental, social, and cultural dimensions. Despite their traditional origins, these materials are being re-evaluated through the lens of modern engineering practices. Research extends beyond structural performance, addressing energy efficiency, cultural heritage preservation, sustainability, and societal relevance. The rammed earth literature demonstrates particular depth in areas such as stabilization techniques and seismic behavior analysis, while the brick literature presents strong sub-themes related to durability and the environmental impact of vernacular construction methods. This study offers valuable thematic insights for engineers and architects working in the field of construction materials, contributing to the identification of key research directions (Figure 2).

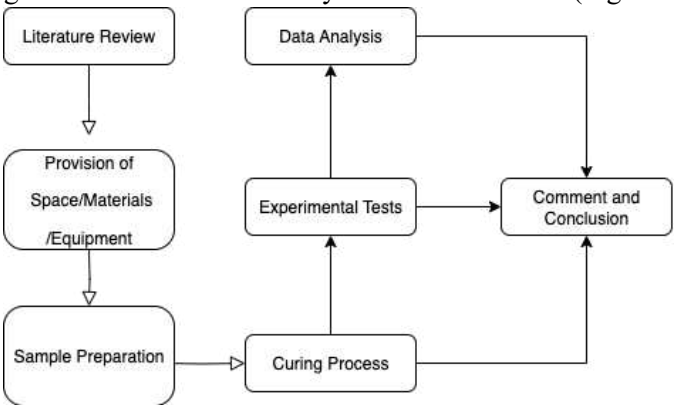

Figure 3. Experimental workflow steps conducted within the scope of the study.

During the initial stages of the study, an extensive literature review was conducted on key thematic areas such as local construction materials, strength tests, rammed earth, and adobe-based techniques. The objective was to establish a strong theoretical foundation to support the scope and structure of the experimental research. For this purpose, both national and international academic databases were utilized (Figure 3). To facilitate the experimental implementation, a suitable laboratory or field environment was selected, and the necessary materials were procured. These included:
-Natural materials: soil, clay, sand, etc.
-Binders and additives: lime, cement, fiber reinforcements
-Equipment: molds
Test specimens were prepared in accordance with established standards (e.g., ASTM, TS). Mixture ratios were adjusted according to the experimental groups, the materials were thoroughly mixed to achieve homogeneity, and the samples were cast into molds. The type of sample (e.g., cube, cylinder) was selected based on the specific objectives of the study.

3 EXPERIMENTAL STUDY

Rammed earth construction, which emphasizes the use of local materials, low carbon emissions, and alignment with sustainable building practices, has recently regained significant attention. Although traditionally limited in mechanical strength, this material can be significantly enhanced through modern engineering interventions, particularly by incorporating binders such as cement, lime, or other stabilizing additives. Within this context, the experimental component of the study aimed to assess the multidimensional impacts of cement-based stabilization on the structural and physical properties of rammed earth. The main objective was to investigate how varying cement proportions influence compressive strength, durability, porosity, and water absorption characteristics under different curing conditions. Various binder compositions and mixture ratios were systematically tested and comparatively analyzed for their structural viability. In the first set of experiments, three different stabilized soil compositions were examined:
-SC (Soil + Cement),
-SCL (Soil + Cement + Lime), and
-SCCI (Soil + Cement + Clay).
All samples were compacted using the same manual technique and evaluated both visually and experimentally. The physical integrity, surface quality, and water absorption rates were compared across samples. The SC mixture was prepared with a 5:1 soil-to-cement ratio. While it exhibited a compact and rigid structure, loose surface particles were observed after demolding, which suggests insufficient bonding and cohesion between particles. Its water absorption rate was measured at 21%, indicating a relatively porous and permeable internal structure. In the SCL mixture, lime was added at the same proportion as cement (5:1:1). The inclusion of lime appeared to improve the microstructure, resulting in smoother, cleaner surfaces with no visible particulate detachment. Despite the improved surface quality, the water absorption was measured at 24%, slightly higher than the SC sample. This may be attributed to the initial hydration characteristics of lime, potentially leading to a more porous matrix during the early curing stage. For the SCCI sample, which contained clay as an additional stabilizer (5:1:1), the resulting surface was observed to be rougher, with slight leakage from the mixture visible. This effect could be explained by clay's plasticity interfering with the bonding capacity of cement. The water absorption also reached 24%, similar to the SCL sample. Due to clay's water-retentive nature, its inclusion likely contributed to increased moisture uptake. These observations collectively indicate that additives influence not only mechanical properties but also surface integrity and water behavior. While lime positively contributes to surface smoothness and cohesion, clay may introduce microscopic inconsistencies that compromise surface integrity. Therefore, careful selection and optimization of additive types and proportions are critical in enhancing both the mechanical strength and durability of cement-stabilized rammed earth blocks (Table 1).

Table 1. Table of three different sample mixtures during the water absorption test

Sample code	*Mixture content*	*Production visualisation*	*Water absorption*	*Comment*
SC	Soil(5) and Cement(1) Ratios 5:1		%21	By using the compression process, it is ensured to gain strength by using soil and cement materials. After leaving the mould, soil dust particles fall from the surfaces.
SCL	Soil(5), Cement(1) and Lime(1) Ratios 5:1:1		%24	By using the compression process, soil, cement and lime materials were used together to gain strength. It is seen that the surfaces are smooth and there is no debris from the surfaces.
SCCl	Soil(5), Cement(1) and Clay(1) Ratios 5:1:1		%24	By using the compaction process, soil, cement and clay materials were used together to gain strength. It is seen that the surfaces are slightly rough and there is a slight spillage of the mixture from the surfaces.

The SC sample exhibited a water absorption rate of 16%, indicating a moderate level of porosity and permeability. According to literature, water absorption values ranging between 15% and 20% are typically considered acceptable for stabilized rammed earth materials [14]. This suggests that while the cement additive partially fills the pore spaces, it does not achieve complete impermeability. Therefore, in practical applications, especially for external wall elements without protective layers such as plaster or cladding, the moisture susceptibility of the material should be carefully addressed. Improvements in compressive strength, stiffness, and long-term performance have been strongly associated with higher cement content in the mixture [15]. The compressive strength at 7 days of curing, which represents early-age performance, was recorded at 2.71 MPa.

This value is deemed sufficient for non-load-bearing elements or rural housing applications, where economic and locally sourced construction alternatives are prioritized. Achieving this level of strength within a short curing period reflects rapid cement hydration and effective cohesion during the initial compaction phase. After 14 days of curing, the SC sample reached a compressive strength of 4.70 MPa, marking a 73% increase over its 7-day value. This significant gain highlights the progressive development of bonding within the matrix due to the continued hydration of cement. Based on the observed trend, the compressive strength is projected to exceed 5 MPa at 28 days, positioning the SC mixture as a viable candidate for use in load-bearing exterior wall systems. Furthermore, the performance aligns well with the minimum strength requirements outlined in TS 2514 (Turkish Standards for Adobe Blocks) and similar standards governing earth-based construction materials (Table 2).

Figure 4. Compressive Strength Test

The SC mixture, formulated with a soil-to-cement ratio of 6:2, demonstrated satisfactory performance in both physical and mechanical aspects. While its water absorption value approaches the upper acceptable limit, it still remains within tolerable ranges for stabilized earthen materials. The compressive strength results, obtained at both early (7-day) and intermediate (14-day) curing stages, confirm the suitability of this mixture for rural construction applications and as an alternative material in non-conventional building systems. Given these characteristics, the SC blend stands out as a promising candidate for sustainable construction, offering a cost-effective and environmentally friendly solution for modular or low-rise building components (Figure 4).

Table 2. List of mixing proportions.

Sample code	*Mixture content*	*Production visualisation*	*Water absorption*	*Pressure MPa 7 Day*	*Pressure MPa 14 Day*
SC	Soil(6) and Cement(2) Ratios 6:2		%16	2.71 MPa	4.70 MPa

Table 3. Comparison table of studies in the literatüre.

Ref.	*Material*	*Compressive strength*	*Water absorption*
Okunade [16]	Brick	15 MPa	%9
Babe [17]	Adobe	6 MPa	%14
Babe [18]	Adobe	6.4 MPa	%16
Zhang [19]	Concrete	45 MPa	%6
Çelik [20]	Stone	13.70 MPa	%26
As a result of this study	R.Earth	4.70 MPa	%16

As a result of the researches, the water absorption and pressure results in the studies in the literature were examined comparatively. This study was carried out by analysing the results of the studies in the literatüre (Table 3). In addition, this comparative table created by comparing different materials explain the unique contribution of the study.

4 CONCLUSION AND DISCUSSION

This study aimed to contribute to the development of sustainable construction materials by examining the effects of different stabilizers on soil-based building blocks. Experimental results clearly indicate that both the type and proportion of binders play a critical role in determining the mechanical strength and physical integrity of the blocks. Among the tested samples, those with increased cement content (SC mixture) exhibited superior performance in terms of compressive strength and porosity. The compressive strength value of 4.70 MPa obtained after 14 days of curing suggests that these blocks may serve as viable alternatives for non-load-bearing elements and rural construction projects. The water absorption value of 16% in the SC mixture indicates a moderate level of permeability, which can potentially be improved through protective surface treatments. Although the SCL mixture, containing both cement and lime, showed a more uniform surface texture, its resistance to water exposure was comparatively lower. This may be due to the porous microstructure created during the initial hydration phase of lime. Similarly, the SCCI mixture with clay exhibited less homogeneity and higher permeability, likely resulting from the clay's water-retaining characteristics and its limited bonding ability when combined with cement. These findings underline that the performance of soil-based blocks should be evaluated not only based on strength values but also by considering the overall production process, homogeneity of mixtures, and curing conditions. The choice of stabilizing materials—both in type and in proportion—significantly affects the final properties of the product. While clay may enhance plasticity, it can also lead to microstructural separations and reduced strength, making careful mix design essential. In summary, this research provides valuable insights into the mechanical and physical behaviors of cement-stabilized compressed earth blocks (CSEBs). Although increasing the cement ratio clearly improves mechanical strength, its influence on water absorption is relatively limited. Therefore, surface protection measures become crucial in real-life applications. For future research, it is recommended to explore other performance-related aspects such as thermal conductivity, long-term durability under environmental stressors, microstructural analysis, and energy efficiency. Overall, with carefully optimized binder combinations and mix designs, CSEBs have the potential to emerge as a reliable and sustainable material choice in modern construction practices.

6 ACKNOWLEDGEMENT
The authors gratefully acknowledge the support provided by Nuh Beton Inc. General Directorate, particularly for supplying the necessary materials and assisting with the execution of the experimental procedures conducted throughout this research.

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Kerpic'25 – Earthen Architectural Heritage
13th International Conference
Rabat, Morocco, 25-27 September / 2025

Vernacular architecture and local development dynamics in the Middle Drâa: Case of the Ksour of Amezrou and Tissergate, Zagora Region, Morocco

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ABSTRACT

The Moroccan architectural heritage built in rammed earth (Cob) faces increasing threats due to structural degradation, socio-economic pressures, and the erosion of its cultural and environmental foundations. In response, the Ministry of National Territorial Planning, Urban Planning, Housing, and City Policy launched in 2015 a National Program for the Sustainable Valorization of *Ksour* and *Kasbahs*. With a five-year budget of over USD 13 million, the program aims to improve living conditions — especially for women and youth — through architectural rehabilitation, income-generating initiatives, and the establishment of a national framework for sustainable heritage management.

The province of Zagora offers two notable examples of the program's implementation: the *ksour* of Amezrou and Tissergate. In Amezrou, a total investment of MAD 13.3 million was allocated to restore deteriorated structures using traditional techniques, and to provide social and economic infrastructure, including a woodworking workshop, a multifunctional community space, and potable water and sanitation systems. Similarly, Tissergate received MAD 7.8 million for the rehabilitation of its vernacular architecture and for the development of activities that enhance local livelihoods.

These integrated actions illustrate the potential of heritage-based development approaches that combine architectural conservation, cultural valorization, and inclusive local development.

Keywords: Earthen architecture, Ksour and Kasbahs, Amezrou, conservation, Oasis development,

INTRODUCTION

The vernacular architecture of the Drâa Valley stands as a remarkable example of human adaptation to the Saharan oasis environment. Built from rammed earth and stone, it embodies ancestral know-how passed down through generations, responding to the requirements of sustainability, climate resilience, and social cohesion. However, this architectural heritage is now in decline, threatened by rapid transformation dynamics that endanger its preservation. Among the most significant examples are the ksour of Amezrou (Zagora) and Tissergate (Ternata). These fortified settlements illustrate a perfect harmony between architecture, climate, local resources, and traditional lifestyles. The Ksar of Amezrou, a former artisanal hub housing a synagogue and jewelry workshops, reflects a rich multicultural and commercial past. The well-preserved Ksar of Tissergate hosts the Museum of Arts and Traditions of the Drâa Valley, a living symbol of collective memory.

In response to the deterioration of this heritage, public authorities have launched a national program for the sustainable enhancement of ksour and kasbahs, led by the Ministry of Territorial Development with the support of various institutions. The program aims to halt the collapse of earthen structures, strengthen territorial attractiveness, and safeguard local cultural identity. More than preservation, this initiative serves as a lever for local development, combining restoration, social and solidarity economy, sustainable tourism, and the transmission of traditional skills. The rehabilitation of ksour could thus revitalize local craftsmanship, create jobs, and foster social cohesion around a living heritage.

1. KSAR AMEZROU AND KSAR TISSERGATE: TWO HERITAGE GEMS OF THE MIDDLE DRÂA

2.1 Ksar Amezrou: A Living Heritage at the Heart of the Caravanning Memory of the Middle Drâa

Located south of the city of Zagora, at the foot of Mount Tazagourt, Ksar Amezrou is one of the most significant historical and heritage landmarks of the Middle Drâa. Built in the 18th century on a surface area of 44.7 hectares, it occupied a strategic position along the trans-Saharan trade routes connecting Morocco to sub-Saharan Africa. It served as a major supply point for caravans transporting gold, salt, and manuscripts between Timbuktu and northern Morocco. The ksar's layout reflects intelligent vernacular architecture made entirely of rammed earth (Cob), adapted to desert conditions: northern and southern bastions, two large gates, narrow alleyways, and crenellated walls. The central street, known as the "assarag", divides the space and connects the mosque, the sheikh's house, workshops, and the mellah, the former Jewish quarter that once housed about 30 families and a well-preserved triangular synagogue (Figs 1 and 2). Until the 1950s, nearly 400 Jewish families lived in Amezrou. Their departure—especially after 1956 and around 1962–1963—did not erase their legacy: artisanal traditions, especially in jewelry-making, still thrive [1]. Though it has lost its former centrality to the growing town of Zagora, Amezrou remains a vibrant space of tourism, culture, and collective memory.

Figure 1 and 2. Restored Jewish Synagogue and Mosque (Ksar Amezrou), 2025

Local initiatives have been launched to help preserve traditional crafts, some of which were inherited from the former Jewish communities that lived for centuries within the ksar. The local population, committed to protecting this intangible heritage, has established artisanal cooperatives that continue these traditions—ranging from jewelry-making to metal and woodwork, including the production of ritual items decorated with Amazigh, Jewish, and Saharan symbols (Figs 3 and 4). The workshops are in the central part of the ksar, where a dedicated artisanal workshop space operates. This setup supports intergenerational transmission of skills and enables sustainable production based on the use of traditional materials and techniques. The finished products are displayed in a dedicated exhibition room, which also serves as a craft museum. This space helps to promote the local living heritage while enhancing the site's touristic and economic value.

Figure 3 and 4. Activities inside the Ksar led by the Amezrou artisan cooperative

2.2 Ksar Tissergate: A Model of Conservation and Transmission

Ksar Tissergate (Fig. 5), located in the commune of Ternata, is one of the few ksour in the Middle Drâa Valley—alongside Ksar Amezrou—that has not fallen into complete ruin. It is also among the best-preserved ksour in the region. Situated 7 km north of the town of Zagora, it covers an area of 25.5 hectares. This ksar was founded approximately five centuries ago. Its defensive role is reflected in its robust surrounding wall, reinforced by thirteen watchtowers and a single entrance gate opening toward the oasis. The design and construction techniques used in building the ksar highlight the ingenuity and craftsmanship of the oasis population during that historical period. Today, the ksar houses the Museum of Arts and Traditions of the Draa Valley, further strengthening its role in intergenerational transmission and cultural mediation (Figs 6 and 7).

Figure 5. Ksar Tissergate / Figure 6 and 7.Selected objects exhibited in the museum (ANDZOA, 2024)"

This ksar also houses the Dar El Hiba kasbah, a historical landmark of the site. Built in 1905, the residence now known as Dar El Hiba holds significant historical importance. It was the residence of Ahmed El Hiba, a symbolic figure of Moroccan resistance against French colonization. He is buried in this very locality, which still bears traces of his presence through the ruins of the old fortress, although only the zaouïa remains well preserved. **How could a heritage development program give this ksar a new purpose?**

As part of a broader program to enhance architectural and historical heritage, Dar El Hiba has been included in a tourism-oriented rehabilitation project led by the Moroccan Company for the Valorization of Kasbahs (SMVK). Three emblematic sites were selected after an in-depth study: Kasbah Aït Abbou in Skoura (Ouarzazate), Ksar Ouled Abdelhalim in Errachidia, and Dar El Hiba in Ternata (Zagora). This restoration program aims to convert these buildings into high-end tourist establishments, while preserving their architectural authenticity [2]. However, several major challenges hinder effective ownership by local stakeholders and the concrete implementation of the projects. The program is facing delays, particularly regarding the acquisition of emblematic kasbahs such as Aït Abbou in Skoura and Ouled Abdelhalim in Errachidia. These delays are primarily due to complex land tenure issues and the difficulty of negotiations with numerous heirs, often scattered or in disagreement, making any legal regularization of ownership impossible. To date, only the Dar El Hiba kasbah has been successfully acquired by SMVK. This transaction was made possible thanks to an exploitation certificate transferred to a rightful heir by the inheritors, allowing the beneficiary to be recognized as the apparent owner. The sale was concluded for 1.8 million Moroccan dirhams. However, after deducting taxes and duties paid to the competent authorities, the seller effectively received only about 1.5 million dirhams—a significant markdown. This undervaluation is directly linked to the absence of a formal property title, which prevents fair valuation of this built heritage. This case highlights one of the key structural barriers to the valorization of kasbahs and ksour: legal uncertainty related to land tenure. This context makes transactions lengthy and uncertain, penalizing both the owners and project developers, whether public or private.

2. STATE PUBLIC POLICY FOR THE PRESERVATION OF ARCHITECTURAL HERITAGE: BETWEEN TIMID LEGISLATION AND VALORIZATION PROGRAMS FALLING SHORT OF EXPECTATIONS

2.1 A Slow-Moving Legislation: From 1912 to 1945, 1945 to 1980, and 1980 to 2025

The Moroccan state has made efforts to update its legal framework for heritage protection. If properly enforced, this legal arsenal could serve as a reference and an effective tool for the enhancement of

the national heritage. The state has also committed to restructuring its institutional system to accompany the process of deterioration and gradual disappearance that continues to threaten earthen architecture, particularly in the southeastern regions of the country. **What role does earthen architecture play in current conservation programs?**

Since 1912—the year the French Protectorate Treaty was signed—the Resident-General, General Lyautey, moved quickly to implement laws that reflected his vision of Moroccan territory [3]. On November 16, 1912, he enacted the dahir (royal decree) on the preservation of historical monuments and engraved inscriptions, emphasizing the importance of protecting archaeological remains tied to the history of the Moroccan state, as well as artistic objects contributing to its aesthetic value [4]. This dahir stressed the need to place historical monuments and related elements under special supervision by the central administration, subjecting them to classification and governance through specific rules and procedures [5]. However, due to the limitations of this decree—its vague terminology and the complex administrative steps required for implementation—a new dahir was promulgated on February 13, 1914. It aimed primarily to protect the areas surrounding historical monuments and sites of artistic value. In 1945, the 1914 decree was suspended and replaced by the dahir of July 21, 1947, which introduced a new set of provisions concerning the protection of historical monuments, sites, engraved inscriptions, works of art, antiquities, medinas, and regional architectural models [6].

Although Morocco gained independence in 1956, it continued to operate under legislation from the Protectorate era until the adoption of Law No. 22-80 in 1980. This law, concerning the protection of historical buildings, landscapes, inscriptions, works of art, and antiquities, entered into force through the dahir dated December 25, 1980 [7]. Law 22-80 defines the concepts of inventory and classification, as well as the categories of heritage concerned, whether immovable (by nature or by designation) or movable, insofar as their preservation serves the interests of Moroccan arts, history, or civilization [7]. The inventory aims to enable the state to conduct a comprehensive survey of the various components of cultural heritage, while streamlining intervention procedures to prevent further degradation, all while respecting property rights in accordance with the law.

It was not until the enactment of Law 33.22 on June 23, 2025, that Morocco began to address the significant delay in its heritage legislation. This evolving legal framework reflects the country's commitment to international heritage conventions it has already ratified—particularly those of 1972, 2003, and others. However, unless the implementation decrees are swiftly issued to operationalize the provisions of this law, progress will remain purely theoretical and ineffective—like spinning one's wheels in oil.

2.2 Support Program for the Sustainable Valorization of Ksour and Kasbahs in Morocco

In response to the growing degradation of earthen architectural heritage — with significant social, cultural, and environmental consequences for populations living in *ksour* and *kasbahs*, often in conditions of extreme vulnerability — the Moroccan Ministry of National Territorial Planning, Urban Planning, Housing, and City Policy launched in 2015 a national program for the sustainable enhancement of *ksour* and *kasbahs*. With a total budget exceeding 13 million USD over five years [8], the program aims to improve living conditions, particularly for women and youth, through the rehabilitation of pilot sites, capacity-building for stakeholders, awareness-raising about the heritage value of *ksour*, and the development of a national intervention framework by 2025. In the province of Zagora, two emblematic *ksour* have benefited from this program: Amezrou and Tissergate (Figs 8 and 9 and 10 and 11). Ksar Amezrou was restored with a total investment of MAD 13.3 million [9], which included architectural rehabilitation, the establishment of artisanal, social, and cultural facilities, as well as water supply and sanitation infrastructure. Ksar Tissergate received MAD 7.8 million [9] for the restoration of its built environment and the implementation of income-generating activities such as beekeeping, a traditional bakery, and the development of a socio-cultural space.

Figure 8, 9, 10 and 11: The Ksar Amezrou and Tissergate after rehabilitation, 2020

The impacts of these interventions are manifold. **I) From a heritage perspective**, the works helped preserve an exceptional urban fabric while making it functional for present generations. **II) On the social level**, improved access to water and sanitation has enhanced health conditions and the overall well-being of residents, helping to curb rural exodus and stabilize the local population. **III) On the economic level**, the introduction of income-generating activities (such as crafts and socio-community spaces) has revitalized the local economy and encouraged youth and women to engage in local development dynamics. While these socio-economic and environmental impacts are ambitious and largely positive, concerns remain regarding the respect for vernacular architectural heritage. Indeed, actions undertaken under the framework of ksour and kasbah valorization—especially through rehabilitation projects—have yielded promising results in terms of job creation, support for income-generating activities, and better integration of oasis territories into sustainable development dynamics. However, these gains must be weighed against the architectural quality of the interventions, particularly regarding adherence to the principles of earthen vernacular architecture.

In the absence of a clear, normative, and operational legal framework governing interventions on earthen architecture, many rehabilitation operations stray from the logic of heritage preservation. This legislative gap, combined with the dominance of industrial concrete supply chains and the reluctance of architects and civil engineers to assume responsibility in the absence of official standards, often leads to a loss of authenticity in restored buildings. A particularly emblematic case is that of the **Dar El Hiba Kasbah**, located within Ksar Tissergate and recently converted into a luxury tourist accommodation facility. While the project has enabled the functional reuse of the kasbah, the methods employed raise questions: the structure was reinforced using concrete (beams, slabs, and supports), while the earthen construction was reduced to a mere decorative cladding. This approach contradicts the very spirit of preserving earthen architectural heritage, which relies on the continuity of materials, techniques, and traditional know-how. Implicitly, this reflects a lack of confidence in the solidity and durability of earth as a construction material.

3. TO AVOID CHAOS, A NEW PARADIGM FOR EARTHEN ARCHITECTURE IS ESSENTIAL

Originally conceived without certified architects, engineers, specialized design offices, or surveyors, the ksour and kasbahs were designed by *maalmin* and local craftsmen—holders of non-formal, earth-inspired knowledge—based on bioclimatic principles. These structures relied on time-tested vernacular techniques: optimized orientation, thick rammed-earth walls, natural ventilation, and the use of local materials such as raw earth, stone, and date palm. These elements ensured comfort, insulation, and resilience while reinforcing harmony with the surrounding palm groves. This deep link between built heritage, palm groves, and the oasis ecosystem is vital: the degradation of one inevitably leads to the deterioration of the others. Therefore, any strategy for sustainable local development in oasis areas must reintegrate ksour and kasbahs into their agro-ecological, cultural, historical, and landscape contexts. However, the valorization of this heritage faces numerous structural, legal, and social constraints, which hinder the implementation of coherent and sustainable projects.

3.1 Land Tenure: A Legal and Social Barrier

One of the major obstacles to the rehabilitation of ksour lies in complex land tenure. Most of these structures are collectively or jointly owned, without clear land titles. The multiplicity of heirs, their geographic dispersion, the absence of a single legal representative, and unresolved family disputes make any restoration, funding, or adaptive reuse operation extremely difficult. This legal bottleneck discourages private investment and limits access to public aid or bank credit. Additionally, the State and decentralized institutions often capitalize on abundant collective land to promote linear urban expansion outside oasis walls. This has given rise to hybrid centers that are neither modern nor traditional, contributing to urban sprawl that disrupts the landscape.

3.2 Post-Restoration Non-Functionality

Even when restoration is technically successful, it may fail to contribute to local development if not accompanied by a functional reassignment. Uninhabited or partially deserted ksour no longer fulfill their social roles, as commerce, education, and services have migrated outside the walls. Without a clear usage strategy (e.g., tourism accommodations, museums, cultural workshops, coworking spaces), rehabilitated ksour risk becoming empty shells that deteriorate again in the medium term.

3.3 A Valuable Resource Without Legal Recognition

Another critical obstacle to the recognition and revival of earthen architecture lies in the lack of a clear and enforceable legal framework to guide its application. While certain post-independence initiatives aimed to integrate this architectural typology into national technical and regulatory standards, no effective implementation in building codes or regulations has occurred to date. This legal vacuum creates uncertainty, preventing architects, engineers, and design offices from assuming responsibility for structures built entirely from earth. In the absence of certified standards and insurance guarantees, occupancy permits are rarely issued for earthen buildings, limiting earth to decorative or non-structural uses, while reinforced concrete remains the load-bearing material of choice. This is further compounded by the influence of industrial lobbies in cement, concrete, and brick manufacturing, which actively hinder the integration of "non-conventional" ecological materials into the formal construction market. As a result, earthen architecture is denied its rightful place, impeding its broader deployment despite its well-documented environmental, cultural, and heritage benefits.

3.4 The Transmission of Know-How: A Silent Emergency

The transmission of traditional know-how—particularly that of *maalmin*, master builders specialized in earthen construction—is now severely threatened. The lack of generational renewal, combined with young people's dwindling interest in these professions, risks the loss of centuries-old techniques within a single generation. There is an urgent need to establish training sites, local craftsmanship schools, and support mechanisms for artisanal education.

3.5 Implementation Challenges for Management Plans

Sustainable management of ksour and kasbahs requires the development of integrated management plans based on a shared territorial vision. These plans should interlink heritage, economic, social, and environmental dimensions around clear objectives: conservation, valorization, transmission, and inclusive development. However, several limiting factors jeopardize their effective implementation; i) lack of inter-institutional coordination; ii) limited local human capacity; iii) absence of rigorous monitoring and evaluation systems and iv) discontinuous financing, especially in the medium and long term. Project sustainability thus depends on the capacity of national and local stakeholders to establish appropriate governance models, engage local communities, and make heritage a key driver in territorial development policies.

4. CONCLUSION AND RECOMMANDATIONS

Earthen architecture, far from being a relic of the past, is a cornerstone of oasis identity and a strategic lever for sustainable development. It intrinsically links habitat, climate, landscape, collective

memory, and local economy. The ksour, as expressions of this architecture, serve as living spaces, symbols of a refined agro-oasis civilization, and reservoirs of economic opportunity: in crafts, tourism, culture, and local product valorization. Yet their future remains precarious. Without an integrated approach—leveraging legal, social, technical, and economic instruments—the rehabilitation of ksour risks remaining marginal, scattered, or incomplete. Key recommendations include:

- **Establish specific legislation** for earthen architecture, complete with technical benchmarks and enforcement tools, to ensure restorations meet heritage standards and remain faithful to the architectural history of oasis territories.
- **Clarify land tenure status**, given the vast reserve of idle, unplanned collective land. Support communities in regularizing their property rights through mediation, participatory cadastral mapping, or the consolidation of co-heirs.
- **Ensure functional reuse of restored sites**: each rehabilitated ksar must be assigned a sustainable purpose suited to its context (e.g., museum, guesthouse, artisanal workshop, community center).
- **Support the training of *maalmin*** and the transmission of vernacular techniques via certified training sites and partnerships with schools of architecture and craftsmanship.
- **Develop territorially anchored management plans**, with clear goals, strong monitoring and evaluation systems, and sustainable financing, involving local authorities, deconcentrated state services, and community representatives.
- **Economically valorize traditional buildings** through the development of local value chains: crafts, integrated tourism circuits, ecotourism, and local product marketing.
- **Strengthen territorial governance** by creating networks of local actors, establishing dedicated heritage consultation bodies, and integrating ksour into regional sustainable development strategies.
- **The CERKAS of Ouarzazate city (Center for the Conservation, Restoration, and Rehabilitation of Ksour and Kasbahs in the Atlas and Sub-Atlas Regions of Morocco)** is the first and only institution in Africa dedicated to the preservation of the architectural heritage of ksour and kasbahs, covering a vast territory from Figuig to Assa in Morocco. Despite the breadth and ambition of its mission, the center suffers from a severe lack of logistical resources and staffing — with only one director and two technicians nearing retirement — as well as insufficient financial means, which significantly limits its operational capacity. It is therefore essential to strengthen this exemplary institution by providing it with adequate logistical, human, and financial resources to enable it to fully carry out its mission.
- **Leverage the mandate of the National Agency for the Development of Oasis Zones and the Argan Tree (ANDZOA)**, established in 2010 to preserve the oasis ecosystem. ANDZOA must take the lead in proposing legislation related to oasis ecosystems, earthen architecture, and oasis heritage. It should also represent oasis causes on international platforms to attract significant funding for the preservation and restoration of ksour and kasbahs. Moreover, the agency should initiate partnerships with CERKAS and international institutions dedicated to earthen architecture.
- **Establish a dedicated institutional and regulatory framework for earthen architecture**, incorporating fiscal and financial incentive mechanisms to support heritage-sensitive restoration efforts. This framework should include the provision of subsidies to tourism operators involved in the rehabilitation of ksour and kasbahs, provided they preserve the characteristics of vernacular architecture.

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Thermal Performance Enhancement of a Historic Riad in Rabat Through Passive Strategies

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ABSTRACT

This study investigates the energy rehabilitation of a traditional Moroccan Riad located in the old Medina of Rabat, a city characterized by a semi-arid Mediterranean climate. Riads, which are known for their inward-facing architecture and central open courtyards, are culturally significant and pose unique challenges for achieving energy efficiency while preserving architectural heritage. The research aims to assess the thermal performance of the building to reduce energy consumption and enhance indoor comfort. A comprehensive analysis of the building envelope was conducted, including thermophysical characterization of walls, roofs, and intermediate floors. Simulations were performed using the DesignBuilder software, based on EnergyPlus, to evaluate the impact of insulation and ventilation strategies under local climatic conditions. The reference building, without thermal enhancements, was compared to an improved model featuring internal wall insulation (4 cm polystyrene), roof insulation, partial patio covering, and mechanical ventilation (0.3 vol/h).
Results demonstrate significant improvement in thermal comfort, with indoor temperatures ranging between 18–21°C in winter and 20–24°C in summer. Humidity levels were also stabilized within acceptable ranges (50–70%), and Predicted Mean Vote (PMV) values remained mostly within thermal comfort zones. The findings confirm the potential of simple passive and semi-passive interventions to enhance energy performance in historic buildings without compromising architectural integrity.
This case study contributes to the broader field of sustainable renovation by demonstrating how modern thermal performance standards can be met in heritage buildings through context-sensitive design and simulation-based analysis.

Keywords: Riad, energy efficiency, thermal simulation, traditional architecture, Mediterranean climate, sustainable.

1 INTRODUCTION

Although the construction sector plays a central role in Morocco's economy, it is also among the most energy-intensive industries in the country. This high consumption is primarily driven by the growing demand for energy to meet heating and cooling needs, especially in residential and commercial buildings. In response, Morocco has adopted a national strategy for energy efficiency aimed at lowering the national energy burden. Within this context, promoting energy efficiency and integrating renewable energy technologies into the building sector appear to be the most promising solutions to address the country's energy challenges and improve long-term sustainability. One of the critical aspects of sustainable construction lies in the choice of materials. In Morocco's rural areas—particularly those in hot arid climates make extensive use of unfired clay is widely used due to its low cost, local availability, and minimal environmental impact. Numerous research efforts have been devoted to evaluating the thermal and energy performance of buildings constructed with this

material. For example, an energy simulation conducted using Design Builder software [1] evaluated a residential building in Lakhyayta, a new urban development near Casablanca, comparing different wall compositions, including traditional materials and clay-based alternatives. The results demonstrated a reduction of approximately 30% in energy consumption for heating and cooling when clay walls were used. Moreover, the study showed that external insulation, even with a thickness of 6 cm, could reduce heating energy needs by up to 72%. In another comparative study [2], researchers assessed three types of unfired clay across different Moroccan regions to determine which had the most favorable thermal properties. A dynamic simulation was carried out to identify the most ecological and energy-efficient clay material. The findings indicated that the thermal performance of all three variants was very similar under the tested conditions. Further studies have focused on the behavior of these materials in colder climates. El Azhary et al. [3], for example, investigated how unfired clay bricks contribute to maintaining indoor thermal comfort in winter, confirming the benefits of optimized envelope designs that rely on passive solar principles. Another study [4] examined how clay, as a raw and natural material, could support thermal comfort in traditional housing. The research emphasized the role of building orientation and material choice in creating a comfortable indoor climate using sustainable construction practices.

The research conducted in [5] evaluated the thermal performance of vernacular buildings in Rissani, using simulation tools to determine optimal building orientation for achieving thermal comfort in both summer and winter. The results revealed that traditional orientation strategies—rooted in vernacular architecture—are effective in moderating indoor temperatures naturally. In another investigation [6], the authors focused on Ksourian architecture in the same region. Through experimental analysis and thermophysical characterization of local earth materials, they identified the optimal building orientation for maximizing thermal efficiency throughout the year. The study showed that orientation has a significant effect on thermal comfort. A related study [7] analyzed two prototype buildings in climatically contrasting zones in Morocco. Through bioclimatic design strategies, the research aimed to identify appropriate architectural responses to each region's thermal challenges. The simulations confirmed that design strategies such as natural ventilation, thermal mass, and shading devices are effective in improving indoor comfort and minimizing energy use. Diz-Mellado et al. [8] explored how building courtyards can be optimized to enhance thermal performance through process modeling. Using Trnsys simulation software, the study tested various courtyard configurations and found that the optimal design depends on climate: square courtyards perform best in cold zones (up to 48% reduction in heating demand), while deep and narrow courtyards are suited for arid climates (achieving a 10% reduction in cooling demand). For temperate climates, narrow courtyards with medium depth provided energy savings of up to 58%.

Similarly, El Bat et al. [9] investigated how interior courtyards influence cooling energy demand. By combining simulation and experimental measurements, the study demonstrated that courtyard geometry and the orientation of adjacent spaces can reduce cooling demand by 8% to 18%, highlighting the architectural importance of internal courtyards for energy performance. A separate study [10] focused on historic buildings in cold climates, specifically examining the impact of internal insulation on hygrothermal behavior. Through simulations and on-site measurements, the researchers assessed risks of moisture damage, energy performance, and indoor air quality, offering insights into the trade-offs involved in retrofitting heritage structures. Akkurt et al. [11] further discussed the challenges of running accurate simulations on historic buildings, particularly the need for precise input data and validation through experimental calibration. They emphasized the complexity of modeling interactions between building envelopes, indoor conditions, and external climate, and pointed out the inherent uncertainties in dynamic thermal modeling of historic environments. The present research aligns with these previous efforts but seeks to propose a new architectural model that balances thermal comfort and energy efficiency while respecting Morocco's architectural heritage. The Riad, a traditional Moroccan dwelling influenced by Andalusian architecture, offers an excellent case study in this regard. Riads are designed around a central open courtyard, often containing gardens, trees, and water features, which not only serve aesthetic and social purposes but also contribute significantly to the building's microclimate. The architectural layout—organizing rooms around the courtyard with windows and balconies facing inward—enhances privacy and supports natural ventilation. In this project, the Riad in Rabat served as the subject of multiple energy simulations. Using Design Builder [15], a detailed model of the building

was created, incorporating various wall compositions tailored to the local climate. The study assessed how the courtyard's microclimate contributes to heating and cooling energy savings, demonstrating that the traditional Riad structure can provide considerable thermal benefits when designed and optimized using modern simulation tools.

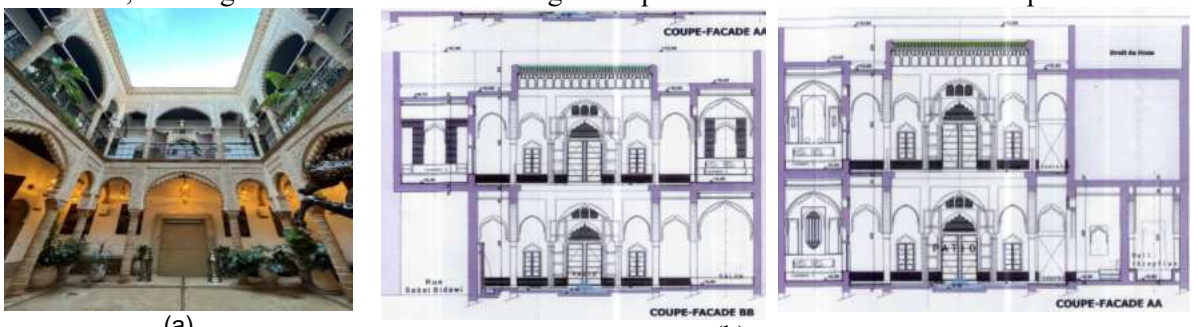
2 CASE STUDY: ENERGY BUILDING

The Riad analyzed in this study is located in the city of Rabat, near the Atlantic coast, which is subject to strong maritime influences. As a result, the region exhibits a semi-arid Mediterranean climate, marked by moderate to low rainfall during the winter months and humid, temperate summers occasionally disrupted by Chergui winds. Rabat's climate shows significant variability, with temperatures ranging from a minimum of 4°C to a maximum of 40°C. In summer, the air temperature can rise notably, particularly in July, when daily highs typically fluctuate between 16°C and 26°C. Annual precipitation levels vary considerably, ranging from 300 mm to 900 mm, depending on the year.

Figure. 1. Riad El Bahi

Situated in the heart of Rabat's historic Medina, the Riad is located specifically on Souk Sebbate Street (Fig. 1), an area renowned for its vibrant ambiance. This part of the souk has recently been restored, featuring a ceiling crafted from rare wood, a stone-paved floor, and gentle natural lighting filtered through moucharabiehs, an architectural upgrade that blends functionality with traditional aesthetics.
To shield the interiors from street-level heat and noise, openings are carefully designed and oriented. The architectural layout of Riads typically revolves around a central courtyard (Fig. 2a), forming the structural core of the building. Surrounding this open space are inward-facing balconies (Fig. 2b), reflecting a design deeply influenced by Arab-Andalusian traditions, Persian elements, and even classical Roman architecture. In most cases, the residential rooms are located on the upper level. The courtyard's roof is adaptable: depending on seasonal conditions, sunlight, and temperature, it can be

left open or covered with a fabric canopy or retractable shade. The roof itself often serves as an open-air terrace, offering views over the surrounding rooftops and the broader urban landscape.



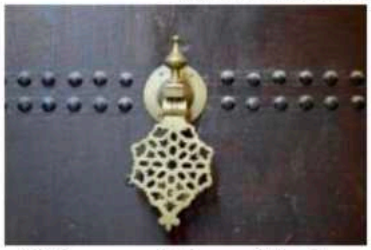
(a) (b)

Figure 2. a) Interior view of Riad, b) Building facades of Riad.

Various traditional materials are employed in the construction of Riads, each contributing to their distinctive architectural identity. Among them is zellige (Fig. 3), a decorative surface material made up of small, hand-cut colored tiles intricately assembled to form elaborate floor and wall mosaics. Plaster is another key element, often used to create ornate, floral patterns that enhance the visual richness of interior surfaces. Wood, known for its natural insulating properties, is widely used in doors (Fig. 4), ceilings (Fig. 5), and windows, lending a unique aesthetic warmth and charm. Metalwork, particularly in the form of wrought iron, features prominently in entrance doors (Fig. 4), adorning them with decorative nails, knockers, hinges, and locks. The Riad examined in this study consists of two levels (ground floor and one upper floor, R+1). The ground level includes two guest rooms, namely La Mauresque and La Bohémienne, along with two salons and an open central courtyard. The upper floor houses four rooms: Amazigh, Andalusian, Berber, and Nomad. The building also features a rooftop terrace offering panoramic views over the historic Medina and its surrounding minarets. The central patio (Fig. 2a), naturally ventilated and thermally moderated, draws inspiration from oases, Islamic gardens, and Persian courtyard traditions. Typically adorned with shade-providing trees, ornamental plants, and cooling water features such as pools or fountains, the courtyard serves as the focal point of daily life. The adjacent open-air salons and dining areas are oriented toward the patio, allowing occupants to enjoy its natural coolness and tranquil ambiance.

(a) **(b)** **(c)**

Figure 3. (a) The zellige. **(b)** The door of Riad. **(c)** The roof of Riad.



(d) the wrought iron of the door

2.1 Wall composition

To calculate the coefficient of thermal transmission (W/m^{2}K) for each wall of the Riad, an inventory must be conducted of the materials comprising the walls.

Table 1. Composition of walls

Internal wall (U=1.16W/m^{2}K) int ------>ext	External wall (U=1.35W/m^{2}K) U_{ref} (RTCM)≤1.20 W/m^{2}K int ------>ext	External roof (U=0.18W/m^{2}K) U_{ref}(RTCM)≤0.75 W/m^{2}K int ----------->ext	Intermediate floor (U=0.17W/m^{2}K) int ----------->ext
Materials		Materials	Materials
Tadelakt (3cm)	Materials	Wooden beams (13cm)	Wooden beams (13cm)
Adobe (30cm)	Tadelakt (3cm)	Floor Wood (5cm)	Floor Wood (5cm)
Tadelekt (3cm)	Adobe (44cm)	Rock wool (15cm)	Polystyrene EPS (15cm)
	Coating-straw (3cm)	Solid slab (15cm)	Solid slab (15cm)
		Bitumen (1,5 cm)	Slope Shape (5cm)
		Slope Shape (5cm)	Smooth concrete tiles (3cm)
		Zellige (2cm)	

The windows of the Riad are fitted with single glazing, offering a thermal transmittance value of Uw = 5.20 W/m²·K. The glazing-to-wall ratio is approximately 13%, calculated by dividing the total glazed surface area by the total surface area of the external walls in contact with the conditioned indoor environment. Located within Climatic Zone Z1, as defined by the Moroccan Thermal Regulation for Buildings (RTCM) [12], the Riad complies with the recommendation of maintaining a glazing ratio below 15% for buildings with an occupied surface area of 103 m². The thermophysical characteristics of the materials used in the building envelope, along with the corresponding U-values (W/m²·K) for each element, are detailed in Tables 1. A comparison with RTCM benchmark values reveals that the external walls fall short of compliance under the regulation's prescriptive method [12]. To meet the thermal performance standards, an interior insulation solution is proposed: the addition of a 4 cm polystyrene foam layer, which lowers the wall's thermal transmittance to U = 0.53 W/m²·K. The floor structure consists of concrete tiles installed over a concrete slab, designed to ensure both thermal insulation and structural durability. The resulting thermal transmittance of the floor is U = 0.23 W/m²·K. It is important to note that for Zone Z1, the RTCM does not stipulate specific regulatory limits for flooring elements.

3 RESULTS AND DISCUSSIONS

The simulation engine to perform detailed dynamic analyses of a building's thermal behavior and a wide range of environmental performance indicators is conducted using Design Builder software [13]. In this study, the modeled building is a Riad used as a guesthouse, accommodating multiple visitors over extended stays. Additionally, the Riad (see Fig. 4 and Fig. 5) serves as a versatile venue, hosting events such as musical evenings or formal dinners for participants in academic gatherings. An occupancy density of 0.15 persons per square meter was assumed in the simulation settings. To maintain both thermal and hygrometric comfort within the Riad without relying on active heating or cooling systems, several passive design strategies have been explored and proposed as viable solutions.

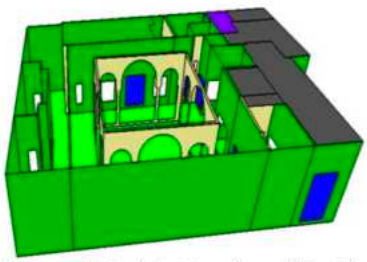


Figure 4. An interior view of the Riad.

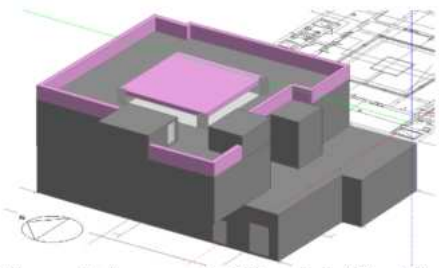


Figure 5. A geometric 3D model of the Riad with a covered patio.

The implemented upgrades have resulted in a more stable indoor temperature profile (Fig. 6), effectively buffering the interior spaces from fluctuations in outdoor climatic conditions. These interventions contribute to enhanced thermal comfort throughout the year. During the winter months, indoor temperatures remain within a comfortable range of 18°C to 21°C, while in the summer, temperatures are maintained between 20°C and 24°C. This consistency underscores the success of the improvements in delivering a thermally regulated and comfortable indoor environment for occupants. However, it should be noted that partially enclosing the patio may reduce natural ventilation, especially when the glazing ratio is low, as illustrated in Fig. 6. This limitation in airflow can result in elevated indoor humidity levels, reaching up to 95% in certain rooms, thereby increasing the risk of condensation on interior walls. To address this issue and preserve healthy indoor air conditions, a mechanical ventilation system was introduced. This system is specifically calibrated to control humidity levels—maintaining them between 50% and 70% and to ensure consistent air renewal. The prescribed air change rate of 0.3 vol/h provides sufficient fresh air exchange, helping to prevent moisture accumulation and supporting both thermal comfort and indoor air quality throughout the Riad.

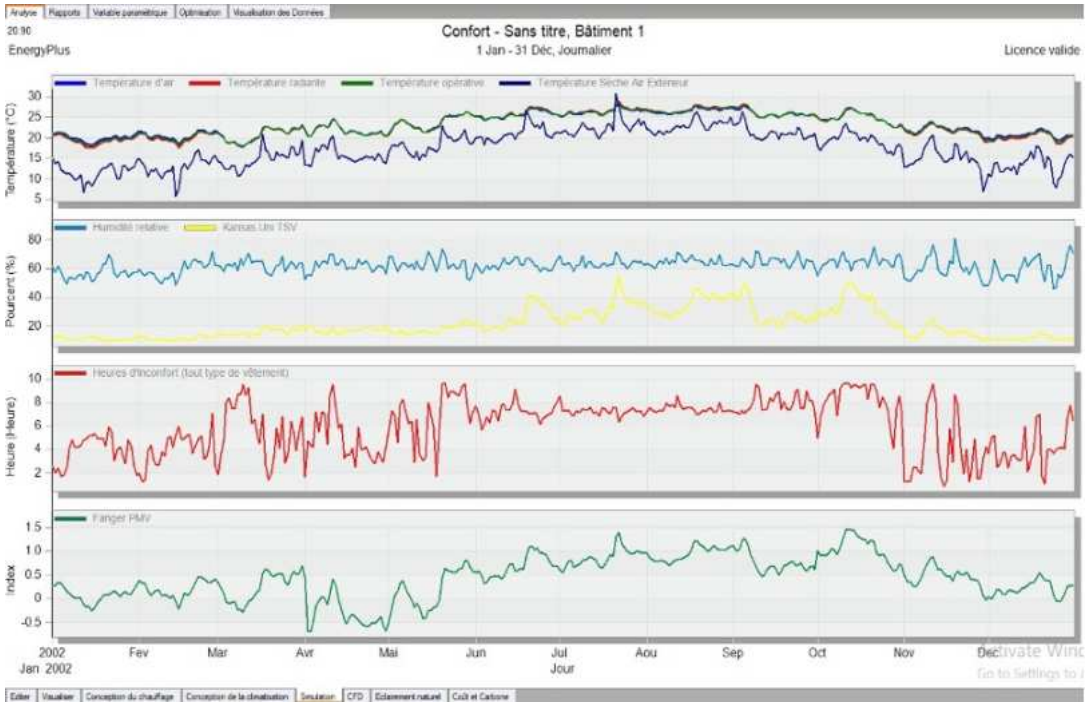


Figure 6. The hourly variation of temperatures and humidities according to the seasons.

The implemented upgrades have resulted in a more stable indoor temperature profile (Fig. 6), effectively buffering the interior spaces from fluctuations in outdoor climatic conditions. These interventions contribute to enhanced thermal comfort throughout the year. During the winter months, indoor temperatures remain within a comfortable range of 18°C to 21°C, while in the summer, temperatures are maintained between 20°C and 24°C. This consistency underscores the success of the improvements in delivering a thermally regulated and comfortable indoor environment for occupants. However, it should be noted that partially enclosing the patio may reduce natural ventilation, especially when the glazing ratio is low, as illustrated in Fig. 6. This limitation in airflow can result in elevated indoor humidity levels, reaching up to 95% in certain rooms, thereby increasing the risk of condensation on interior walls. To address this issue and preserve healthy indoor air conditions, a mechanical ventilation system was introduced. This system is specifically calibrated to control humidity levels—maintaining them between 50% and 70% and to ensure consistent air renewal. The prescribed air change rate of 0.3 vol/h provides sufficient fresh air exchange, helping to prevent moisture accumulation and supporting both thermal comfort and indoor air quality throughout the Riad.

4 CONCLUSION

Through the insulation of the roof terrace and exterior walls, along with the partial shading of the central patio, the Riad has been brought into complance with the thermal performance requirements outlined in Morocco's Zone 1 regulations. These enhancements significantly improve the building's energy efficiency by limiting heat exchange with the outdoor environment and maintaining a stable and comfortable indoor climate. Additionally, the implementation of mechanical ventilation systems and partial patio covering plays a crucial role in regulating temperature and humidity, thereby improving the Riad's overall hygrothermal behavior. The comparison between the baseline configuration and the improved model provides valuable insights into the effectiveness of insulation and ventilation strategies in enhancing the thermal efficiency of traditional Riad structures.

5 ACKNOWLEDGMENTS

We extend our sincere gratitude and deep appreciation to the following individuals, whose invaluable support and contributions have played a pivotal role in the resounding success of our work:
Mr. Emmanuel Muguet: Owner of Riad Al BAHI.
Mr. Mohammed Taibi Mouline: Director of MMT architectures and author of the Riad's refurbishment.

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Photos

The Common Sense of Arid Geographies: Adobe Beehive Building Culture from Harran to Cameroon

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ABSTRACT

In traditional architecture, environmentally compatible building production relies not only on using local materials but also on synthesizing climatic factors, sociocultural needs, and technological skills. Adobe brick, one of the earth-based building materials, has been used for thousands of years as a sustainable building material that responds to local needs in diverse geographies. The adobe dome/beehive building culture, shaped by the collective wisdom of arid regions, has produced similar formal solutions across different geographies but has evolved with regionally specific techniques and details. This study compares the formal and technical features of domed, conical, or vaulted structures constructed with adobe materials developed in different geographies within similar arid or semi-arid climate zones, such as Türkiye, Syria, Iran, Sudan, Chad, Cameroon, and Niger, but specialized in local techniques. The research attempts to reveal common and different aspects by analyzing the structures in terms of their form, construction technique, and relationship to climate using data obtained through a literature review and sample visual document scanning. In this context, the study not only shows how traditional knowledge can be evaluated in terms of contemporary architecture and sustainable building production, but also provides a multidimensional contribution to the history of architecture by presenting common solutions produced by different cultures in similar geographical conditions.

Keywords: Adobe, beehive architecture, traditional building, climate-compatible architecture, sustainable building culture.

1 INTRODUCTION

As one of the oldest and most widespread building materials in architectural history, adobe stands out for its functionality and formal potential. With its ability to be produced with local resources, high thermal mass, low energy requirements, and structure suitable for cyclical use, adobe represents the historical continuity of sustainable building practices. Building production in arid and semi-arid regions has largely evolved into an architectural strategy that seeks to respond to climatic and topographic conditions. In this context, adobe, thanks to its ease of construction, natural climatic capacity, and transformability, has become not only a building material but also a defining generator of architectural form. In particular, forms such as domes, vaults, and conical roof systems have achieved maximum spatial efficiency with minimal material use and served as passive climate stabilization tools. The architectural use of adobe has not been limited to residential scales; it has also assumed a significant place in monumental structures. In the basins of civilizations in the central zone, such as Mesopotamia and Anatolia, adobe architecture can be traced back to the Neolithic period. Settlements such as Ja'de el-Mughara (Syria, 9,000 BC), Jericho (West Bank, 8,000 BC), and Çatalhöyük (Turkey, 7,000 BC) stand out as advanced examples of early adobe architecture [1]. Similarly, domed structures unearthed in Neolithic excavations at Arpachiyah (Mosul), Schulaveri (Georgia), and Cyprus indicate that adobe-based structural systems date back to the 6th millennium

BC [2],[3]. One of this historical continuity's most striking spatial expressions is the conical-domed structures known as "beehives." These structures are found in the Harran and Suruç districts of Şanlıurfa in Turkey, rural Syria, Iran, and countries such as Sudan, Chad, and Cameroon in Africa. Despite geographical distances, the emergence of similar forms and construction techniques proves that local material possibilities, climatic requirements, and social lifestyles determine architectural production.

2 THEORETICAL FRAMEWORK

The theoretical framework of this study aims to understand the multilayered relationships among the fundamental components that determine architectural production: material, climate, form, construction culture, and spatial organization. Traditional architectural forms, particularly those shaped by local and natural building materials such as adobe, offer the most unique examples of contextual architecture that emerge from the interplay of these components. This study used a qualitative approach based on a literature review and visual comparisons. Morphological structure, construction techniques, material properties, and spatial organization were comparatively examined in case studies.

3 HARRAN AND SURUÇ HOUSES (TÜRKİYE)

Domed houses are found in Anatolia. A few villages in and around Suruç, between Urfa and Birecik, and in and around Harran, between Urfa and Akçakale, are also domed. However, unlike these houses, which are covered with adobe domes, Harran dwellings are covered with brick domes.

3.1. Traditional Harran Houses

Harran houses, one of the unique traditional housing typologies of Southeastern Anatolia, are characterized by conical dome roof systems constructed of adobe or fired brick. The Harran settlement, registered as an archaeological and urban site in 1979, has been documented with a holistic conservation approach and defined as a unique representation of the local architectural heritage [4]. The plan layout of these structures is generally shaped by spatial arrangements organized around an inner courtyard, enclosed from the outside. Thick adobe walls provide thermal insulation against the region's hot and arid climate, while small openings provide controlled natural lighting and ventilation. The superstructure system, built on a nearly square rectangular base plan, is transformed into a conical dome with rows of bricks. It is built using an overlapping technique and tapering as it rises. This cover, which requires no structural framework, functions as a self-supporting structural shell. The transition to the dome is achieved through simplified squinch and pendentive elements, known locally as "bingi." These elements establish structural continuity between the vertical supports and the superstructure. These domes, which reach a height of approximately 4.5–5 meters on the interior, are constructed with an average of 30–40 rows of bricks. The need for spatial size and flexibility is met by modularly grouping two or more domes and connecting them with internal arches. This system allows for functional diversity within the residence along with structural continuity. In the construction of the domes, protruding bricks placed at regular intervals on the exterior surface simplify construction and maintenance and allow the opening at the top to be closed off according to weather conditions. This opening also functions as a chimney and skylight, providing smoke extraction and daylight. The structure is built with clay-based mortar, which serves as a binding agent, and then plastered on interior and exterior surfaces. This practice improves the building's thermal performance by reducing the surface's air permeability and also provides limited protection against water (Fig 1).

Figure 1.Harran in the 60s [4]

3.2.Suruç Houses

Beehivet houses, one of the traditional rural housing typologies unique to the Suruç region, stand out with their adobe-based construction systems and climate-responsive roof forms. The adobe mortar used in local construction practices includes soil, water, straw, fine stone fragments, and a certain amount of salt. The resulting plastic-like mixture is poured into wooden molds for various sizes and shapes. Common adobe modules in Suruç examples are rectangular prismatic elements measuring approximately 30 × 50 cm and 10 cm thick. Once shaped in the molds, the raw adobe bricks are exposed to direct sunlight [5]. Approximately 1,500–2,000 adobe bricks are required to construct a single room of a typical dome house. The load-bearing walls are adobe blocks built using the corner-locking method, set on a stone foundation. The average wall height is 3 meters, and the thickness varies between 55 and 60 cm, depending on the adobe module size. Rooms are square in plan, with simple arch systems defining transitions between rooms and entrances opening to the exterior (Fig 2).

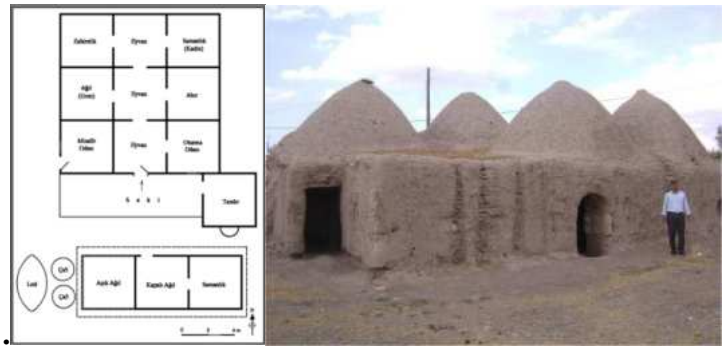

Figure 2. Suruç Beehive House Plan and Facade [6] 899-896

The roof system in tomb houses has evolved around two main roof forms: pointed conical and truncated conical domes. Pointed conical domes are formed by overlapping circular adobe rings that taper toward the center, starting from the top level of the load-bearing walls. The opening left at the top serves as a chimney/skylight, providing natural ventilation and daylight. An approximately 0.5-meter-thick earth fill is applied between the dome surface and the inner cover to increase the structural strength and climatic performance of these domes. These domes reach a height of approximately 1.5–2 meters from the top level of the wall. Blunt conical domes are built using a similar overlapping technique, but the rise ends after 1–1.5 meters, and the upper cover is then provided with wooden poles. A wooden flooring is placed on these poles, followed by agricultural waste such as grain or cotton stalks, and a layer of mud to create a flat roof covering the horizontal plane [6] (Fig. 2).

4. SYRIA (ALEPPO COUNTRYSIDE, HAMA SURROUNDINGS)

Adobe beehive houses, common in northern Syria, particularly in Aleppo, Hama, and surrounding rural settlements, are crafted entirely by hand using a mixture of red clay, animal dung, and straw, the primary building material, according to traditional production methods. This building tradition has been preserved virtually unchanged for many years, particularly in rural villages northeast of Hama, due to the limited construction alternatives and the sustainable nature of adobe production [7], [8], (Fig. 3). Examples observed around Aleppo and Al-Safira generally consist of 4 × 4 m modular units clustered around a central courtyard to form a unified settlement pattern [9]. The load-bearing adobe walls are covered by pointed, conical domes reaching a height of approximately 4 to 5 meters. This covering form is notable for its structural efficiency, which concentrates loads at the center and provides natural air circulation and temperature balance in interior spaces. The interior and exterior surfaces of the walls are plastered with straw-added mud mortar; this practice increases surface strength and creates a breathable interior shell with its porous texture [10], [6]. Thermal performance measurements show that the interior temperature of beehive houses remains constant between 24–30°C even on days when the outdoor temperature reaches 60°C in summer [8], [10], [11]. These findings reveal that the thick adobe walls, thanks to their high heat capacity, function as passive air conditioning and provide thermal comfort for the house without mechanical intervention.

Figure 3. Beehive house village near Blas, south of Aleppo, Syria [9], [12]

5 IRAN (YAZD AND SISTAN-BALUCHESTAN)

In Iran's hot and arid desert regions, particularly Kerman, South Khorasan, and Yazd, the local material adobe is used in various ways, from residential architecture to complex climatic adaptation systems. Conical domed dwellings constructed of adobe in this region, and passive cooling structures such as Yakhchal and wind towers, are unique examples of optimizing thermal comfort through material and form. Yakhchal structures, dating back to 400 BC and meaning "ice pit" in Persian, are sophisticated systems integrated with underground and aboveground components, enabling the preservation of ice and food during the summer months [13]. These structures typically feature a large underground storage area (up to approximately 5,000 m^3) and conical adobe domes reaching approximately 15–20 meters above ground. The lower portions of the dome are shaded, while only the upper portions are exposed to sunlight, allowing the interior to remain cool even in summer. In winter, ice, sourced from the mountains, is transported to and stored in shaded, north-facing sections; in summer, it is distributed to the public through openings in the south. Wall thicknesses begin at approximately 240 cm at the base and taper towards the top, reaching 20 cm, thus balancing load transfer and lightening the structure (Fig 4).

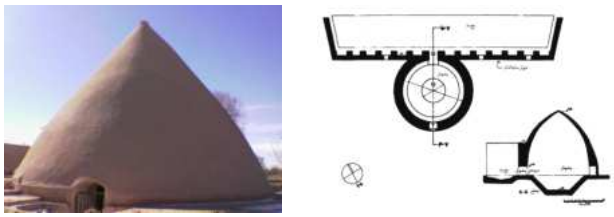

Figure 4. Meibod NimVar Yakhchal [14], [15]

Yakhchal structures also feature badgir (wind tower) systems positioned according to the wind direction. Traditional residential buildings in the Sistan region of eastern Iran offer examples that combine the passive ventilation capacity of adobe with formal design. Prevailing wind directions orient the buildings, have domed ceilings, and inward-facing plans. The southeast orientation of the entrances provides physical protection against dust storms, while narrow, long ventilation shafts opening into the interior spaces direct airflow in a controlled manner. These shafts gently slope to the north to avoid direct exposure to the prevailing winds. This prevents sudden air pressure spikes and ensures continuous, balanced air circulation within the interior [16]. The badgir systems in traditional residential buildings in the city of Yazd, like those in the Yakhchal structures, function as passive air conditioning devices, directing cool air into the spaces (Fig.5).

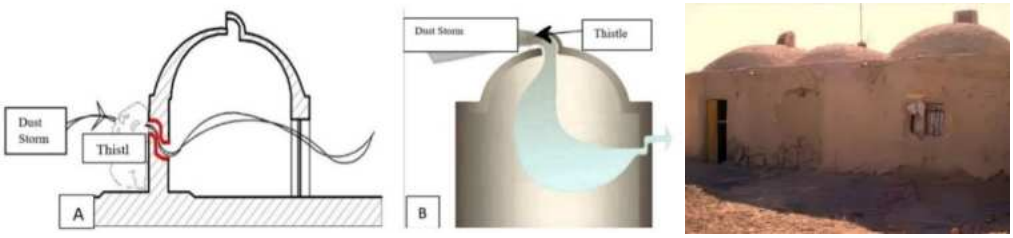

Figure 5. View of the combination of dome roofs and one-way windproof in Sistan [16]

6 SUDAN (NUBIA REGION)

Nubian architecture, which developed along the Nile Valley in northern Sudan, features adobe as a formative element in residential and monumental structures. Its use is in conjunction with vaulted residential structures and the conical qubba structures of Islamic tomb architecture (Fig 6a-6b). The Nubian Vault, a characteristic construction technique of Nubian architecture, is adapted to climatic and environmental conditions, enabling the construction of vaulted roof systems without wooden scaffolding or formwork. In this technique, the vault rising between the walls is constructed by freehand masonry, overlapping each row of adobe bricks at an angle of approximately 5–10° to the previous one. This achieves maximum structural efficiency with minimal resources in both materials and labor. Construction begins from the interior of the building, and the vault is built sloping toward the rear wall. This orientation preserves entrance openings, and the vault's self-supporting nature makes the construction process more flexible and economical. Window and door openings are temporarily closed during construction to reduce potential wall stress.

Figure 6.a. Nubian vaulted structures and details [17], **b**.The Conical 'Qubba' Tombs at Old Dongola [18], [19]

The adobe used in Nubian structures in Sudan is produced from a mixture of mud, sand, and straw from the Nile River. In the Nubian Vault system, the adobe bricks used in vault construction are different sizes from the wall elements. Wall adobe bricks are approximately 20 × 10 × 5 cm and have a more compact form, while vault bricks measure 23–26 × 13–14 × 4 cm. These elements, with their larger surface area, create a stronger adhesion with the mortar, conforming to the vault slope. The striations created by fingerprints on the vault bricks are intentionally applied to increase adhesion to the clay mortar. Organic additives used in adobe—such as chopped straw, threshing residue, coal, bone, and ceramic shards—increase the adobe's tensile strength and prevent shrinkage deformations that may occur during drying.

Conical structures called qubbas, built for "saints and sheikhs" as a reflection of Islamic belief, are quite common in Sudan [17], [18]. In the Old Dongola settlement, qubbas are defined in Islamic architecture as domed tomb monuments. Generally constructed of adobe, these structures create a conical or cylindrical mass effect on the exterior while offering interior spaces covered by complementary domes.

7 CAMEROON (MUSGUM HOUSES)

The buildings built by the Musgum people of northern Cameroon, known as "Tolek," are considered among the most sophisticated examples of adobe architecture, with their hyperbolic conical forms, ribbed façade designs, and organic construction technologies. This form closely resembles the chain arch principle, which is based on the natural curvature of a chain under the influence of gravity. This allows the structure to achieve maximum structural stability with minimal material use. The organic form is optimized for both structural efficiency and thermal comfort. This conical mass, which can reach a height of up to 9 meters, creates a calm and stable interior climate despite significant temperature fluctuations throughout the day. The conical structure of Musgum houses is grouped into modular units connected by vertical walls with flat roofs, creating the residential composition. Each building contains functional units for individual use and spatial organization within the community: different functions, such as housing, kitchen, and animal shelter, are integrated through formal continuity and material unity. Adobe is used as a building material; It is made from a mixture of clay, water, and straw. This mixture is formed by raising it upwards in layers of approximately 50 cm using a spiral technique known as "coil pottery." Each new layer is applied to the previous layer before it dries completely, supporting the material's self-supporting properties. The walls are plastered from the outside, creating a shell structure. The rib patterns applied manually to the surface of the plaster provide both visual richness and structural advantages. These patterns direct rainwater runoff, allowing the wall surface to dry more quickly; they also help control cracking. The indentations and protrusions on the surface also function as natural scaffolding, making it easier for workers to climb during maintenance and repair. The opening at the top provides passive ventilation, enabling air circulation within the interior and improving thermal comfort (Fig. 7).

Figure7.A Musgum Chief's homestead in the 1850s [20]

EVALUATION AND CONCLUSION

Harran beehives offer a modular housing typology. The conical form provides both static efficiency and natural ventilation. Suruç structures exhibit a more hybrid technique compared to Harran. The blunt dome form demonstrates an effort to cover a large area with minimal material. Syrian beehives are notable for their natural air conditioning performance. Simplicity, continuity, and high thermal mass are prominent. The Iranian example encompasses complex systems where adobe is optimized for multiple functions, such as food, water, climate control, and housing. Beehive-like structures in Sudan reflect the high technical know-how of "smart building physics" produced with traditional knowledge. Musgum toleks are unique structures that synthesize traditional knowledge with structural efficiency and biomorphic aesthetics. Accordingly, a typological is presented below (Table 1):

Table 1. Typological Evaluation Table

REGION	FORM	MATERIAL	CONSTRUCTION TECHNİQUE	TOP OPENING	CLIMATIC ADVANTAGE
HARRAN	Conical	Clay + Straw	Masonry, Wood-free	✓	Thermal mass
SURUÇ	Conical /Truncated Conical	Clay + Salt + Straw	Earth fill, Wood	✓	Insulation
SYRIA	Conical	Red Clay + Fertilizer	Masonry, Plain form	✓	30°C internal temperature
IRAN	Conical/Vault	Clay + Gravel	Yakhchal, Badgir		Cooling system
SUDAN	Vault/Conical	Nil mud	Nubian vault, Angular	✓	Shading, Volume
CAMEROON	Hyperbolic	Spiral Adobe	Shellform, coil tech.	✓	High circulation
EFFECT ON THERMAL COMFORT	Diffusion of solar radiation, natural ventilation, radiant cooling	High thermal mass, low thermal conductivity, insulation, rainwater drainage		Natural lighting, discharge of hot air, air circulation	

The "Beehive" architectural form is characterized by symmetrical, conical, or hemispherical masses developed around a central core. Although produced using different techniques in different

geographies, adobe stands out as one of the fundamental elements determining building form and spatial organization. Dome, vault, and conical forms reflect a common knowledge production process, a synthesis of environmental and cultural conditions, and the material's physical limitations. This building culture extends from Harran to Cameroon and is considered a spatial expression of local knowledge, climate adaptation, and sustainability principles. The dome and conical roof forms of beehive structures increase natural lighting, thermal comfort, and passive ventilation. Sunlight entering through the opening at the tip of the dome reflects on the wall surfaces, indirectly illuminating the interior [21]. In addition, this form allows the hot air rising from the base in the interior during the summer to gather at the dome's apex and be discharged from there. This provides a natural airflow. Furthermore, since only one surface of the dome roof is exposed to sunlight, the entire structure is never directly and perpendicularly heated; this reduces the interior temperature, while at night the whole dome cools, increasing radiant cooling [11], [21], [22]. These roofs also prevent water infiltration during rainy periods. Since their shape allows rainwater to drain quickly, they also minimize erosion on the mud plaster surface. In addition, thanks to the high insulation properties of adobe walls, temperature differences in the exterior environment do not directly affect the interior; a calm interior environment is obtained in summer and a warm interior environment in winter [7], [23], [8], [10]. Conical domes are resistant to high pressure in terms of construction method and can be constructed without requiring reinforcement materials or molds; It can be easily manufactured even with unskilled labor [8], does not emit toxic chemicals such as VOCs (volatile organic compounds) or ozone-depleting HCFCs during the construction process, and has a low environmental impact [24]. In this respect, adobe buildings are often considered within the scope of ecological architecture; they stand out with their ability to be produced with local materials, low energy costs, and environmental sensitivity. Thanks to adobe's sustainability, local production capabilities, and environmental compatibility, the potential for reinterpretation of these building systems in contemporary architecture is clear. This chain of architectural knowledge extending from Harran to Musgum is not only a legacy of the past but also a strong source of inspiration for the environmentally friendly building systems of the future.

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The Contribution of the Adobe House to Children's Holistic Development

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ABSTRACT

This paper aims to reveal the impact of educational activities carried out in adobe structures built with natural materials on the holistic development of children. Unlike traditional approaches that focus solely on cognitive skills, holistic development emphasizes the integration of biological (physical), cognitive (mental), and socio-emotional domains. It has been observed that adobe houses contribute to children's sensorial awareness and environmental consciousness due to their natural textures, colors, and indoor climate benefits. Activities such as storytelling, art, kitchen practices, and adobe brick making conducted in the 'Natural Adobe House' at Bahçeşehir Preschool promote creativity, empathy, teamwork, and physical activity. These experiential learning opportunities allow children to grow into balanced and responsible individuals, supporting their lifelong learning journeys.

Keywords: Holistic development, Adobe house, Early childhood, Natural materials, Experiential learning

1 INTRODUCTION

Early childhood is the most important stage of every child's development. The steps it takes at each stage of growth form the basis for progressing towards adulthood. Holistic development in children is a process that encompasses physical, emotional, spiritual, intellectual and creative elements. In contrast to traditional developmental methods, holistic development focuses on establishing a strong bond between mind, body and mental health by supporting the co-nurturing of all dimensions of the child's existence. While these strong bonds increase the quality of life of the individual, they make the world surrounding him, living and inanimate beings, people, animals, plants, natural formations and the cooperation connections between them. It supports children's brain development, strengthens neural connections, increases the capacity to learn and adapt to the environment. When evaluated together with all these formations, we should accept that children are not only learners, but also tiny developing individuals, and each aspect affects other areas of development.

According to UNICEF; Scientific research makes it clear that early childhood determines every shade of color for a person's entire life. "Children's brains are built as they interact with their environment. In the first few years of life, more than a million neural connections are formed every second; This is a pace that will never be repeated again. The quality of a child's early experiences makes a critical difference as their brain develops, providing strong or weak foundations for learning, health, and behavior throughout life." Holistic development is completed by supporting

the basic areas of children's biological development, cognitive development and social-emotional development. Accordingly;

- **Biological development: Biological** development, also known as physical development, is a fundamental aspect of holistic development during early childhood. It involves the growth and improvement of gross motor skills, fine motor skills, hand-eye coordination, and children's overall health and well-being.
- **Cognitive development:** Cognitive development refers to a child's mental processes, such as thinking, problem-solving, and language skills. Also called intellectual development, this encompasses the development of memory, attention, and the ability to understand and communicate ideas.
- **Social-emotional development:** Social-emotional development involves a child's ability to understand and manage their emotions, form relationships, and interact with others. It involves the development of the child's empathy, self-esteem, self-expression, and social skills.

From an early age, children learn to respect, realizing that all life forms are interconnected, that every action has consequences. Children who grow up with this awareness grow up as environmentally friendly individuals by making their decisions thoughtfully. Because young children learn by interacting with the environment, educators and other adults need to contribute to the frequency, nature, and quality of child-environment interactions in the early years. As in all ages, the time spent outdoors in early childhood is also very important for the physical health of the child. As Hearron and Hildebrand (2013) and Bilton (2010) point out, fresh air, sunlight and movement are the main benefits of well-planned outdoor play. Nature is the source of vitamin D through sunlight. Outdoor activities increase fine motor development and the development of eye-hand-foot coordination. For example, it has been determined that statistically significant improvements are obtained in the levels of better coordination, balance and agility of children who play in natural areas in motor sports (Fjortoft, 2001, 2004; Fjortoft and Sageie, 2000). Such activities are extremely important for children of this age because motor skill development is one of the primary and critical developmental tasks of preschoolers (Davies, 1996; Essa, 1992). As stated in the National Association for Sport and Physical Education (NASPE) (2005), it is recommended as preventive treatment to ensure that children spend at least 60 minutes of free time outdoors a day from early childhood, and in addition to this, the time they are inactive does not exceed one hour. The development of basic motor skills in early childhood is important not only for children to move easily and functionally, but also because competence in movement is related to children's social and emotional development (Poest, Williams, Witt, & Atwood, 1990, akt. Davies, 1996; Fjortoft, 2004). As can be seen, outdoor education is a rich environment that supports the holistic development of the child. The Biophilia Hypothesis articulates the deep-rooted need of the human species to relate and connect with other life forms in nature. When this need is not met, "nature deprivation syndrome" emerges with the definition of Louv (2010), which emphasizes the negative impact of alienation from nature on humans. These effects include less use of the senses, attention problems and problematic conditions such as physical-mental illnesses, and increased crime rates. This syndrome can occur in individuals, families, and communities. The solution is the healing effect of nature. Similarly, Woolley and Lowe (2013) state that playing in a natural environment for the child can lead to an increase in motor skills such as confidence, independence, coordination, balance and agility, reduce the effects of stress and reduce the symptoms of Attention Deficit Hyperactivity Disorder (ADHD). For these reasons, time spent outdoors contributes to the all-round development of the child as well as his physical and mental health. For this reason, it is very restrictive to consider activities carried out outdoors and especially in nature separately from educational environments. Outdoor activities should be an integral part of the educational environment.[1]

How do our skills develop in relating and connecting with life forms in nature? We call these skills social skills. Social skills are the general name of attitudes, behaviors and thoughts that affect individuals' ability to behave appropriately in their social environment, to acquire them in society and

to perform their interpersonal communication in a positive way. Social skill acquisition starts from the first years of life and continues throughout life (Samancı and Uçan, 2017). In preschool educational institutions, children should have the opportunity to play together freely without adult intervention. In this way, children learn to make decisions, to cooperate, to appreciate group interaction and to evaluate themselves. Peer groups support children's social skills and help them understand themselves better. Relationships within the group are based on mutual respect and cooperation. Social emotional skills can be taught through a learning-by-doing activity. Therefore, it provides an opportunity for active learning methods. It creates an easier ground as it offers the opportunity to learn by doing outdoor activities and living. The individual can develop his social skills to the extent of the adequacy of the environmental conditions he is in (Baydan, 2010). Nature education is a learning process by doing and living, which takes place primarily by being exposed to those around you. This learning process is experiential. Experiential learning requires the full use of the six senses (sight, hearing, taste, touch, smell, and intuition) and includes three domains of learning (cognitive, affective, and motor). The regular participation of nature activities in preschool education institutions and the opportunity to interact with nature play an important role in terms of both the healthy development of children and their being individuals who love nature and try to embrace and protect nature. Questions such as "what am I, what kind of person am I?", which start from childhood and reach their peak especially in adolescence, have been the research questions of many disciplines such as sociology, psychology, philosophy and behavioral science (Güllü, 2018). In the preschool period, individuals can try to solve the problems they encounter in daily life through steps such as observation, prediction and planning, through the experiences they have gained in their environment and family. These stages can also support the development of children's self-regulation skills. Positive self-perception can be achieved in the individual who acquires self-control and regulation skills in his emotions and behaviors (Tuzcuoğlu et al., 2019). A healthy perception of self or identity is possible with the acceptance of personal characteristics, abilities, competencies and behaviors. One needs to love and approve one's uniqueness (Gul, 2018). In studies conducted abroad, it has been revealed that outdoor nature-based education gives more efficient results compared to formal education models. For example; In his study, Fjortoft (2001) examined how the natural environment in Norway provides a stimulating play environment for kindergarten children and how different features in the landscape allow for play activities. The effect of such outdoor activities on children's motor fitness was tested and it was seen that there was a better improvement in the experimental group than in the reference group. Significant differences were found in balance and coordination abilities. The study showed that there is a possible relationship between multifaceted play in the natural environment and the effect on motor development in children. In a study conducted at Bursa Uludag University Institute of Educational Sciences, located in Bursa, Turkey's province famous for its green forests; (Investigation of the Effect of Nature-Themed Outdoor Activities on Children's Social Skills and Self-Perception in the Preschool Period) In the 2023-2024 academic year, in a study consisting of 15 experimental and 15 control preschool students within the official kindergarten affiliated to the Ministry of National Education in Osmangazi district of Bursa Province, the "Social Skills Development System Rating Scale" was used to determine the social skill levels of children. In a study conducted using the "Demoulin Self-Perception Scale for Children", it was concluded that nature-themed outdoor activities significantly increased children's social skills and self-perception. This actually allows teachers to implement nature-themed activities with children, to enable children to learn by doing, to understand nature, to explore their surroundings without the need for forests or large gardens, even if there are schools with very limited natural areas in the garden, to make children contact with nature and to carry out activities by making the most efficient use of even the small piece of land and concrete areas. It shows that it is possible. At this point, the question of whether we can create a healthy environment for children and healthy learning environments in our school gardens, away from the safety concerns of the teacher, welcomes us. Can sustainable buildings replace concrete-based schools, especially in big cities? In order to find solutions to these questions, we need to know that many diseases such as rheumatism, allergies, skin fungi, cancer, tuberculosis, asthma, fatigue, which adversely affect human health, as well as our global problems, start and develop with the effect of the place where we live. Factors such as material properties of spaces lived in for a long time, heat-humidity balance, and fresh air intake are important for human health. Many industrial building materials have recently been introduced to the

market. The harms of chemicals used in their production or preservation to human health are discussed. Asbestos fibers, radon gas, synthetic resins, solvents, radioactive materials, etc. are among the research topics of "Building Biology". Increasing air pollution, energy scarcity and global warming are leading us towards using renewable, healthy resources. Since ancient times, humanity has used earthen structures as the basic building material for its shelter needs. The earthen structure provides the easiest and most advanced use of the abundant resources in the country, effective energy savings, the most suitable living conditions for the user in the building in all seasons, the highest level of use of solar energy with the easiest methods, and the application of all kinds of equipment required by today's civilization in the building. For this reason, the "earthen structure" has gained the quality of "contemporary building" today. According to Prof. Ruhi Kafesçioğlu and Assoc. Prof. Dr. Erol Gürdal; In order to obtain adobe that is resistant to pressure, has less sensitivity to moisture, does not disperse in water, has smooth surfaces and does not produce dust, adobe with improved gypsum-added qualities by adding cement, lime, gypsum and some other additives to the soil is called "Alker". Research on adobe technology at ITU Faculty of Architecture has been continuing uninterruptedly since 1978. During the basic research phase, the properties of the gypsum adobe building material were completed with TÜBİTAK MAG 505 in 1980. UNESCO ICOMOS ISCEAH Scientific Board Turkey representative Prof. Dr. Bilge Işık's experiments carried out in the laboratory of ITU Faculty of Civil Engineering from 1978 to the present day and the "Earthquake Safety Masonry Construction Technology" obtained and the 1995 TÜBİTAK INTAK TOKI 622 project structure; It was not damaged in the 1999 Istanbul earthquake. The 2000 Urfa GAP Administration earthen lodging building was not affected by the February 6, 2023 earthquake. These results made our teachers, who are concerned about safety and fear of earthquakes, very happy. It is possible to renew with renewable building materials, materials that do not pollute the nature as a result of cheap energy consumption and use, and earthquake-resistant schools. And Akman, who has been conducting international academic and architectural studies on building ecology and biology for 28 years, shared the bioclimatic comparison analysis performed in kindergartens (one adobe, the other briquette) in his abstract published with the code "Building Biology and One Bioclimatic-Diagnostic Examination" in the paper he presented at the international conference Living in Earthen Cities. (Austria, Montafon). In this study, the differences between the health conditions of the children in the two buildings were emphasized: It was measured that the adobe structure (Loam nursery school) provided more favorable conditions in parameters such as air temperature, relative humidity, radioactivity, electric and magnetic fields, and it was stated that the children in the adobe nest had better values in health parameters. According to the results obtained from ITU Maslak Campus kindergartens, children in adobe kindergartens have a more regular and harmonious sleep and dependent play process compared to children in new kindergartens. Indoor temperatures in the adobe nest are 28% healthier than in the new nest. In terms of humidity in the indoor air, the adobe nest has 19% healthier values than the new nest. Among the measurements made in the research, the measurements in which the most striking differences emerge are electrical and magnetic alternating fields. The electrical alternating field densities in the briquette housing are 23 times higher than the adobe housing and 16 times higher than the magnetic alternating field densities. The sleep patterns of children in adobe daycare centers are 92% better than those of children in briquette nests. The adobe nest was built with 36% more qualified materials than the briquette nest.

Its sensitivity to water and moisture, its structure that does not produce dust and dirt, its contribution to the self-development of children in the molding process, its unique observation opportunity for children during drying, and the sparring use of resources in the construction of adobe structures appear as "new green open space learning environments". The fact that adobe structures are made of soil used as a natural main material, that they are breathable structures suitable for all seasons, and that the cold and hot humidity environment and the air can be balanced inside the building provide ideal body temperature for children. It has been observed that children who grow up in such natural building environments develop sensory characteristics and increase their aesthetic perception. The interior wall texture of the adobe building, the visibility of the layers of earth colors, the fact that the floor is covered with wood, and the use of natural stoves in the interior trigger socio-emotional development areas in the holistic development of children. In addition, natural structures contribute to the integration of children with the garden, nature, establishing a strong bond, and their physical well-

being with every step they take. Outdoor activities offer opportunities to run, jump, climb, or generally be active. The basic need of every human being is healthy life norms, our common life cycle (such as birth, growth, development, change, aging) is our common problem for all developmental stages of humanity. For this reason, as And Akman stated, we have to share the responsibilities brought by the concept of "structure" together.
As Bahçeşehir Kindergarten, in November 2022, in line with the nature-based sustainable life philosophy, we brought the "Natural Adobe House" structure to the garden of our school under the leadership of our esteemed ITU Adobe Structures Specialist Prof. Dr. Bilge Işık. As a result of the activities carried out in this adobe structure; We have observed that our children's stress and anxiety levels are reduced in the presence of nature, and their mental health is strengthened as they are offered a quiet place to express their feelings and thoughts. In this natural space, we contribute to children's lifelong knowledge, experience, and becoming balanced and responsible adults. In order to support the full-fledged and all-round development of children, we carry out many activities in the "Natural Adobe House" and in our natural garden area that surrounds it.

2 STORY TIME IN THE ADOBE HOUSE

Reading and telling stories is much more than having a pleasant time. It may seem simple, but it encourages many areas of development. Their listening skills improve, their language is enriched by learning new words, their imagination expands. Q&A about the story helps them think, supports their cognitive literacy skills as well as their emotional and social development.

3 CRAFTS AT ADOBE HOME- MATHEMATICS

Art is one of the other examples that support holistic development. While creating their masterpieces, children also develop their fine motor skills, express their creativity and emotions, and learn about different materials and concepts. In addition, it offers the opportunity to develop cognitive development, creativity and aesthetic perceptions such as problem solving by trying different methods on how to create different designs in the texture, color, shapes, sizes of different materials used. It involves using everything from arts to science, literacy, and numeracy and blending them to create a comprehensive, well-rounded learning experience.

4 ADOBE HOME KITCHEN ACTIVITIES

In this atmosphere that burns with wood fire and makes crunchy sounds, the children carried out traditional cooking methods of our culture, the concepts of hot and cold, measuring instruments, group work and collaborative studies on a stove. We used to develop life skills with our activities such as making winter tea, cooking chestnuts on hot fire, cooking potatoes on embers, boiling magic eggs, and drying spices.

5 ADOBE HOUSE BRICK CONSTRUCTION

By applying natural construction methods by using natural accessible materials (soil, gypsum lime, etc.), our children gained new hand skills and different experiences. They learned the importance of acting together, effective use of time and patience. Within the scope of permaculture training, children experienced how a structure is built with garden equipment that can be used in the construction of houses, which are basic life needs. Children's social development areas were supported with the most important achievements of the 21st century such as teamwork, sharing, waiting in line and communication. Living in touch with nature, natural learning environments, the use of natural materials and the nature-based education model, which is the last link of this component, have shown us educators the versatility and practicality of a holistic approach by including the subject of Natural Structures and where children are a part of sustainable life.

The following photos show the experience of the students at our kindergarten.

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Experimental Study on Material Characterization for Stabilized Rammed Earth Structures

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ABSTRACT

Alker is a composite building material produced by mixing local soil, gypsum, and lime in specific proportions. These ratios are determined through laboratory experiments and field trials. Recognized as a healthy, sustainable, economical, and environmentally friendly material, Alker has gained increasing attention in contemporary construction practices. The findings aim to answer the research question: What proportions of gypsum, lime, or cement, when mixed with local soil, yield the most structurally durable building block? In addition to Alker, cement-stabilized mixtures were also examined as part of the experimental setup. Earthen materials offer cost-effective and rapid solutions to housing needs. They provide high levels of thermal comfort, require minimal production costs, and are the only materials that do not necessitate the establishment of manufacturing facilities. Alker, specifically, is a type of stabilized earthen construction material that incorporates 10% to 20% gypsum and lime into suitable soil. Compared to traditional unfired adobe, its physical and mechanical properties are significantly enhanced to meet the demands of structural applications. Based on this understanding, the study seeks to determine the ideal Alker formulation for achieving optimal structural strength. This research builds upon previous studies by modifying mixture ratios and material compositions and by evaluating the compressive strength of experimentally produced earthen blocks under controlled laboratory conditions. The mechanical performance of each block is assessed on the 7th, 14th, and 28th days using standardized compressive strength tests. This study is supported by the TÜBİTAK 2209 project with the code 1919B012332760.

Keywords: Alker, Stabilized Earth Block, Material Characterization, Compressive Strength, Experimental Study

1 INTRODUCTION

Earth has been used as a building material for thousands of years. In addition to its use in vernacular architecture, notable examples such as the Great Wall of China and the Arslantepe Mound (Malatya) demonstrate the diversity of construction techniques, scales, and functions. Examples include sun-dried adobe blocks, 'cob' buildings made from unbound earth mixtures, and applications such as rammed earth and compressed earth blocks [1]. Earth-based construction materials are regaining importance due to their sustainability, use of local materials, and economic advantages. Beyond traditional techniques like adobe and cob, contemporary approaches involve stabilization by adding various binders (e.g., gypsum, lime, cement, ash, bio-materials, industrial waste) or physical treatments (e.g., compaction, firing) to enhance strength. In cement stabilization, hydration products formed by the interaction of cement and water solidify the soil [2,3], and this is often preferred for high-strength structures.
The term *Alker*, introduced by Prof. Dr. Ruhi Kafesçioğlu, refers to the stabilization of earth using gypsum and lime [4-7]. Alker is composed of soil, gypsum, and lime in specific proportions. Even

soils from nearby locations may vary in content and performance, making laboratory and field testing essential for determining optimal binder ratios. Alker is considered a healthy, sustainable, affordable, and eco-friendly material [8]. In terms of seismic resistance, Prof. Dr. Bilge Işık has developed the horizontal flexibility method and implemented it in various applications [8-11]. One such application is the second prototype structure built in 1995 on the ITU Ayazağa Campus (TÜBİTAK İNTAG TOKİ 662) [10].

Alker's potential lies in its low carbon footprint, recyclability, thermal insulation, moisture regulation, and cost-effective accessibility. Literature suggests that increasing the cement ratio enhances compressive strength, achieving up to 25–30 MPa when optimized water-cement ratios and reduced porosity are maintained [12]. Gypsum-lime stabilization can reach 8–12 MPa within 7–14 days due to rapid setting and microcrack filling, with lime carbonation providing additional strength over time [13,14]. Therefore, diversified and in-depth research on Alker's material behavior and construction potential is required. This study explores the structural strength enhancement of soil through optimal combinations of gypsum, lime, and cement. Its novelty lies in determining the ideal mixing ratios using soil sourced from the back garden of ITU Faculty of Architecture, Taşkışla Campus located in Istanbul, Türkiye. The findings offer critical insights into the research question: "What proportions of gypsum, lime, or cement added to local soil yield the most structurally durable earth block?"

2 MATERIALS AND METHODS

Before commencing the experiments, literature reviews and expert consultations were conducted. The project site was selected as the ITU Faculty of Architecture Taşkışla Campus. Experimental sets were prepared by varying the proportions of soil with gypsum, cement, and lime. Compressive strength tests were performed at ITU Civil Engineering Faculty's construction materials laboratory. The test set included blocks made by mixing soil with 10–20% gypsum to form Alker [4]. The first sample included only raw soil. The rest were created by volumetrically mixing soil with binders into 10x10x10 cm blocks using the following combinations:

- 100 units of soil,
- 100 soil + 5 cement,
- 100 soil + 10 cement,
- 100 soil + 15 cement,
- 100 soil + 10 gypsum + 10 lime,
- 100 soil + 10 gypsum + 5 lime,
- 100 soil + 5 gypsum + 10 lime,
- 100 soil + 15 gypsum + 5 lime,
- 100 soil + 5 gypsum + 15 lime.

Figure 1 illustrates the procedural steps in preparing these mixtures in a simulated site environment using tools such as shovels and buckets. Samples were tested for compressive strength after 7, 14, and 28 days. The results were analyzed and compared to the literature.

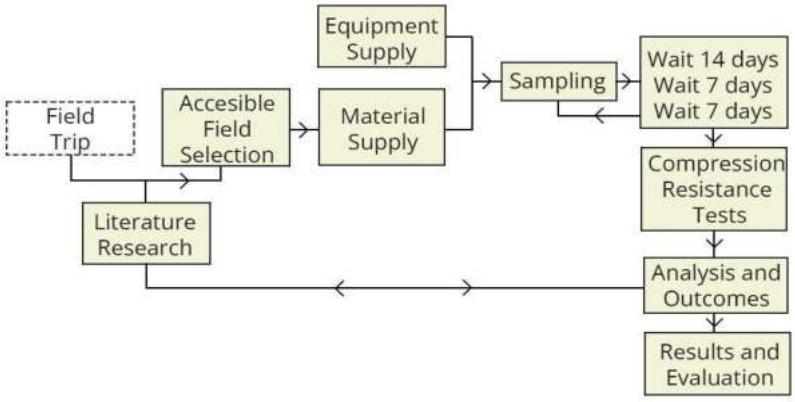

Figure 1. Workflow of the Experimental Procedure.

The mixture ratios of the samples were designed with consideration of Alker's field and on-site construction applications.While mass-based dosage is often preferred in laboratory studies for accuracy and reproducibility, this study deliberately adopted a volumetric approach. The rationale was to reflect construction site practices, where scales are not always available and materials are typically measured with shovels or buckets. Although volumetric mixing may involve a higher margin of variability compared to mass-based dosing, it remains critical for bridging laboratory findings with field applications. Especially in low-resource or rural contexts, this approach allows experimental results to be directly transferable and practically relevant [15,16]. The mixtures were prepared volumetrically using a ladle. First, the dry materials were thoroughly mixed until homogeneous and then water was added gradually until the desired moisture content was achieved. The amount of water added was kept similar across all samples and was kept constant throughout the experiment. This is because the strength of rammed earth depends not only on mechanical compaction but also on water content and the resulting matric suction [17]. The mortar was manually mixed and placed into molds in 4–5 layers and compacted with a tamper at each stage. After compaction, the samples were left in the molds for a specific period. The mixture proportions of the nine samples produced are listed in Table 1.

Table 1. Mixture Ratios

Mixture Code	*Composition (Units based on volume)*
M1	100 soil
M2	100 soil + 5 cement
M3	100 soil + 10 cement
M4	100 soil + 15 cement
M5	100 soil + 10 gypsum + 10 lime
M6	100 soil + 10 gypsum + 5 lime
M7	100 soil + 5 gypsum + 10 lime
M8	100 soil + 15 gypsum + 5 lime
M9	100 soil + 5 gypsum + 15 lime

3 EXPERIMENTAL STUDY

The mixture ratios, derived from both field practices and the literature, were recreated in a laboratory environment using soil obtained from the garden of ITU Taşkışla Campus. The soil used in this study was formed through the long-term weathering of greywacke and clayey schists under the effects of air and water [4]. Primary materials such as cement, gypsum, lime, and soil, along with essential equipment including metal molds, tampers, and ladles, were sourced from a local construction

materials supplier. Once the procurement of materials and tools was completed, the sample production phase began.

Sample Code	Mixture	Duration	Image
M1.D28	100 Units of Earth	*28 Days*	
M2.D28	100 Units of Earth + 5 Units of Cement	*28 Days*	
M3.D28	100 Units of Earth + 10 Units of Cement	*28 Days*	
M4.D28	100 Units of Earth + 15 Units of Cement	*28 Days*	
M5.D28	100 Units of Earth + 10 Units of Gypsum + 5 Units of Lime	*28 Days*	
M6.D28	100 Units of Earth + 15 Units of Gypsum + 5 Units of Lime	*28 Days*	
M7.D28	100 Units of Earth + 5 Units of Gypsum + 10 Units of Lime	*28 Days*	
M8.D28	100 Units of Earth + 10 Units of Gypsum + 10 Units of Lime	*28 Days*	
M9.D28	100 Units of Earth + 5 Units of Gypsum + 15 Units of Lime	*28 Days*	

Figure 2. Cast of the sample set produced and cured for 28 days.

In accordance with the experimental setup, a total of 27 samples were planned, consisting of 3 groups with 9 samples in each group. These groups were categorized according to their curing durations as 7 days, 14 days, and 28 days, to observe the differences in setting times (Figure 2). The samples were prepared using 10x10x10 cm clamped metal molds available in the laboratory.

Figure 3-4. Behavior of the samples under compressive load during testing.

The tests were conducted based on the maximum force (in Newtons) that could be sustained per square centimeter. Accordingly, the maximum force each tested sample could withstand was divided by its surface area, and this value was used as the basis for comparison (Figure 7).

Figure 5-6. Compressive strength testing machine (MTS Criterion).

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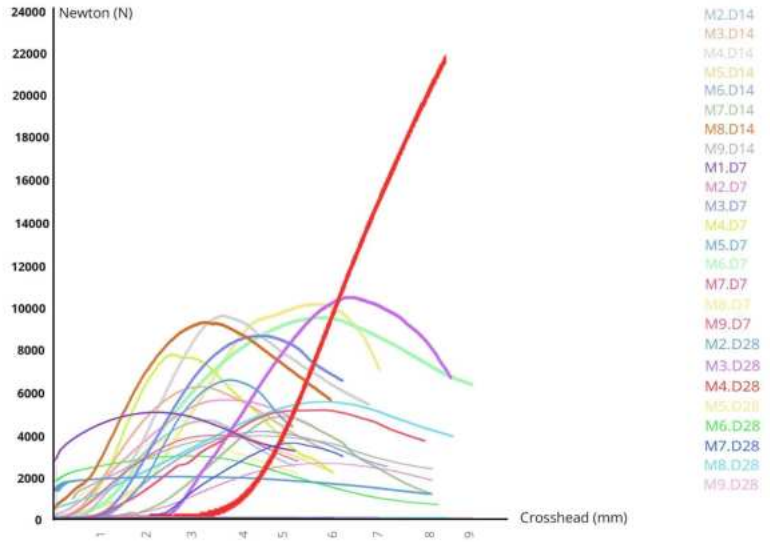

Figure 7. Graphs showing the Newton values of the tested samples.

4 FINDINGS AND OUTCOMES

In this study, the compressive strength of soil-based mixtures containing different additives was systematically examined in a laboratory environment after specific curing periods. All samples used in the experiments were prepared under appropriate physical conditions, and once the necessary equipment (such as paper, pen, ruler, and camera) was provided, they were subjected to standard compressive strength testing using the MTS Criterion Model 43 machine(Figure5-6). Based on the collected data, the maximum load-bearing capacity of each sample, the surface area exposed to compression and the ratio between these two parameters were calculated and analyzed in tabular form.

Among the samples cured for 28 days, the highest values in terms of structural strength were observed. The M4.D28 sample exhibited the highest compressive strength across all sets, reaching 315.25 N/cm². The fact that this sample consisted of only 100 units of soil and 15 units of cement clearly demonstrates the positive effect of cement on long-term strength.

Sample Code	Newton (N)	Kilogram(Kg)	Area(cm²)	MPa
M1.D28	X	X	X	**X**
M2.D28	2.023,45	206,29	74,88	**0,269**
M3.D28	10.111,91	1031,04	69,68	**1,45**
M4.D28	22.244,08	2268,26	70,56	**3,151**
M5.D28	9.082,54	926,11	66,95	**1,356**
M6.D28	3.030,09	308,97	69,68	**0,434**
M7.D28	3.021,25	308,06	58,88	**0,512**
M8.D28	5.604,40	571,45	80	**0,7**
M9.D28	5.551,10	566,04	80	**0,693**

Figure 8. Visual representation of the compressive strength test results for samples cured for 28 days.

When compared with values reported in recent studies, the compressive strength results obtained in this research are relatively lower. Cement-stabilized rammed earth mixtures have been shown to reach 25–30 MPa under optimized laboratory conditions [12], whereas gypsum–lime stabilization typically achieves 8–12 MPa within 7–14 days [13,14]. The maximum value recorded in this study, 315.25 N/cm² for the M4.D28 sample, confirms the positive contribution of cement while also indicating the need for further optimization. These findings underline the influence of soil characteristics, curing conditions, and mixture ratios on performance.

In addition to the numerical comparisons, differences were observed between cement-stabilized and gypsum–lime formulations. Cement-based samples exhibited a steady increase in strength, reaching their highest values at 28 days. Gypsum–lime mixtures, by contrast, set faster and achieved higher early strength, consistent with reports that gypsum accelerates hardening and lime contributes to carbonation strength [13,14]. Although their ultimate values were lower, the rapid early strength of gypsum–lime mixtures can be advantageous for construction processes requiring early load-bearing capacity.

Figure 9. Sample exhibiting an X-shaped fracture pattern.

During the testing process, not only the strength values but also the fracture patterns of the samples were analyzed. The majority of the samples exhibited a characteristic "X"-shaped fracture, resembling an hourglass form. This pattern indicates that the load was distributed uniformly, suggesting that the measurements obtained are reliable.

5 CONCLUSION AND DISCUSSION

This study presents important findings on the optimization of stabilized earth systems based on the specific properties of local soils. It offers a comparative evaluation of two stabilization methods: Alker and cement-stabilized earth blocks. The samples produced were tested after different curing durations to assess their compressive strength.

In prior research at ITU, Prof. Ruhi Kafesçioğlu and colleagues investigated the use of gypsum-lime stabilization (Alker) on soil from the ITU campus [4]. However, those studies did not include comparative testing under identical laboratory conditions. To our knowledge, no earlier work has directly compared both Alker and cement-stabilized mixtures using the same soil in a single experimental framework. Furthermore, this study emphasizes volumetric dosage, aligning more closely with on-site construction practices. This dual methodological and comparative perspective constitutes the main scientific contribution of the present work.

The results revealed that cement-stabilized mixtures, particularly the M4.D28 sample containing 15 units cement, achieved the highest structural performance after a 28-day curing period. This confirms the anticipated outcome, supported by previous research, that cement enhances structural strength over time. In clay samples stabilized with cement, the extension of the curing period generally leads to higher unconfined compressive strength, regardless of the cement ratio. However, in some cases, the expected increase was not observed, which may be explained by micro-scale deformations during testing that were not accurately captured by the testing device, negatively affecting the results. In real world applications, the performance of stabilized earth blocks is highly dependent on environmental exposure. Cement stabilized mixtures show greater resistance to moisture and climatic fluctuations, as noted in recent studies [16]. Gypsum–lime blocks, while eco friendly and economical, are more vulnerable in humid conditions due to gypsum's solubility. Therefore, protective measures such as plaster coatings, roof overhangs, or hydrophobic treatments, commonly recommended in the literature [14], are essential to ensure their durability in diverse climates.

Although this study is limited to Istanbul soil, it also provides methodological insights for wider use. Soil variability requires caution, yet the combined steps of characterization, pilot testing, and climatic validation form a practical pathway for implementation [12]. Such an approach facilitates adaptation across regions and underscores the need for standardized protocols.

Given the complex structure and moisture sensitivity of earthen materials, most existing construction standards are based on tests developed for concrete, which do not fully reflect the nature of earth-based materials. Recognizing this gap, a technical committee was established by RILEM in 2016 to develop more suitable testing protocols. The experimental findings of this study are expected to contribute to the further development and standardization of Alker, a material originally introduced by Prof. Dr. Ruhi Kafesçioğlu and his team under the leadership of Istanbul Technical University. This contribution may enhance the material's visibility and encourage its wider use in international construction practices.

These findings suggest that earth-based construction materials like Alker can be considered not only for their sustainability, accessibility, and cost-effectiveness, but also for their structural viability when the right combination of additives and curing practices is applied. The results indicate that Alker has strong potential for broader application in the construction sector, particularly in contexts aiming for local production and reduced carbon footprint. When appropriately enriched with additives, Alker can be confidently integrated into modern building systems.

6 ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Faculty of Architecture at Istanbul Technical University for providing access to the project site and supporting the preliminary phases of this study. Special appreciation is extended to the Construction Materials Laboratory of the Faculty of Civil Engineering at Istanbul Technical University for granting access to testing

equipment and providing technical support throughout the compressive strength testing process. This research was supported by the TÜBİTAK 2209-A Research Project Support Program for Undergraduate Students under project number 1919B012332760. The authors also wish to thank Maleyka Minasazlı and Sena Arsevenoğlu for their dedicated contributions to the experimental process, including material preparation, mixing, molding, and testing. Additionally, the authors are deeply grateful to retired faculty member Prof. Dr. Bilge Işık for generously sharing her theoretical insights and longstanding expertise, which greatly enriched the conceptual foundation of this study.

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Parametric Variations of the Cobogó: Designing Non-Standard Compressed Earth Blocks

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ABSTRACT

Cobogó is a perforated architectural element developed in Brazil in the 1920s, traditionally used as a partition or wall system in both interior and exterior spaces. Typically made from ceramic or concrete, Cobogó blocks provide environmental and spatial advantages such as daylight modulation, natural ventilation, and the creation of semi-transparent boundaries that balance openness with privacy. However, Cobogós are generally non-load-bearing, serving primarily as architectural screens. In response to sustainability challenges, this study explores the use of Compressed Earth Blocks (CEBs) as a low-carbon, affordable, and environmentally responsible alternative to conventional concrete Cobogós. CEBs reduce embodied energy, rely on locally available materials, and improve indoor thermal comfort. By integrating digital design and fabrication techniques, such as 3D-printed molds, the production of non-standard Cobogó units becomes possible, offering formal diversity while maintaining efficiency. The research employs parametric design tools, specifically Rhino and Grasshopper, to create unique block geometries. These designs are transformed into custom molds through additive manufacturing. The workflow includes four main steps: (1) parametric design of void patterns; (2) 3D printing of custom molds; (3) casting CEBs with stabilized earth mixtures; and (4) digitally generating and physically initiating prototype walls by assembling heterogeneous blocks. This project reinterprets a traditional architectural element through contemporary digital methods, proposing a sustainable and resilient construction approach that blends vernacular wisdom with innovation. The resulting blocks and wall assemblies are evaluated both digitally—focusing on visual porosity and shading—and physically, assessing geometric accuracy and material performance.

Keywords: Cobogó, Compressed Earth Blocks (CEBs), 3D-printed formwork, Sustainability, Permeability

1 INTRODUCTION

Compressed Earth Blocks (CEBs) are increasingly recognized as sustainable alternatives to conventional building materials. CEBs offer significant reductions in embodied energy and carbon emissions, utilize local resources, and can achieve mechanical and thermal properties suitable for a range of construction applications. They require much less energy to produce than fired bricks or concrete, resulting in lower greenhouse gas emissions and reduced environmental impact [1-3]. These blocks are often made from locally available soils and can incorporate waste materials (e.g., rice husk ash, construction waste, bottom ash), reducing transportation emissions and promoting

resource efficiency [2, 4-6]. As such, compressed earth blocks embody a convergence of ecological thinking and material intelligence in contemporary architecture.
In this context, traditional architectural elements that offer both environmental responsiveness and cultural value are being reconsidered for reinterpretation through sustainable materials. One such element is the Cobogó, a perforated block system originally developed in Brazil in the 1920s [7]. Traditionally made of ceramic, concrete, or glass [7], Cobogós serve as non-load-bearing screens that enhance natural ventilation, modulate daylight, and provide privacy while maintaining visual openness. Parallel to the resurgence of interest in earth-based materials, this study proposes to reconsider the Cobogó as a sustainable architectural element by reimagining it in the form of Compressed Earth Blocks (CEBs). Accordingly, this study aims to bridge vernacular design principles with low-carbon material systems.
The study positions the Cobogó not only as an aesthetic and traditional architectural element but also as a generative design approach in which each unit can be differentiated to produce formal variations. This approach makes it possible to generate context-sensitive outputs responsive to changing environmental conditions. In addition to the rule-based model that defines the geometric relationships of each unit, the study also includes the fabrication process of customized molds using 3D printing technologies. Within this experimental framework, the Cobogó becomes a design component that brings together digital modeling and sustainable material practices, enabling formal and performative explorations in architectural applications.

2 BACKGROUND

Historical precedents for rule-based ornamental systems can be found in a variety of cultural and artistic contexts, where geometry and repetition were employed to generate visually rich and structurally coherent patterns. From the complex tiling systems of the Alhambra [8] to the recursive logic in Escher's graphic works [9], such examples demonstrate how rule-driven composition has long been used to explore form, variation, and spatial continuity. In this background, related studies can be grouped under three complementary axes. The first focuses on two-dimensional pattern generation through mathematical or geometric rules, often involving tiling strategies, symmetry operations, or morphogenetic systems as seen in historical surfaces or formal analyses of prototiles [8-11]. The second involves three-dimensional form studies, where such pattern logic is extended into volumetric architectural elements and structural components. The third axis addresses material and fabrication aspects, particularly the use of non-standard geometries and how digital or hybrid production techniques engage with historical principles of modularity and transformation.

Blanco and Harris [8] demonstrate that all seventeen wallpaper symmetry groups are represented in the Alhambra, highlighting the mathematical precision and compositional logic embedded in Islamic ornamentation. Castera [10] investigates five-fold geometric systems in Persian architecture, introducing morphogenetic strategies that explain how simple prototiles transform into complex and coherent surface patterns through local rules. Bonner [12] identifies recursive strategies in Islamic pattern-making that resonate with the logics of parametric design, offering a formal grammar for the generation of self-similar configurations. These studies collectively inform the computational reinterpretation of the Cobogó, which is approached in this research not only as a performative screen but as a generative design element responsive to both environmental inputs and formal rules.

Rule-based design approaches and computational methods enable the generation and analysis of generative form variations with a limited number of parameters [13]. In *Porocity – Opening Up Solidity* (2018), the concept of porosity is explored at the urban scale, with parametric investigations examining how variations in density and void ratios affect spatial quality and public space usage. The study demonstrates how rule-based systems, and in particular a hybrid computational method incorporating cellular automata, can be applied to design permeability at both urban and architectural scales [14]. In another example, a digital framework based on local brick masonry traditions has been developed, employing a shape grammar to generate parametric models evaluated through performance simulations [15]. These evaluations optimize criteria such as daylight utilization, cooling loads, and permeability, resulting in wall systems that are physically producible and environmentally and structurally coherent [15].

The digital design and fabrication of freeform structures has been widely explored in relation to the use of non-standard geometries and the ways digital or hybrid production techniques can engage with historical principles of modularity and transformation. In this context, the Cobogó has been examined as a culturally rooted modular screen element whose geometric logic can be extended through advanced fabrication methods to enable innovative material–form integrations that retain environmental responsiveness while expanding formal adaptability beyond conventional limits [7]. While in Natividade's [7] study such elements are produced in concrete, the present research reinterprets these principles through the use of compressed earth blocks, advancing a resilient, low-carbon construction approach that integrates functional, environmental, and cultural values for contemporary built environments.Related research on digitally fabricated form liners for rammed earth modules has demonstrated how CNC milling and 3D printing can be employed to generate variable textures and performative surfaces, integrating digital workflows with traditional earthen construction to achieve customization, environmental performance, and material innovation [16].

3 CASE STUDY

3.1 Aim and Scope

This case study aims to explore the integration of rule-based geometric design with sustainable material production by reinterpreting the Cobogó as a compressed earth block. The focus is on developing modular, adaptable, and environmentally responsive units through a combination of parametric design and additive manufacturing.

3.2 Form

Form investigation was conducted in Rhinoceros 3D 7. A 5×5 unit matrix (each unit measuring 10 cm × 10 cm) was used as the base grid for generating a single block module. Filled and empty cells were assigned along the edges according to predetermined fill ratios ranging between 2/5 and 4/5, ensuring both structural stability and visual variation. Four final block variations were selected from the generated set, then extruded and scaled to fit the grid dimensions for mold fabrication. An example of these variations applied to a single piece is shown in Figure 1. The design process was guided by a geometric rule requiring each block to have at least two matching faces, enabling seamless modular connections and multiple composition possibilities (Figure 2).

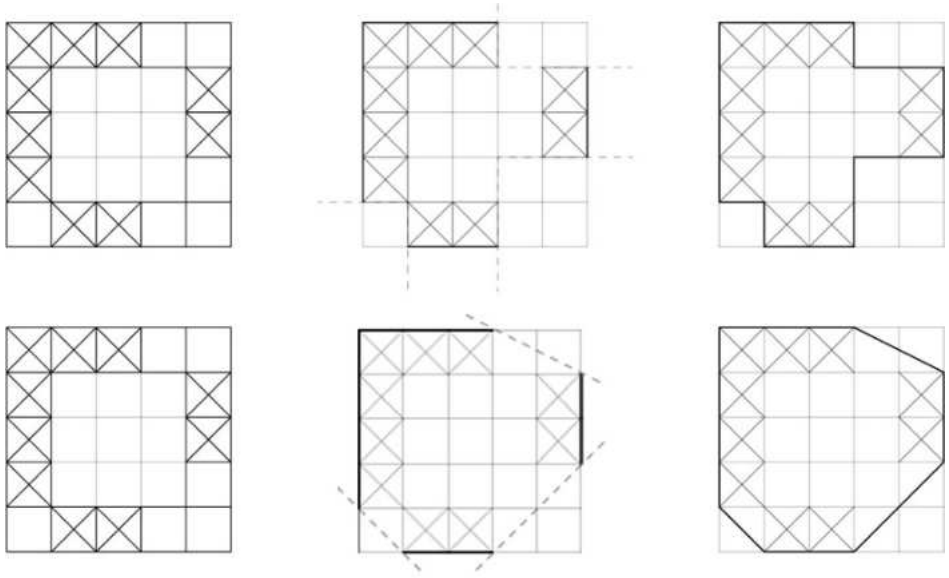

Figure 1. Block variations generated from the 5×5 grid matrix

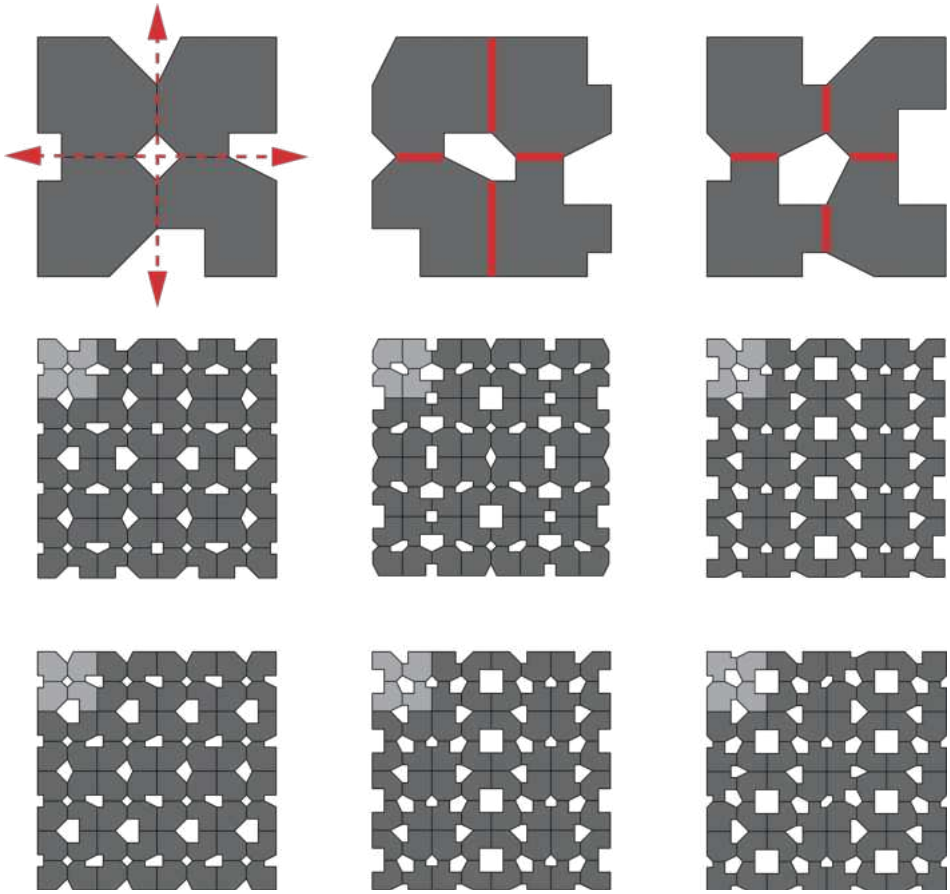

Figure 2. Selected block variations demonstrating matching faces for seamless assembly

3.3 Mold

Following the finalization of the digital models, individual mold geometries were exported from Rhinoceros 3D 7 in *.stl format and prepared for additive manufacturing in Bambu Lab Studio, where G-code was generated. Each mold was fabricated with a Bambu Lab A1 3D printer at a layer resolution of 200 µm (0.2 mm). The molds were dimensioned to accommodate the complex, non-standard block geometries and configured for repeated use in the subsequent casting process.

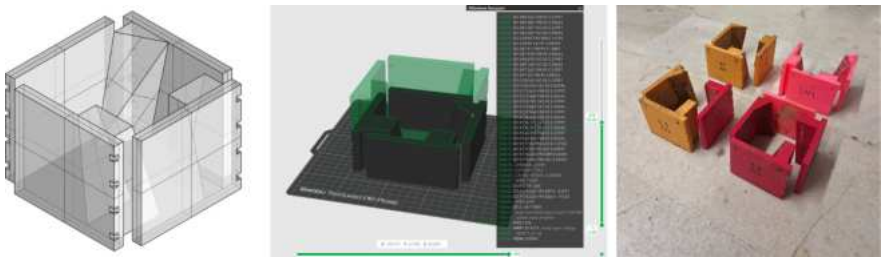

Figure 3. Digital modeling and additive manufacturing workflow for custom Cobogó molds.

3.4 Material

For the prototyping phase, a stabilized earthen mixture was prepared using 100 units soil and 15 units cement by weight, a proportion consistent with ranges recommended in the literature for enhancing the compressive strength of compressed stabilized earth blocks [17]. The mixture ratios, derived from both field practices and the literature, were recreated in a laboratory

environment using soil obtained from the garden of ITU Taşkışla Campus. The soil used in this study was formed through the long-term weathering of greywacke and clayey schists under the

effects of air and water. The mixture was manually pressed into the 3D-printed molds to ensure compaction. Approximately five minutes after pressing, the blocks were removed from the molds and left to dry under ambient conditions.

Figure 4. Compaction of stabilized earth mixture into 3D-printed molds and demolding process

4 FINDINGS AND OUTCOMES

The iterative design–fabrication process enabled the refinement of the initial parametric rule set through feedback from physical prototyping. Beyond the original constraints, additional rules were introduced to address assembly precision, material behavior, and joint alignment during construction. Variations generated within this expanded rule set included adjustments to edge boundary conditions, a selection of which is illustrated in Figure 5.

Figure 5. Edge boundary transformations from base sample to variants.

In Figure 5, Columns 1–3 depict the stepwise modification of edge boundaries: Column 1 presents the base sample, Column 2 applies the initial boundary adjustment, and Column 3 shows a further refinement before generating the variants illustrated in Column 4.

Following mold fabrication and the production of compressed earth blocks (CEBs), the digital model was updated to incorporate measured deviations and assembly observations from the physical prototypes. This ensured that design variations could be fully compatible with material-specific limitations and practical construction needs. The updated model informed the proposal of new rules, reinforcing the adaptability of the Cobogó typology for low-carbon earthen construction.

When assigning filled and empty cells along edges, the maximum fill ratio was limited to 4/5 to prevent configurations with two fully filled corners, which would disrupt the sequence of the generative rules. Allowable edge fill ratios between 2/5 and 4/5 ensured that, when four units were assembled around a central corner, filled and empty cells aligned consistently with their counterparts on adjacent blocks.

Three variations produced under these constraints were extruded directly from their surfaces. To facilitate soil compaction, they were produced at double the original size, maintaining compatibility with a 10 × 10 cm grid. To assess the performance of these modules, three parametric experiments were conducted to evaluate light transmittance, using two representative pieces as base geometries:

1. **Sample 1** – The bottom surfaces of the two selected pieces were rotated 90° counterclockwise, then reassembled into a module based on the top surfaces (Figure 6a).
2. **Sample 2** – The same base pieces were rotated 180°, and the module was reconstructed accordingly (Figure 6b).
3. **Sample 3** – The top surface of the assembled quad module was rotated 90° counterclockwise, and its corner points were joined to the bottom surface to create the side faces (Figure 6c).

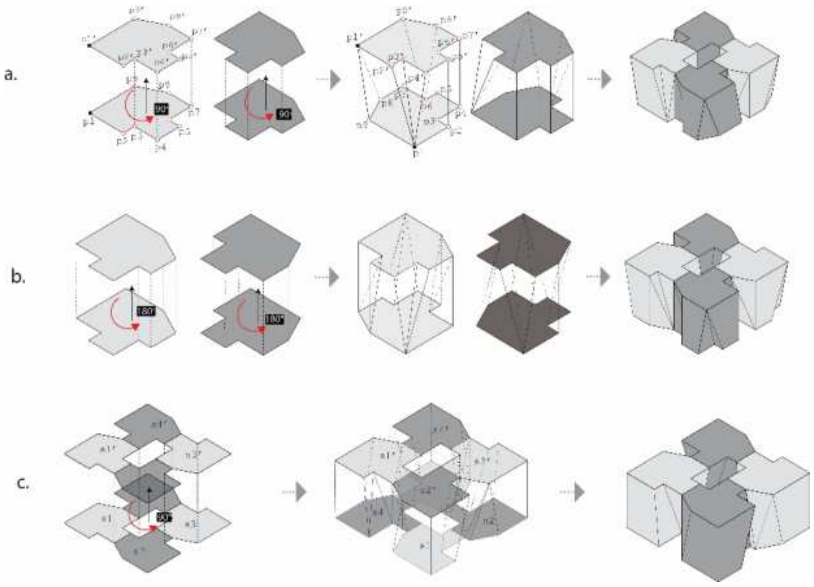

Figure 6. Digital models by rotating the bottom surface (a: 90°CCW, b: 180°CW/CCW, c:90°CCW), where *p* indicates points and *s* surfaces.

The configuration in Figure 5 combines elements from Samples 1 and 2. These three arrangements (Figures 6) demonstrated that geometric variations generated through both the original and newly added rules significantly influence light permeability while maintaining structural compatibility.

Overall, the integration of revised parametric rules, as well as the post-fabrication update of the digital model, strengthened the link between computational design intent and material realities. This approach expands the generative potential of the Cobogó for diverse environmental and cultural contexts while ensuring that variations remain manufacturable and performatively robust.

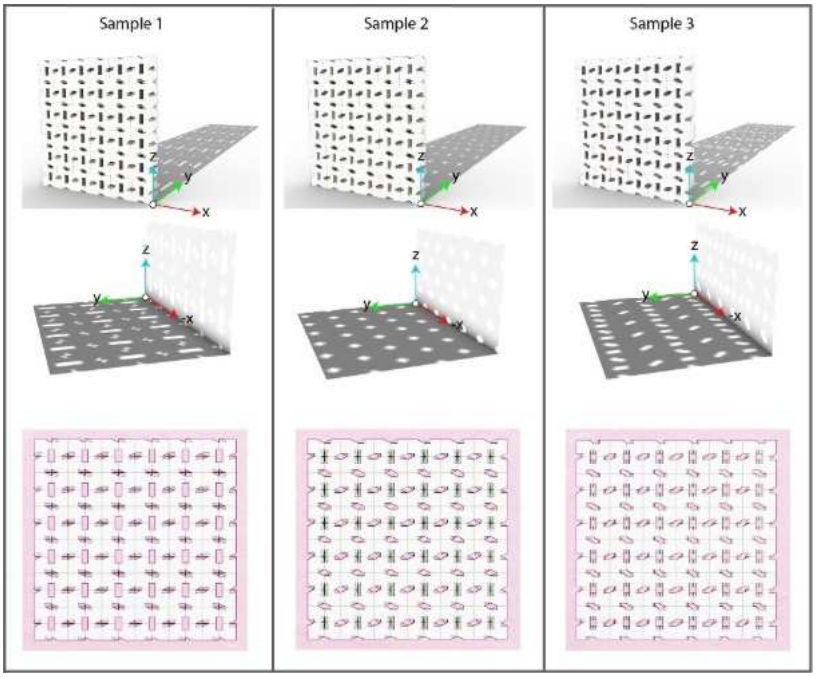

Figure 7. Digital Model of Cobogó Variations

1 CONCLUSIONS

This study presented a computational design and fabrication workflow for reinterpreting the Cobogó as a low-carbon, modular wall system using compressed earth blocks. By combining rule-based parametric modeling with additive manufacturing of custom molds, the process enabled the creation of non-standard yet repeatable geometries that integrate environmental performance, cultural continuity, and material efficiency. The iterative feedback loop between digital modeling, physical prototyping, and model refinement proved essential for aligning computational design logic with the constraints and opportunities of earthen construction. Physical testing informed the introduction of additional generative rules, enhancing both structural compatibility and environmental responsiveness. The results demonstrate that advanced digital tools can be effectively integrated with vernacular-inspired design principles to produce context-specific, sustainable building components. This approach not only extends the formal adaptability of the Cobogó typology but also positions compressed earth construction as a viable, resilient, and culturally grounded alternative for contemporary architecture.

Future work will expand on these findings by conducting systematic compressive strength testing to validate the structural performance of the blocks, which is essential for scaling the system into larger assemblies. In parallel, further investigations will focus on the behavior of light and shadow across different configurations, evaluating how geometric variations influence permeability, shading, and spatial experience. Exploring these aspects together with community-based fabrication methods will enhance the participatory and performative dimensions of earthen Cobogós, positioning them as resilient, sustainable, and culturally grounded components for contemporary architecture.

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The Heritage of Earthen Building from the time of Troy to present day in Canakkale

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ABSTRACT

Troy is an ancient city located in Çanakkale and is considered one of the most important archaeological sites in history. Here, we will discuss the earthen building heritage from Troy to the present day and the work carried out to protect this heritage. The excavations carried out in Troy revealed the existence of adobe structures, especially from the Troy II and III periods. These structures were built using soil material and reflect the construction techniques of the period. Adobe; It has been used since the Neolithic Age, when settled life began, thanks to its easy access and mechanical preparation. The architectural design of the Ancient City of Troy consists of an adobe wall on a stone foundation. The earthen building heritage of Troy is not only a construction technique, but also an important indicator reflecting the place and cultural richness of the past in human history. The protection of this heritage is of great importance both historically and culturally. Çanakkale has a rich cultural heritage with adobe structures, especially in its rural areas. Adobe brick is a natural building material made by mixing soil, straw and water and offers an economical and environmentally friendly construction method that is compatible with the climate conditions of the region. Çanakkale is a region that draws attention with its traditional adobe houses; it stands out with both its historical and natural structures. Earthen buildings in Çanakkale are both an example of traditional architecture and an ideal option for those seeking sustainable living.

Keywords: Earthen Building, Earthen Architectural Heritage, Troy, Canakkale

1 INTRODUCTION

Çanakkale is a city on Türkiye's coastline, bordering the Northern Aegean and Southern Marmara Seas, and straits the Dardanelles. Türkiye's two largest islands, Gökçeada and Bozcaada, are within Çanakkale.
Many great civilizations have lived in the lands of Çanakkale from ancient times to the present day, and the cultural heritage created by these civilizations has been passed down from generation to generation.
With its climate, nature, geography and fertile lands, Çanakkale is a paradise of ancient cities, with more than 200 ancient settlements within its borders.
Known ancient cities in Çanakkale: Troy, Assos, Alexandria Troas, Parion
The best-known ancient city is Troy, considered one of history's most important archaeological sites. Excavations at Troy reveal its historical and cultural richness. Çanakkale possesses a legacy of earthen structures from Troy that has survived to the present day.

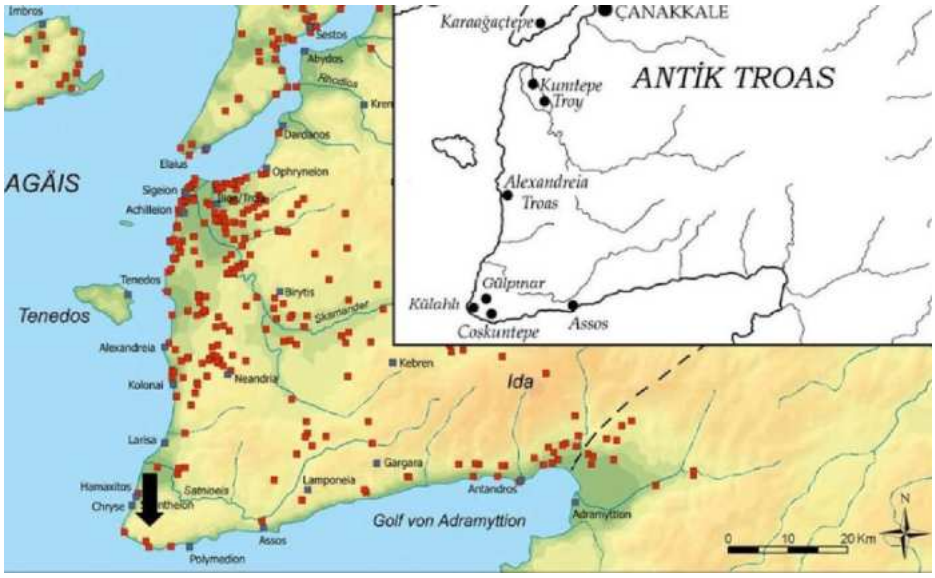

Figure 1. Ancient settlements in the Çanakkale region

Thanks to its easy accessibility and mechanical preparation, adobe has been used since the Neolithic Age, when settled life began. In Çanakkale, structures made of adobe, the raw material of which is earth, have existed from the earliest periods of history to the present day. Examples of earth-produced adobe brick have been found in Anatolia dating back to 5700-5500 BC. The use of these traditional earthen building materials has continued to this day and continues to be used in buildings for its many beneficial purposes. Buildings that are optimally suited to human health are constructed using traditional local building techniques and materials, which are a cultural heritage. The aim here is to ensure the continuity of adobe structures built from ancient times to the present day with contemporary adobe and to contribute to the use of adobe, the most natural building material, in new projects.

2 EARTHEN (ADOPE) BUILDING IN THE ANCIENT CITY OF TROY

Troy is an ancient city located in Çanakkale and is considered one of the most important archaeological sites in history.

Figure 2. Aerial photograph of the Troy Archaeological Site (Troy Archive).

Excavations at Troy have revealed the existence of adobe structures, particularly from the Troy II and III periods. These structures were constructed using earthen materials and reflect the construction techniques of the period.

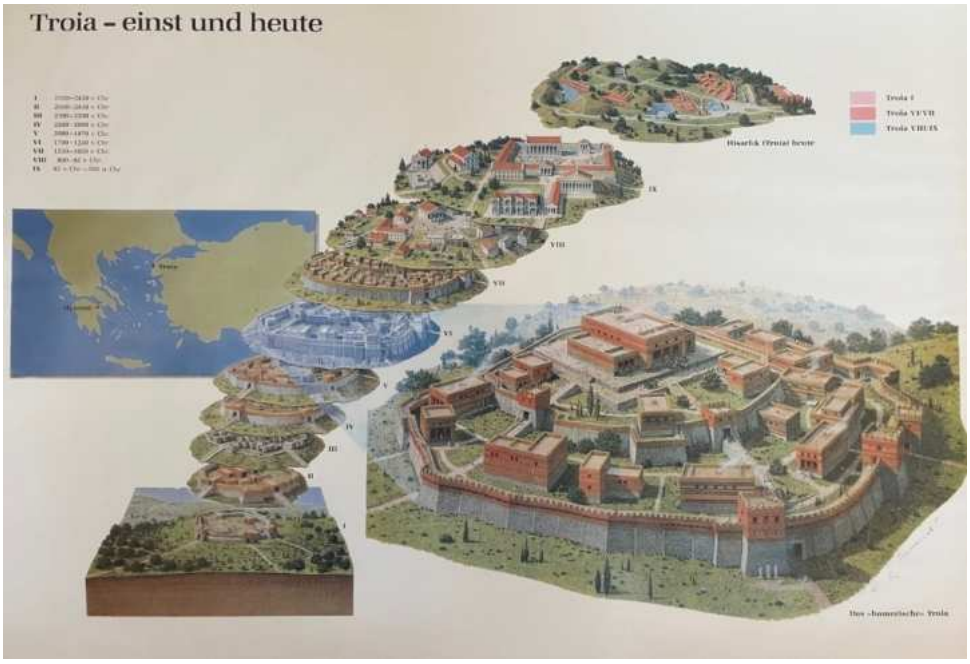

Figure 3. Layers of Troy

Troy's earthenware heritage is not merely a construction technique, but also a significant indicator reflecting its place in human history and its cultural richness. Preserving this heritage is of great historical and cultural importance.
The architectural design of Troy consists of adobe walls on a stone foundation or stone pavement. However, because it is not always possible to preserve adobe material against external influences at archaeological sites, we can only speak of authentic Trojan adobe in a few locations (Fig. 4). While the adobe bricks at Troy vary depending on the layer, they were generally produced by adding abundantly ground straw to a yellowish clay soil. The mud used to bind the adobe bricks together was made of finer-grained clay soil (Schliemann, 1884: 65; Dörpfeld, 1902: 90).

Figure 4. Troy II-III Castle wall made of adobe (Dörpfeld, 1902: 72).

An examination of the side surfaces of the adobe bricks reveals that molds were used in production at Troy throughout history. The bricks in Troy's Bronze Age adobe walls, identified through archaeological excavations, vary in size across different layers and are also found within the same layer. The partially preserved adobe walls of Troy II were repaired and reused in Troy III, where they were heightened by additions (Schliemann, 1884: 63).

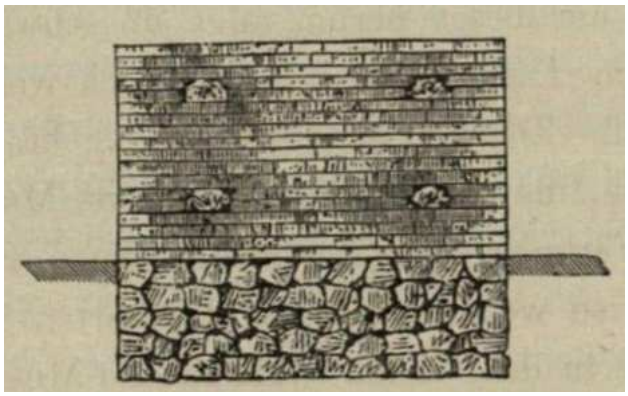

Figure 5. Image of channels created for artificial burning in the Troy II-III Castle wall (Schliemann, 1884: 66).

The adobe bricks that make up the Troy II-III Citadel walls were constructed by sun-drying clay soil mixed with abundant straw. The presence of numerous pottery shards within the adobe bricks indicates that the clay was not ground, but was used in brickmaking as is, to strengthen the wall. Furthermore, to enhance the strength of the wall, the masonry was artificially fired by fire after construction. Channels were dug to apply a firing process to a wall identified as different from the fire layer it had experienced during its time (Figure 5). While the channels were surrounded by completely burnt adobe bricks, the wall opposite the channel was found to be completely unfired. This is arguably the first example of artificially firing a wall composed of sun-dried adobe bricks in situ (Schliemann, 1884, 63-67). The interior and exterior surfaces of the castle walls were plastered by diluting the adobe prepared for the walls.

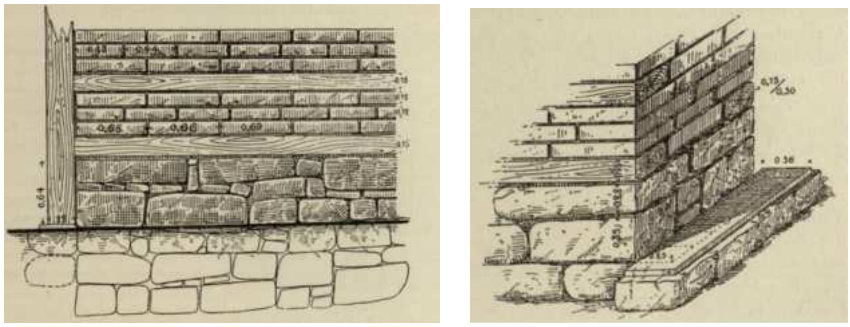

Figure 6. Wooden beams on the IIA adobe wall (Dörpfeld, 1902: 87).

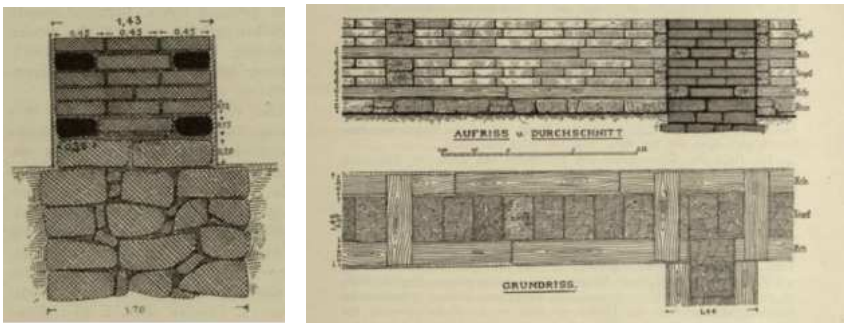

Figure 7. Long side section, elevation and plan images showing the wooden beams of the IIA adobe wall (Dörpfeld, 1902: 90-91).

Figure 8. View of the Troy II-III Castle wall in 2000 (Troy Archive, TRdia43952).

The city of Troy has been destroyed numerous times throughout its history due to various reasons, including earthquakes, fires, and wars. Consequently, throughout its settlement, it underwent numerous repairs using primitive methods. Numerous studies have been conducted throughout the archaeological excavations to enhance the city's legibility and perception.
The original adobe brick sample from Troy is a brown-pink, crumbly, and likely a lime-binding earthenware. The sample's aggregates are below a 1 mm sieve. Based on the results obtained from the analysis of the original adobe samples, new adobe bricks were produced for repair and completion. The remanufactured adobe bricks, prepared by sun-drying, were used in some areas for repair purposes and in others as support walls. Several formulas were developed as a result of trial studies. The resulting adobe bricks were prepared by pressing a mortar composed of sifted clean sand, small and red gravel, in some mixtures, large gravel, powdered amorphous Troy ceramics, and local clay soil into molds and drying them in the sun. In the adobe bricks where firing trials were carried out, a fine binding agent such as straw was used and in order to give a natural appearance, an irregular texture was given by hand by applying wet adobe mortar to the surface after the wall construction.

Figure 9. In the integration of the Troy II-III Castle wall, a section of the wall was left open with a layer of adobe bricks so that the original material could be perceived (Troy archive).

Megaron I was found to be well-preserved, and its design comprises adobe walls on a stone foundation. The main room measured 4.5 x 9 m, and the ante, or front entrance, believed to be supported by supporting piers, was determined to be 4.5 m high. The adobe wall, which is 1.5 m high in its preserved state, was found to have been plastered with lime several times, but due to fires during its use, the lime changed its color to light brown and pink (Figure 9). Arpa Megaron I has been dated to 2290-2200 BC.

3 ADOPE HOUSES WHERE LIFE CONTINUES IN ÇANAKKALE

Figure 10. Adobe house Kutluoba, Üzümlü, Bayramiç, Çanakkale (Ö. Kuralay 2025)

As in Troy, life continues healthily in adobe houses with wooden beams on stone foundations and stone basement walls.

Figure 11. BEKE Institute building adobe wall and 110 year old adobe brick and alker brick (Ö. Kuralay 2025)

A sample of gypsum lime stabilized ALKER adobe brick was made in the same size as the 110-year-old traditional adobe brick (dimensions 12x20x42 cm) used in the BEKE (Bayramiç Ecological Region Institute) building that we will restore.

Figure 12. Adobe house Çavuşlu, Bayramiç, Çanakkale (Ö. Kuralay 2025)

These houses are built with traditional adobe bricks and will continue to provide a healthy life if they are maintained and repaired.

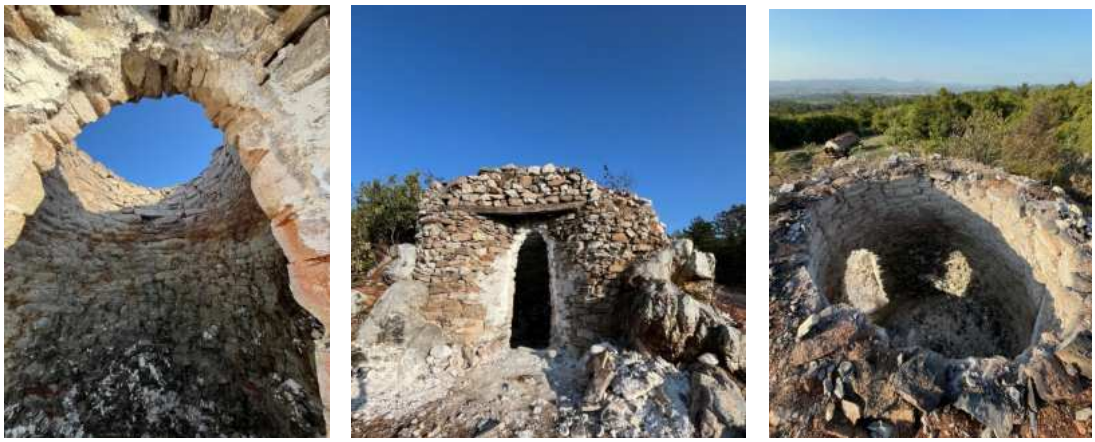

Figure 13. Traditional Lime Kiln Kutluoba, Bayramiç, Çanakkale (Ö. Kuralay 2025)

From ancient times to the present, quicklime has been made from limestone in traditional kilns and slaked in pools, where it has been used as building lime. Applying lime plaster to the earthen plaster of earthen structures has increased their resistance to moisture and surface deterioration.

4 CONCLUSION

Çanakkale, where the earthen building culture has survived from ancient settlements to the present day, boasts a rich cultural heritage, particularly in its rural areas, with adobe structures. Adobe bricks, a natural building material produced by mixing soil, straw, and water, offer an economical and environmentally friendly construction method compatible with the region's climatic conditions.
Çanakkale is a region notable for its traditional adobe houses, a region distinguished by both its historical and natural features. The earthen structures in Çanakkale are an example of traditional architecture and an ideal choice for those seeking a sustainable lifestyle.
Adobe is a low-cost, easily accessible, mechanically produced, highly insulating, recyclable, and waste-free ecological material. With proper maintenance and repairs, earthen structures are long-lasting and healthy structures. It is possible to build long-lasting earthen structures with Alker, a mixture of gypsum, lime, and soil. Ensuring the continuity of adobe buildings and developing contemporary adobe (alker) building projects will be possible by developing building regulations and increasing awareness of adobe buildings.

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Beyond Traditional Earthen Walls: Earthquake Resistance Evaluation of Innovatively Constructed Rammed Earth Walls

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ABSTRACT

Rammed earth structures have long been recognized as a widely used construction method due to their sustainability and accessibility. Despite their historical and contemporary applications, limited research has thoroughly addressed their seismic performance. This study experimentally investigates the earthquake behavior of rammed earth walls through shake table tests. In addition to the traditional wall, the walls are constructed with an innovative method and are formed using two new geometric forms that have not been seen before in order to increase the earthquake performance of the walls. In the first form, the wall is constructed by generating a gradual structure along the height of the wall during the construction of the wall in order to provide horizontal flexibility to the wall. In the second form, the wall is constructed to represent the existing constructed structures and then horizontal flexibility is provided to the wall. The analysis focuses on the development of crack patterns, dynamic properties, and displacement profiles under simulated seismic loading. The results provide critical insights into the structural integrity and resilience of these walls when subjected to both in-plane and out-of-plane seismic forces. Findings indicate that rammed earth walls demonstrate relatively low deformation while preserving their load-bearing capacity throughout seismic excitation. Furthermore, the research underscores the necessity of integrating traditional construction techniques with modern seismic design strategies to improve overall earthquake resistance.

Keywords: Adobe wall, Earthquake behavior, Horizontal flexibility Rammed earth, Shaking table.

1 INTRODUCTION

Rammed earth construction is an ancient building method that has regained attention due to its environmental sustainability. The technique involves compacting layers of soil within formwork and has been used across many cultures. Today, it is being adapted with modern engineering advancements. With increasing demand for sustainable construction, rammed earth offers an attractive alternative to conventional materials because of its low environmental impact. However, its mechanical behavior, particularly under lateral and seismic loads, remains a critical research question.

Recent studies have investigated the mechanical properties and seismic performance of rammed earth walls using modern testing methods. Research has focused on compressive and shear strength under various conditions [1-3]. Comparative analyses with adobe and cob structures further clarify differences in mechanical response [4]. Experimental work on in-plane behavior includes monotonic and cyclic loading tests [5, 6] as well as studies on timber-framed panels [7] and cement-stabilized walls [8].

A review of existing research reveals a lack of comprehensive studies on the seismic performance and earthquake resistant design of compressed earth structures. This study addresses this gap by

experimentally evaluating the earthquake behavior of rammed earth walls. The experiments were conducted at the Istanbul Technical University Structural and Earthquake Engineering Laboratory (ITU-STEELab), a facility with extensive experience in structural testing [9]. The walls were constructed using an innovative method specifically designed to enhance their seismic performance. The findings provide valuable insights into the earthquake behavior of rammed earth structures, which represent a significant portion of the global building stock, and contribute to the development of strategies for improving their earthquake resistance.

2 INNOVATIVE RAMMED EARTH WALLS

In this experimental study, an L-shaped rammed earth wall was tested on a shaking table to evaluate its seismic performance.

Figure 1. Construction of the walls; (a) mixing of materials. (b) making the formwork. (c) compaction (ramming) process. (d) appearance of the wall after construction.

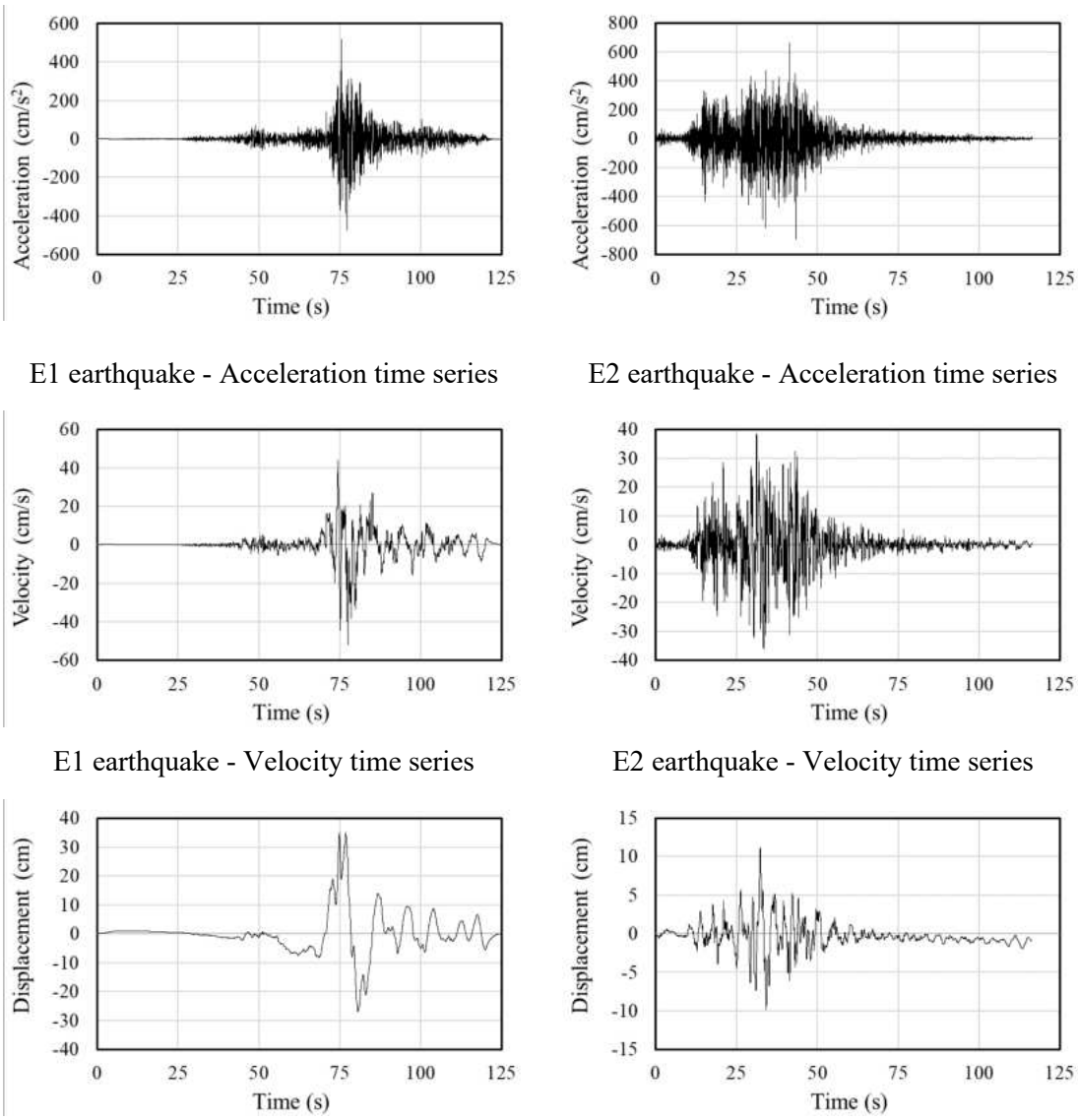
Rammed earth structures can experience failure both in-plane and out-of-plane, with wall junctions being particularly vulnerable under earthquake loading. To capture these critical behaviors, the test specimen was constructed with an L-shaped plan configuration. The model was built at half scale, based on typical building dimensions. It measures 150 cm in height, with the long arm of the L extending 150 cm, the short arm 90 cm, and a wall thickness of 30 cm. The wall is anchored between two reinforced concrete caps: a 25 cm thick base and a 15 cm thick top cap. The rammed earth portion, stabilized with plaster and lime, occupies the 110 cm section between these caps. The specimen was tested under its self-weight to simulate realistic loading conditions. The walls

were constructed by placing rammed earth between two reinforced concrete caps. Fig. 1 illustrates the construction stages. The material mixture (Fig. 1a) consisted of 85% soil, 10% plaster, and 5% lime. After assembling the formwork according to the wall geometry (Fig. 1b), the soil mixture was placed in layers approximately 10 cm thick and compacted mechanically (Fig. 1c). This process was repeated until the full wall height was achieved, resulting in a rammed earth wall enclosed between the two reinforced concrete caps (Fig. 1d). The stabilized rammed earth achieved an average compressive strength of 1.5 MPa after 45 days of drying. The material density was measured as 1700 kg/m³. To increase horizontal flexibility, a stepped profile was constructed along the height of the wall. This was achieved by using simple paper in the intermediate layers. The wall's construction phase is shown in Fig. 2. The third wall was made horizontally flexible by creating horizontal slits on the wall after it was built.

Figure 2. Construction of the horizontal flexible wall; (a) compaction process (b) placement of stretch material for horizontal flexibility.

3 EXPERIMENTAL ANALYSIS

During the shaking table experiments, the two earthquake records shown in Fig. 3 were scaled with different scale factors and applied. The first of these earthquakes (E1 earthquake) is the acceleration record recorded at a station in Hatay (station TK.3136, North-South component) during the February 6, 2023 Kahramanmaraş earthquake. The maximum ground acceleration, velocity, and displacement (PGA, PGV, and PGD) in this record were recorded as 518.0 cm/s^2, 52.1 cm/s, and 35.0 cm, respectively. This earthquake record was scaled with scale factors of 0.10, 0.25, 0.50, 0.75, and 1.00 and applied to the table.
The second of these earthquakes (E2 earthquake) is a record recorded during the 1985 San Salvador earthquake. The maximum ground acceleration, velocity, and displacement (PGA, PGV, and PGD) of this record are 693.5 cm/s^2, 38.4 cm/s, and 11.2 cm, respectively. This earthquake record was scaled with scale factors of 0.50, 1.00, 1.50, and 2.00 and applied to the table.
Following the experiments, the data obtained is analyzed to evaluate the performance of the wall under earthquake loads. For this purpose, cracking and damage conditions in the structure, changes in the structure's dynamic parameters during the experiment, and analysis of displacements and accelerations on the structure are examined. The loads applied to the wall are designated L-ST-#, representing the loads applied to the L-shaped wall designed for testing on the shaking table. # represents the load number.



E1 earthquake - Acceleration time series

E2 earthquake - Acceleration time series

E1 earthquake - Velocity time series

E2 earthquake - Velocity time series

E1 earthquake - Displacement time series

E2 earthquake - Displacement time series

Figure 3. Acceleration, velocity and displacement records for E1 and E2 earthquakes

During the testing under earthquake records scaled with different coefficients, structural damage observations are made for wall 1. Crack lengths and widths are recorded, and comparisons are made for the wall at each step. No structural damage was observed during L-ST-01. Similarly, no structural damage was observed during L-ST-02. During L-ST-03, horizontal cracks formed around the upper reinforced concrete bond beam layer. During L-ST-04, the upper reinforced concrete bond beam layer separated from the rammed earth section. A total of 1 mm wide cracks formed. Torsional shear cracks (especially on the short arm) began to form on the specimen. Vertical crack widths around the joint area remained around 0.1-0.2 mm. Crack lengths under the upper reinforced concrete bond beam layer extended. During L-ST-05, the separation crack in the upper reinforced concrete bond beam layer reached 2 mm. The separation crack in the second layer reached 1.2 mm, and the hairline cracks reached 0.2-0.4 mm. Existing cracks extended. During L-ST-06, existing cracks widened, and new cracks formed. At the lower end of the short arm, small sand grains near the coarse aggregates lost structural integrity. Adherence was lost. The sand grains became removable by hand. During L-ST-07, existing cracks widened and extended. The 1.2 mm crack width increased to 1.6 mm. Plan rotation occurred in the upper concrete layer. During L-ST-

08, existing cracks widened, and new cracks formed. During L-ST-09, existing cracks widened, and new cracks formed. Post-test photographs of the sample are shown in Fig. 4.

Figure 4. Crack propagations and structural damages status in the sample wall at the end of the experiment

The displacements measured at the control point at the upper free end are shown in Fig. 5. These points are strategically placed on a structure or specimen to capture key data such as displacement, strain, or acceleration. Properly defined control points enable precise tracking of structural behaviour, identification of critical deformation zones, and assessment of performance criteria. By analysing displacements, engineers can identify weak points, evaluate ductility demands, and determine whether a structure remains within acceptable performance limits. A collapse occurred during the test in Wall 3. The results shown in the graphs are highly significant.

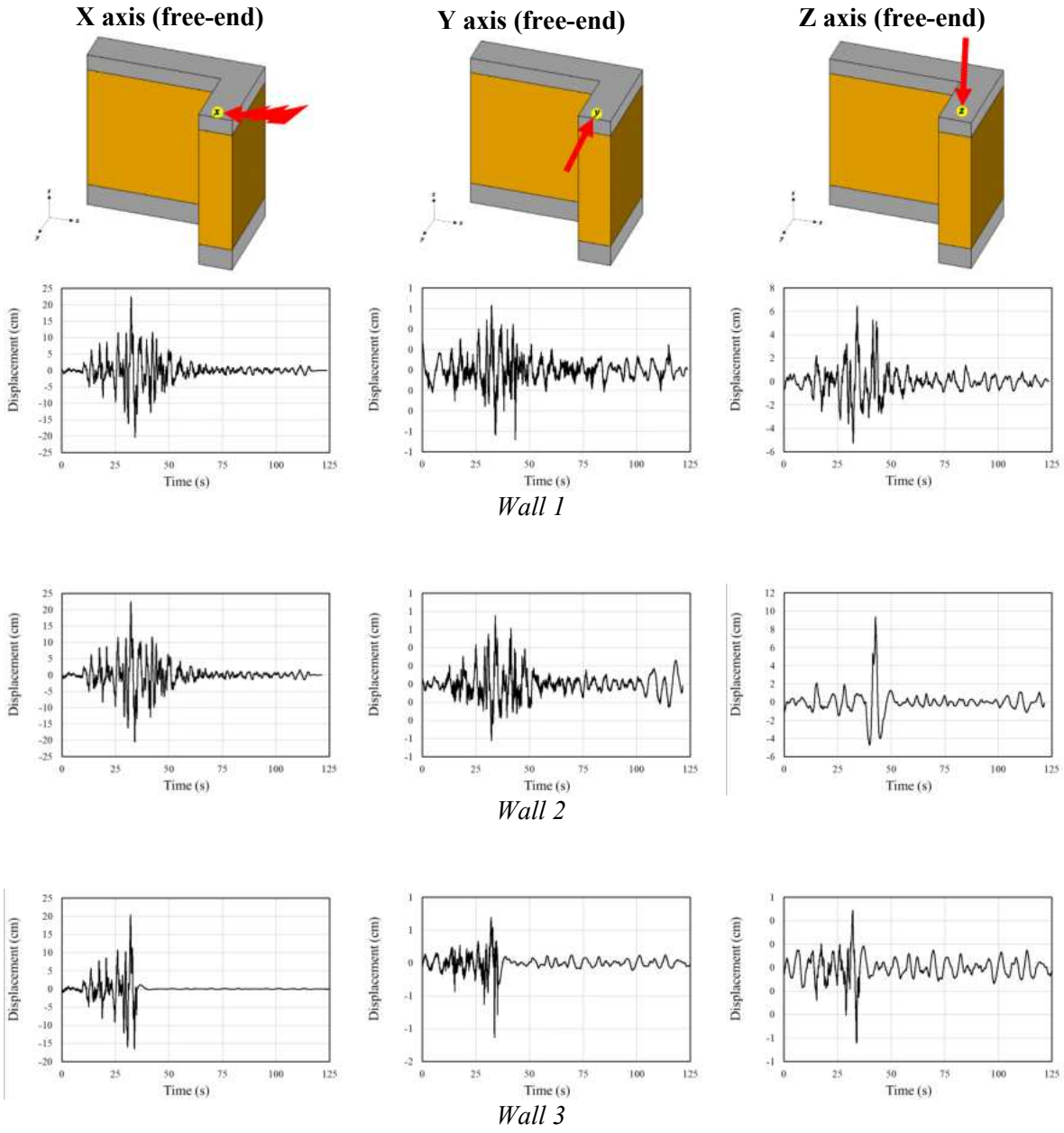


Figure 5. Upper free-end displacements in three-axes for *L-ST-09*

4 CONCLUSION

In this study, the seismic behaviour of the three rammed earth wall specimen were evaluated through shaking table tests, during which crack development, deformation, and acceleration measurements were recorded. The walls' stepped and layered configuration contributed positively to its seismic performance by dissipating seismic energy. This configuration prevented the formation of transverse cracks and significant deformations, thereby delaying the onset of failure. Relative sliding at the concrete-rammed earth interface was minimal, with a maximum displacement of only 0.04 cm, indicating that the joints exhibited relatively holistic behaviour under adequate bonding conditions. Acceleration and displacement profiles, along with measurements at control points, provide valuable datasets for further analysis of rammed earth structural performance. Crack development was primarily observed at the junction of the upper

reinforced concrete cap and the rammed earth section, where torsional effects and horizontal shear cracks were more pronounced, particularly along the short arm. Notably, visible damage occurred only during the final phase of testing. The observed failure mechanism consisted of a horizontal shear crack near the base. Due to the walls' weight and granular nature, minor cracks exhibited partial self-healing. Overall, the rammed earth wall completed the tests with moderate damage.

5 ACKNOWLEDGMENTS

The experimental program was carried out at the Structural and Earthquake Engineering Laboratory (ITU-STEELab) of the Faculty of Civil Engineering, Istanbul Technical University. The authors gratefully acknowledge the invaluable support provided by the laboratory team throughout the execution of this study.

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Historical Continuity in Small-Scale Earthen Religious Structures: A Study on the Geneği Mescid in Ankara

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ABSTRACT

The Geneği Mescid is a significant structure located in the Altındağ district of Ankara. In the absence of an inscription, the mescid is dated to the late 14th or early 15th century based on a comparative analysis of its architectural and decorative features with other mescids in Ankara.
The historical building, analyzed in this study, is a typical example of a small-scale neighborhood mescid in Anatolia, distinguished by its modest and functional design. The plan is organized around the prayer hall (*harim*). The last prayer hall (*son cemaat yeri*), arranged as a portico, is located on the entrance façade in accordance with traditional mosque layout principles. While such spaces are generally placed on the north side—opposite the qibla wall—in classical Ottoman mosques, here it faces west.
The Geneği Mescid is a valuable architectural heritage that reflects the historical fabric of Ankara. Its architectural and decorative features convey the artistic and construction approaches of its era. The building's interior architectural characteristics exhibit influences of the Late Seljuk and Early Ottoman periods in Anatolia. Constructed with a simple and functional design using stone, wood, and adobe, the structure reflects traditional techniques commonly seen in the Ankara region.
The primary aim of this study is to document the architectural characteristics of the Geneği Mescid—a local religious structure—through written and visual records, contributing both to the preservation of transitional-period architecture and its representation in academic literature. Furthermore, through the example of small-scale buildings like the Geneği Mescid, the study seeks to reveal how religious architecture was localized in Anatolia and how cultural continuity is reflected in architectural form.

Keywords: Adobe, Geneği Mescid, Religious Architecture in Ankara, Late Seljuk Period, Early Ottoman Period in Anatolia, Architectural Heritage.

1 INTRODUCTION

The Turkification of Anatolian cities, which began in the 11th century with the migration of nomadic Turkish tribes from Central Asia (following the Battle of Manzikert in 1071), continued through subsequent centuries. The first wave of this migration primarily involved Turkmen tribes settling in Eastern and Central Anatolia, initiating the gradual spread of Turkish-Islamic influence in the region [1]. The second wave in the 13th century was triggered largely by Mongol invasions and consisted of new groups moving westward. Unlike the earlier nomadic settlers, many of these migrants were urban dwellers and artisans, bringing with them knowledge, craft, and socio-economic networks that would shape emerging urban centers [2].

Among these migrants, many artisans and craftsmen felt the need to organize themselves both against the local Byzantine population and in response to the instability caused by the Mongol threat. This led to the emergence of the Ahi Order, a socio-economic and religious fraternity

system [3]. More than a professional guild, the Ahi organization functioned as an ethical and religious union that provided social protection and communal solidarity in the face of political instability [4].

Ankara was among the cities where the Ahi Order exerted the most profound influence, not only in terms of production and commerce but also in political, economic, and military matters. Until its integration into the Ottoman realm in 1362, Ankara was effectively administered by the Ahis as a kind of city-state [3]. The organization's endowments included zawiyas (Sufi lodges), inns, bathhouses, charitable soup kitchens (*imarets*), agricultural fields, and mosques [5]. During this period, the flat terrain just outside Hisar Gate functioned as a marketplace. Several prominent structures were erected around it—such as the Arslanhane Mosque (likely a Friday mosque), the Ahi Şerafeddin Mosque, and various inns and fountains—all located outside the medieval city walls. This indicates a shift in Ankara's spatial orientation in the early 14th century, marking its transition from a border fortress to a commercial urban center [6].

Ahi culture as an ethical-based guild system in which morality and craftsmanship coexisted, remained influential in Anatolian cities, towns, and even villages from the 13th to the early 20th centuries. The philosophy of the Ahi movement was built on a balance between its material and spiritual dimensions [7]. In Ankara, the Ahi Order operated not only as an economic institution but also as a moral and religious regulator of social life, establishing behavioral norms among craftsmen and reinforcing communal cohesion [8]. The strong organization of the Ahis in Ankara left its mark on the city's religious architecture: mosques, zawiyas, and mescids were not merely places of worship but also centers for education, social interaction, and moral guidance. Within this context, the Geneği Mescid**,** located in Ankara's Altındağ district, stands as a unique example reflecting the dual religious and social function of Ahi culture through its simple architectural expression and use of local materials [9].

Furthermore, between the late 14th and late 15th centuries, significant changes occurred in Ankara's urban morphology. During this period, 25 mosques and mescids were constructed outside the castle walls, along the slopes and adjacent plains—including the Geneği Mescid, which is the focus of this study. Considering that each of these structures likely formed the nucleus of a neighborhood, it can be inferred that by the 15th century, approximately 30 neighborhoods existed in Ankara, including those within the castle. By the first quarter of the 16th century, this number had risen to 81 [10].

The religious architecture of Anatolia provides unique insights into regional construction techniques, material usage, and spatial organization. Among these structures, small-scale mescids have played a crucial role in shaping neighborhood identity and influencing patterns of urban development. The Geneği Mescid, located in present-day Altındağ, is one such example that embodies the influence of Ahi culture and illustrates the architectural transition from the Late Seljuk to the Early Ottoman period. Despite the absence of documentary sources such as inscriptions or the deed of endowment (*vakfiye*)*,* the architectural language of the building offers valuable clues about its historical and cultural context.

2 ARCHITECTURAL DESCRIPTION

2.1 General Description and Exterior Features

The Geneği Mescid is situated on a sloped site and is accessed via a set of stairs descending from Oluk Street (Fig. 1). The structure features a longitudinal rectangular plan and includes an open-ended last prayer hall. The substructure of the outer walls is composed of rubble stone, while the upper section is built with adobe supported by wooden beams [11]. This construction technique was widely used in Ankara during the relevant period. The hipped roof is covered with traditional Turkish roof tiles (*alaturka kiremit*) and includes pronounced eaves. The mosque does not have a

minaret. The building provides important clues regarding its construction period through its use of wooden craftsmanship, painted decorations, and its plaster mihrab.

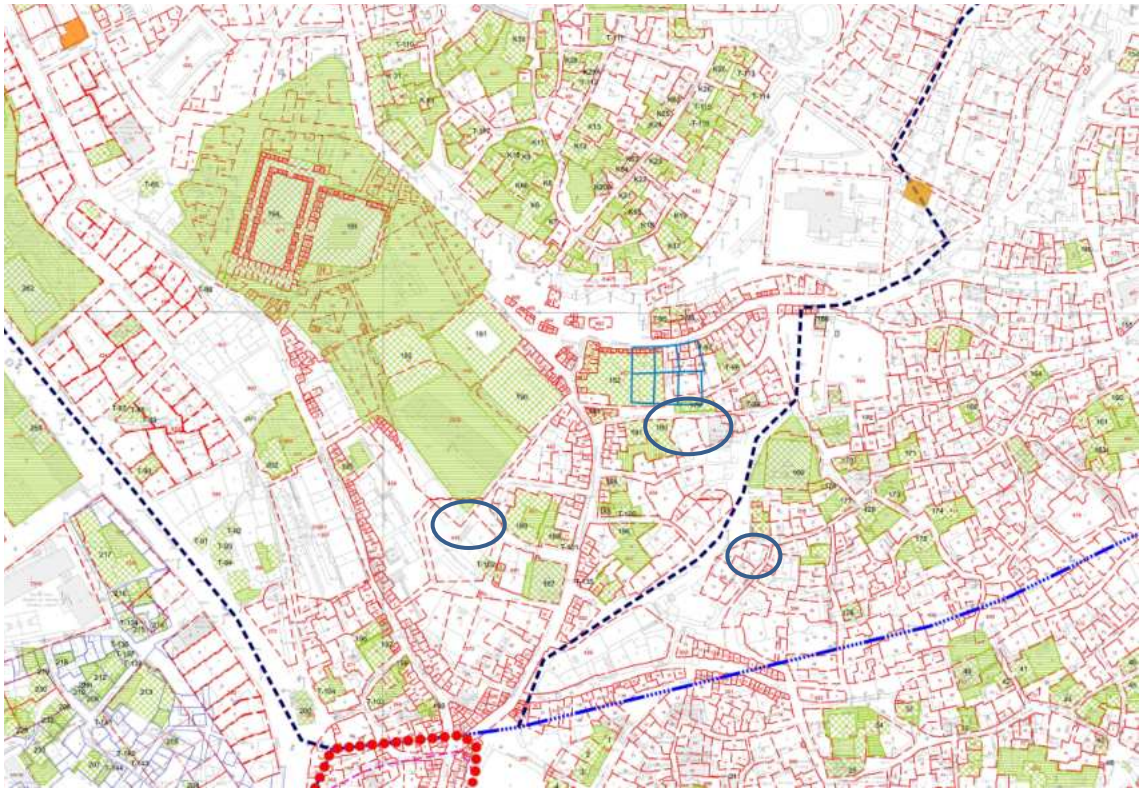

Figure. 1 The map shows the location of Geneği Mescid (No. 176) and its surroundings, including Ahi Elvan Mosque (No. 187) and Ahi Şerafettin (Arslanhane) Mosque (No. 169) (Ankara Conservation Council for Cultural Heritage).

The Geneği Mescid exhibits a modest and functional layout, comprising a single prayer hall (*harim*) covered with a flat wooden ceiling supported by a central timber column—a structural typology commonly seen in Anatolian mosques of this era. The last prayer hall (*son cemaat yeri)*, designed as a portico, is located on the western façade, which is unusual as this space is typically placed on the northern side. This deviation may be attributed to the topography or local building customs (Fig. 2).

Entry to the last prayer hall, which is open on its west and south sides, is through a double-leaf wooden door on the western façade. The space is supported by timber columns connected by wooden balustrades. One column is attached to the north wall of the narthex, another to the west wall, while the remaining columns are free-standing along the western façade. The capitals of these columns resemble profiled pillows and support timber beams. An additional wooden column was later inserted between two of the existing ones to support the load of the beam. The ceiling of the prayer hall consists of wooden beams laid in the east-west direction. A nearly square rectangular window connects the last prayer hall with the prayer hall (Fig. 3, 4).

The southern façade features two rectangular windows at both the ground and upper levels, along with a small square basement window embedded in the foundation. The eastern façade contains a single rectangular window on each level. All window casings and frames are constructed from timber. The northern façade is adjacent to neighboring residential parcels and is largely obscured.

2.2 Interior Space and Architectural Elements

The interior prayer hall (harim), which follows a longitudinal rectangular plan, is entered through a double-leaf wooden door located at the northeast corner of the last prayer hall (Fig. 2, 3, 4, 5, 6). Although modest in appearance from the outside, the Geneği Mescid contains notable interior elements. A large central timber column supports the ceiling beam [11]. This circular-sectioned column rests on a stone base and features a muqarnas-carved wooden capital—a fine example of Seljuk wooden craftsmanship. A profiled wooden element (*yastık*) is positioned between the capital and the beam, and a series of similarly profiled corbels are placed between the beams. Decorated laths forming rhombus motifs are nailed onto the beam surfaces [12] (Fig. 3, 4, 5, 7a, 7b, 8a, 8b).

Painted decorations are visible on the ceiling beams and on the interior surfaces of the beams in the last prayer hall. These embellishments reflect the aesthetic preferences and woodworking finesse of the period.

The wooden beams and column capital are adorned with painting decorations (*kalem işi)* executed in natural dyes. While red dominates the color palette, yellow, green, and blue hues are also used. The capital features stylized floral and pomegranate motifs, while the beam borders are adorned with composite arabesques, scrolling foliage, prominent rosettes, and other intricate vegetal patterns in a classical ornamental tradition. [13]. Historical sources report that these painted ornaments once covered the entire ceiling and window frames but were painted over during a renovation in 1948 [12].

The interior walls include niche cupboards with rectangular cross-sections—one on each of the east and west walls, and two on the north wall. The floor is paved with hexagonal terracotta tiles.

2.3 Mihrab

The mihrab, located on the southern wall of the harim, was produced as a set of plaster panels using a molding technique. Based on its decorative features—featuring both low- and high-relief carvings—it is stylistically dated to the first half of the 15th century [14] (Fig. 2, 3, 6).

The mihrab niche is bounded externally by three ornamental borders, with engaged columns flanking both sides of the niche. The first ornamental band features intertwined floral and foliate patterns accompanied by a naskh-script inscription of the *kalima-i tawhid* (Islamic declaration of faith). The second and third borders contain vegetal ornamentation arranged within geometric compositions, highlighting the stylistic richness of the piece. The semi-dome (*kavsara*) of the niche features five tiers of muqarnas: at the base, blind niches with circular arches; at the top, a series of almond-shaped forms and wing motifs. Between the semi-dome and the lower section of the niche, a horizontal inscription band repeats the kalima-i tawhid. The lowest portion of the niche is decorated with interlacing geometric patterns [12-13].

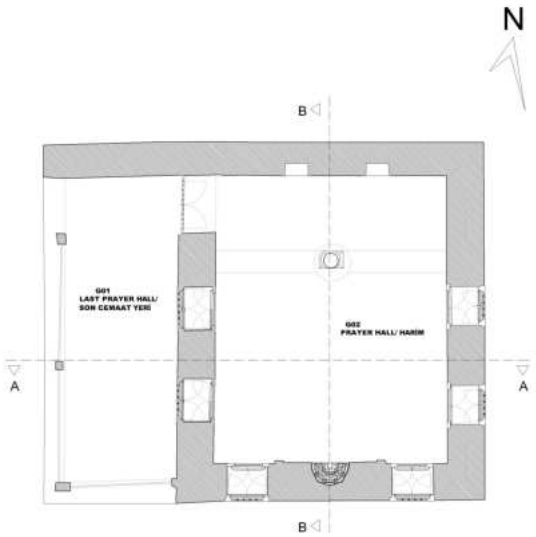

Figure. 2 Plan

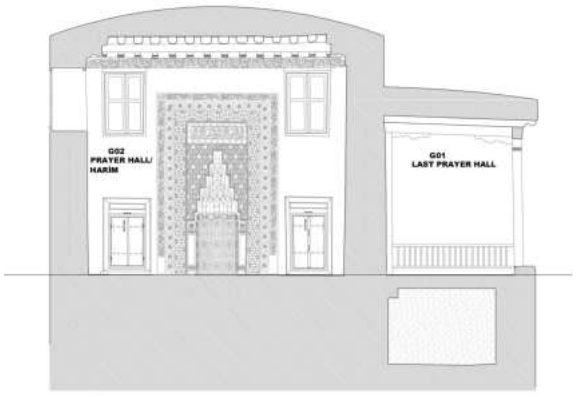

Figure. 3 AA Section

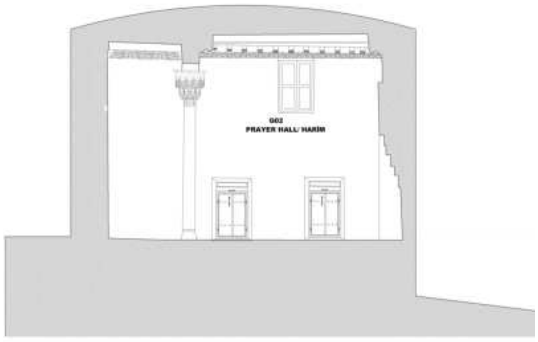

Figure. 4 BB Section

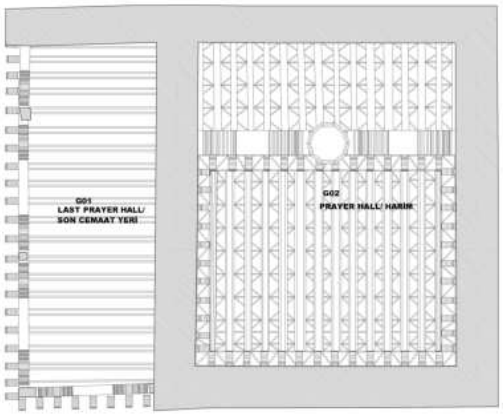

Figure. 5 Ceiling Plan

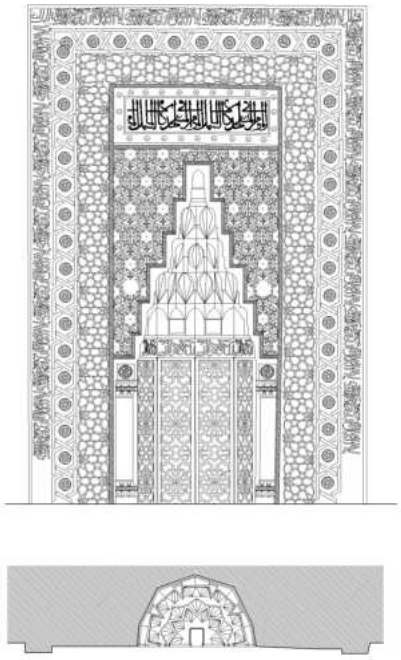

Figure. 6 Detail of Mihrab

Figures 7a, 7b A large central timber column supports the ceiling beam.

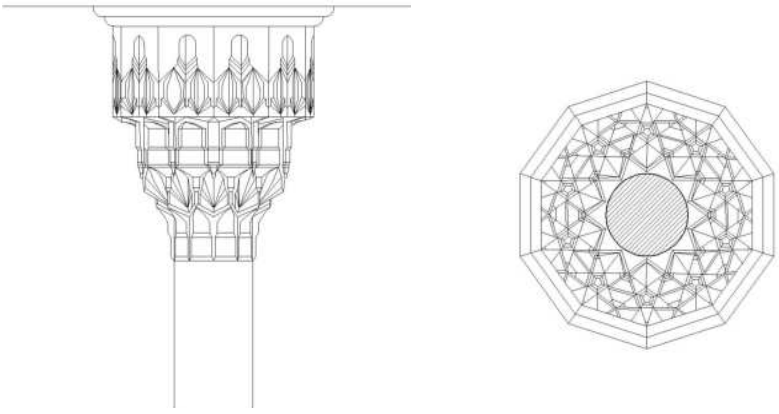

Figure. 8a, 8b Detail of wooden capital (elevation and plan).

3 COMPARATIVE AND GENERAL EVALUATION OF 14TH AND 15TH CENTURY MOSQUES AND MESCIDS IN ANKARA

The mosques and mescids built during the period marked by the influence of the Ahi Order—when the social and religious structure of society reflected the organizational ideals of Ahilik—are typically constructed with adobe walls over stone foundations, flat wooden ceilings, and timber columns. These structures generally have rectangular floor plans, include a last prayer hall, and often lack minarets. While the last prayer hall is commonly situated on the north side of mosques across Anatolia, many mescids in Ankara exhibit a deviation from this norm, placing this space on the east or west sides. In the Geneği Mescid, the last prayer hall is located on the west side of the main prayer hall. This arrangement is also observed in other mescids in Ankara, such as the Rüstem Nail (Dındın) Mescid (15th–16th century) and the Telli Hacı Halil Mescid (dated to 1766).

Painted wooden decorations with dominant vegetal motifs, as seen on the ceiling beams, cupboards, and window casings of the Geneği Mescid, are also found in contemporaneous mescids in Ankara, including the Eyüp, Örtmeli, Poyracı, and Sabuni Mescids. In all of these examples, the ceiling beams are covered from above, and the decorative painting is found on the consoles, the beams themselves, and the spaces between beams [15]. Although similar flat wooden ceilings and plaster mihrabs are present in other examples, the centrally positioned timber column with a muqarnas-decorated, painted capital—supporting the ceiling of the Geneği Mescid—has no known analog. The earliest examples of muqarnas-carved, painted timber column capitals are found in the Afyon Grand Mosque, the Ayaş Grand Mosque, and the Beyşehir Eşrefoğlu Mosque.

Studies of 14th and 15th-century mosques and mescids reveal that many of their original roofing systems have been lost, and that these structures are now covered with hipped roofs clad in tiles. However, a passage from the Travelogue (*Seyahatname*) of Evliya Çelebi supports the idea that many of these buildings originally had flat earthen roofs: "There are few lead-covered mosques. Most are covered with clean, fragrant earth. The rest are neighborhood mescids" [16]. This suggests that, like the Geneği Mescid, many early neighborhood mescids originally featured earthen flat roofs.

The Geneği Mescid, functioning as a neighborhood mescid, represents an example of early Anatolian Turkish religious architecture in the timber-supported mescid tradition. Built with a stone foundation and adobe walls, the mescid has a single-room plan covered with a flat earthen roof. The *qibla* wall containing the mihrab functions as the primary element defining the spatial orientation of the interior.

At the center of the prayer hall stands a large timber column, which supports the beam system that carries the ceiling. This column is especially notable for its muqarnas-carved capital. The flat wooden ceiling is supported by beams adorned with painted motifs and geometric patterns. These painted decorations reflect both the early Ottoman aesthetic and the craftsmanship of the period. Their religious and artistic value enriches the otherwise modest structure.

The Geneği Mescid may be considered a transitional architectural example, blending Early Ottoman style with Seljuk-influenced features. Its plan schema, structural system (timber columns and beams), and restrained decorative vocabulary mark it as a continuation of the post-Seljuk traditional Anatolian mescid typology. In terms of architectural typology, the Geneği Mescid belongs to the lineage of timber-columned mosques in Anatolia, with notable parallels found in the Afyon Grand Mosque and the Sivrihisar Grand Mosque (Tab.1).

Table. 1 A timeline and comparative chart presenting the architectural positioning and stylistic features of the Geneği Mescid within its historical period **(**Development of Timber-Columned Mosques in Anatolia)

Period	**Example Structures**	**Architectural Features**	**Position of Geneği Mescid**
11th–13th (Seljuk Period)	Afyon Grand Mosque (1272), Sivrihisar Grand Mosque (1274)	Timber columns, flat wooden ceiling, plain façades, mihrab niche	Belongs to this tradition (influenced by)
14th–15th (Transitional/Early Ottoman)	Beyşehir Eşrefoğlu Mosque (1299), Ankara Ahi Elvan Mosque (1382)	Continuation of timber-columned typology, simplified ornamentation, advanced stone/wood mihrab and minbar craftsmanship	Geneği Mosque (ca. early 15th c.) was built in this period
16th–17th (Classical Ottoman)	Süleymaniye Mosque, Selimiye Mosque	Domed system, centralized plan, dominance of stone structures with arches	Differs from the architecture of this period

The Geneği Mescid is not merely a place of worship; it embodies the cultural continuity of a community over centuries. Its spatial configuration, material usage, and construction techniques align it with other regional examples, allowing it to serve as a representative model for understanding local interpretations of religious architecture. It also illustrates how architectural identity was maintained through traditional knowledge systems despite political and dynastic changes. While modest in scale and design, the structure incorporates ornamental features that reflect the artistic sensibilities of its era, bridging the stylistic gap between the Late Seljuk and Early Ottoman periods (Tab. 2).

Table. 2 Comparative Table of Architectural Features

Feature	**Seljuk Wooden Columned Mosque**	**Geneği Mosque**	**Classical Ottoman Mosque**
Plan Type	Rectangular, multi-columned	Rectangular, columned	Central plan, domed
Structural System	Wooden columns, beams	Wooden columns and beams	Stone columns, arches
Ceiling System	Flat wooden ceiling	Flat wooden ceiling	Domes and semi-domes
Ornamentation	Minimal decoration, wooden mihrab/minbar	Simple decoration, stonework on mihrab	Rich decoration, tiles and stone
Material	Stone, wood	Adobe and wood on stone basement	Ashlar stone, brick, tile
Lighting	Small window openings	Small window openings	Large arched windows, drum base openings

4 CONCLUSION

The architectural features of religious structures like the Geneği Mescidi are deeply intertwined with the socio-cultural dynamics of their respective periods. During the Late Seljuk era, architecture was shaped by a fusion of nomadic Turkic traditions and established Islamic urban culture, resulting in modest-scale yet symbolically rich buildings. In the following Ahi-dominated

period in Ankara, the emergence of autonomous guilds introduced a civic-religious architectural typology, where mescids not only served as spaces of worship but also as community centers reflecting ethical, social, and economic cohesion. As the Early Ottoman period began to assert centralized control, architectural vocabulary became more standardized, yet local expressions—such as material choices (e.g., mudbrick or ashlar) and layout configurations—remained closely tied to community identity, craftsmanship traditions, and neighborhood-based religious practices. Thus, each architectural layer in such buildings stands as a physical manifestation of shifting cultural identities, power structures, and communal values.

The Geneği Mescid represents a vital component of Ankara's architectural heritage. Through its modest yet symbolically rich design, the structure provides insight into the spatial, cultural, and religious dynamics of its era. Documenting and analyzing such buildings is essential for preserving the architectural memory of transitional periods. Furthermore, studying local mescids like Geneği contributes to broader discussions on how regional identities manifest in architectural form, ensuring these narratives are recognized within academic literature and conservation practices.

This mescid is not merely a place of worship; it embodies the cultural continuity of a community over centuries. Its spatial configuration, material usage, and construction techniques align it with other regional examples, allowing it to serve as a representative model for understanding local interpretations of religious architecture. It also illustrates how architectural identity was maintained through traditional knowledge systems despite political and dynastic changes.

The interior of the Geneği Mescid, with its simplicity and hand-crafted construction, serves as a notable example of early Ottoman religious architecture within the context of 14th-century Ankara, under the influence of the Ahi organization. While modest in scale and design, the Geneği Mescid incorporates ornamental features that reflect the artistic tendencies of its time. Its architectural style displays transitional characteristics between the Late Seljuk and Early Ottoman periods.

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Resilience of Vernacular Intermediality Devices in Colonial Housing in Morocco

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ABSTRACT

This paper analyses the evolution of spatial intermediality in collective housing in Morocco, revealing the remarkable persistence of traditional models despite the introduction of modern colonial urbanism. The study examines how intermediate spaces (landings, staircases, courtyards, shared gardens) have gradually been reappropriated by residents since the advent of the French Protectorate in 1912.

Despite the break in form introduced by colonial urban policies and the application of modernist standards, collective housing has been subject to subtle strategies of appropriation and diversion. Residents have transformed circulation spaces, which were initially designed according to a functionalist logic, into places for social exchange and the territorialisation of customary practices. This perpetuates the spatial codes inherited from the vernacular model.

This research is based on the hypothesis that the "informality" observed in these adaptations is not a conceptual dysfunction, but rather a strategy for living that draws on collective spatial memory. Drawing on a corpus of archive documents, plans and projects from different periods, the analysis reveals a complex process of hybridisation between architectural standardisation and cultural continuity. The traditional model's resilience demonstrates societies capacity to adapt in the face of imposed transformations, calling into question the dichotomy between designed and lived spaces.

Keywords: Collective housing, intermediality, appropriation, vernacular conception, colonial architecture.

INTRODUCTION

The advent of the French protectorate in Morocco in 1912 marked a major formal break in the history of Moroccan urban housing. Under the impetus of Marshal Lyautey and his urban planner Henri Prost, a unique urban policy was put in place with the creation of new towns juxtaposed with historic medinas. This transformation raises questions about the resilience of the traditional housing model and its persistence within colonial developments.

Examining this issue reveals an important paradox: the introduction of new architectural and urban planning models inspired by the modern CIAM (International Congresses of Modern Architecture) movement and the adaptability and resilience of vernacular spatial logic. Rather than rejecting colonial innovations outright, this resilience is expressed through a series of subtle strategies of appropriation, diversion and reinvention of designed spaces.

This analysis examines historical documents and collective housing projects from two periods: pre-colonial housing and the first housing complexes established under the protectorate. This diachronic

approach reveals how intermediate spaces evolved, how they were appropriated, and the regulatory frameworks that governed collective housing.

THE TRADITIONAL MODEL, A STRUCTURED SPATIAL ORGANISATION

To understand the resilience of the traditional model, particularly in urban areas, it is necessary to analyse the fundamental characteristics of Moroccan vernacular housing. Far from being a simple juxtaposition of individual houses, the traditional urban fabric of medinas represents a sophisticated model of urban organisation, based on a meticulously regulated spatial hierarchy. This organisation incorporates the principles of intermediality[1], expressing a spatial hierarchy that governs access, social interactions, and views. The vernacular design[2] gradates spaces from private to public, clearly distinguishing between the city's public spaces, segmented neighbourhoods, and private house spaces through the hierarchy: street, derb (dead end), threshold, courtyard (Dabbour, 2020) (Pezeu-Massabuau, 1983, pp. 87-92).

The *derb*, the main component of this structure, can be considered a collective proto-space (Pezeu-Massabuau, 1983, p. 104) that ensures transitions and regulation as a semi-public space. When closed at night, it forms a collectively used area allowing intense sociability, particularly among children and women, who develop shared activities there. Community surveillance ensures safety and social learning (Abu-Lughod, 1980, pp. 115-118). This introverted configuration, where main living areas open onto a courtyard or central patio, guarantees privacy while facilitating community life.Vernacular architectural features such as the bent entrance and the wast eddar (central patio) embody this spatial intermediality. The bent entrance obstructs direct views and acts as a ritualised passageway (Ragette, 2006, p. 53). The patio, a semi-open central space for communal domestic life, reconciles seclusion and interaction by hosting various activities depending on the time of day (Chahbi, 2024, pp. 576-578). The terraces of traditional houses also formed a network of communal spaces mainly used by women for domestic activities such as drying laundry and food preparation, becoming important places for socialisation and providing an alternative circulation system (Zoulagh, 2014, pp. 154-155), ‘fig. 1’.

Figure 1. Vernacular housing: (1) Map of the Medina of Fez (Ragette, 2006); (2) View of an alleyway in the Medina of Fez (waitandsea.fr); (3) bent entrance (Chahbi, 2024).

This spatial organisation is based on two fundamental structuring values: *horma*, which guides architectural design by imposing strict protection of family privacy; and *joura*, which governs neighbourhood solidarity through a system of mutual aid and responsibility. These values are governed by a legal and customary system of collective management, including the right of joint ownership, *el jarr*, which was developed within Islamic jurisprudence and is regulated by traditional institutions such as the *amin*, the *mohtassib*, the *fqih* and the *Jmaâ* (Kerrou, 2005; Moujaddidi, 1995).

THE COLONIAL BREAK: SEGREGATION AND MODERNITY (1912-1946)

The establishment of the French protectorate signalled a formal break with the centuries-old spatial organisation of the region. Colonial urban policy focused on two key axes : preserving ancient cities and creating separate new towns[3]. The housing built during this period was part of a segregationist logic that enabled the spatial hierarchy of different social classes to be established (Abu-Lughod, 1980, p. 178). There was a clear distinction between apartment buildings designed for Europeans and other forms of housing intended for Moroccans. In Casablanca, a laboratory of architectural modernity in Morocco, architects developed a typology of buildings inspired by European models and adapted to the local context(Cohen & Eleb, 1998, pp. 124-145).

These buildings, which are generally intended for wealthy clients, are characterised by their moderate height and decorative elements borrowed from the Art Deco and Neo-Moorish styles. According to Cohen and Eleb (1998, p. 124), they contribute to the creation of a new urban identity, as "the Casablanca apartment building of the 1920s and 1930s constitutes an original synthesis between European standards of modern comfort and an aesthetic incorporating local references, thus creating a specific colonial style", 'fig. 2'.

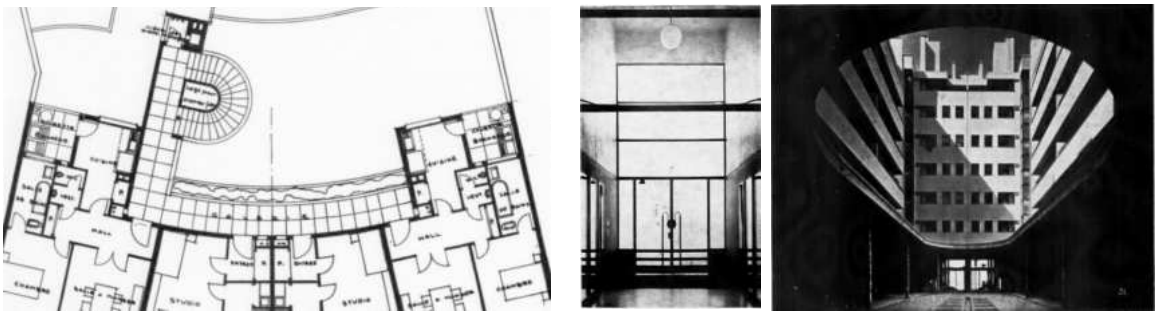

Figure 2. Apartment buildings for Europeans: (1) Standard floor plan, apartment building, Casablanca (Architecture d'Ajourd'hui, no. 3, 1936); (2) and (3) views of the entrance and courtyard, Brazza building complex, Casablanca, (Architecture d'Ajourd'hui, no. 3, 1936).

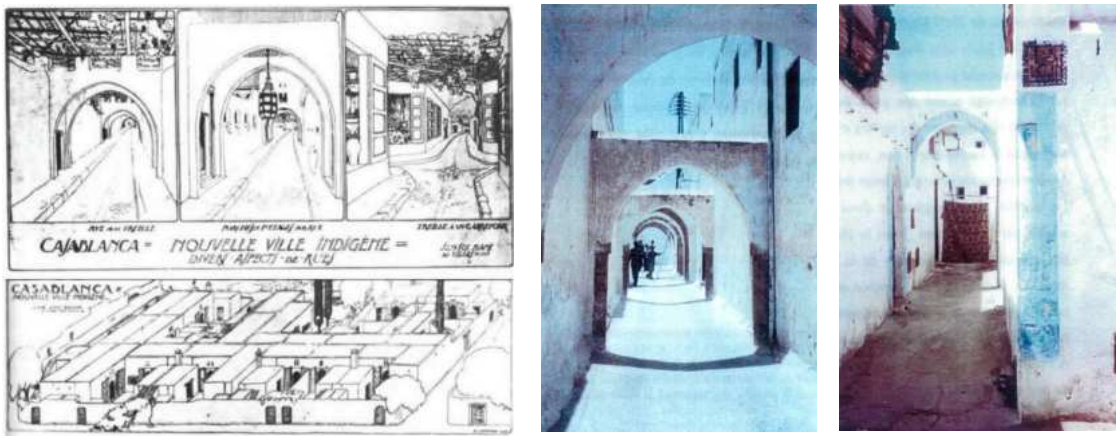

Figure 3. Housing for the Moroccan population: (1) Albert Laprade, Sketches used to develop indigenous neighbourhoods (Bouzoubaa, 2018, p. 62); (2) Alleyway in the Habous neighbourhood, Casablanca (new indigenous city); (3) Dead-end street serving the housing units, with a stretched cover delimiting and enlarging the living space, Cosumar housing estate, Casablanca (Hauw, 2004).

At the same time, the colonial administration began to address the issue of housing for the Moroccan population. However, initial interventions remained limited in the face of the large-scale migration of rural dwellers (Rachik, 2002, pp. 43-46). The initial projects focused on creating "new medinas", where housing was organised around courtyards and narrow alleys, incorporating modernised hygiene standards. Other projects designed for Moroccan workers, in the form of workers' towns on

the outskirts, were characterised by basic conditions that failed to meet the requirements for social integration(Hauw, 2004, pp. 84-97), 'fig. 3'.

THE ECOCHARD EXPERIMENT: ATTEMPTS AT HYBRIDISATION (1946-1960)

The post-war period saw a significant change in approach. Michel Ecochard's appointment as head of the urban planning department in 1946 led to the professionalisation and systematisation of collective housing production(Ecochard, 1951). Inspired by the principles of the modern movement and the Athens Charter, Ecochard developed a socially focused approach[4] to urban planning centred on the concepts of "housing for the greatest number", "innovative emergency housing models" (Atzeni&Mocci, 2017, p. 92) and "neighbourhood units" (Écochard, 1955, p. 101).

Ecochard develops two main types of housing. The first, the horizontal grid or "Ecochard grid", designed for Moroccan Muslim families, is a flexible model based on an 8x8m grid, consisting of north-south facing patio houses grouped in fours. Although inspired by Spanish quadras[5], this approach and its grid-based layout reflect an attempt to reconcile modern rationality with traditional lifestyles by reproducing the vernacular model in terms of integrating gradation and preserving access and patios, 'fig. 4'.

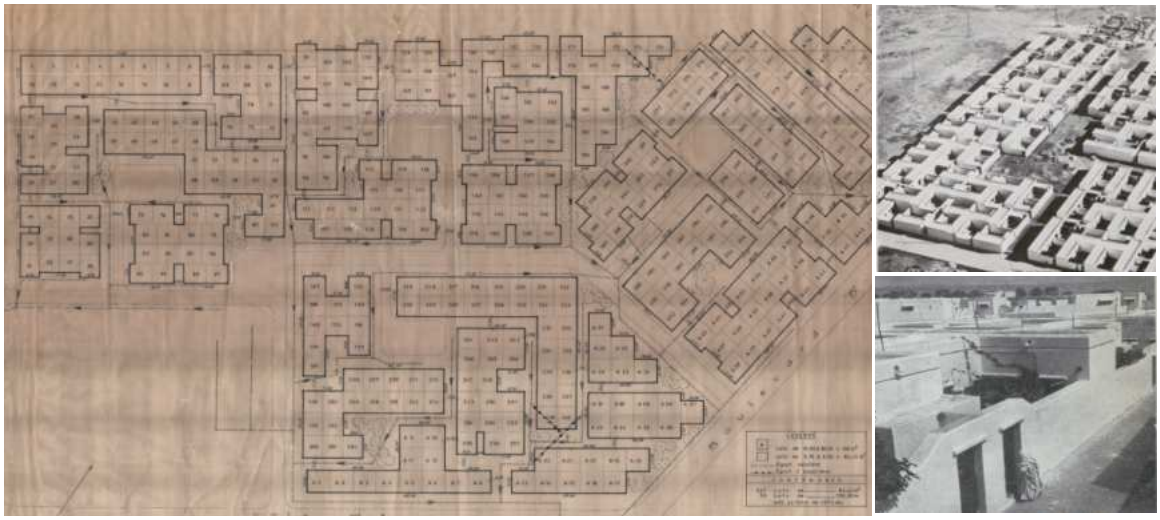

Figure 4. (1) Assembly plan for the horizontal grid, Yacoub Mansour district, Rabat (archive of the DU-MATNUHPV, P1-E0-491). (2) Aerial view of the 8x8 grid assembly and clearing of open spaces (L'Architecture d'Aujourd'hui, No. 57, 1954). (3) Casablanca, Ain-Chok, ground floor or upper floor housing, accessed via narrow alleys, with a bent entrance protecting the interior patios from prying eyes (Architecture française, 1952, No. 131-132).

The second form, which stemmed from reflections on collective housing, was mainly introduced by the architects GAMMA and d'ATBAT-Afrique. These architects developed innovative typologies that reconciled modern collective housing with traditional lifestyles. The most emblematic examples are the Tour de Bodiansky, Sud (Honeycomb) and Est-Ouest (Semiramis) buildings[6], which introduced the concept of "vertical collective housing adapted to the Moroccan context" and aimed to gradually familiarise the Muslim population with verticality "in line with the rise in living standards" (Ecochard, 1951, p. 103). This approach reflects a gradualist conception of housing modernisation, considering verticalisation to be a staged process of urban acculturation (Pinson, 1994, p. 194). These projects experiment with walkways and suspended patios to create recessed loggias in the façade, offering each apartment a private outdoor space that is hidden from view. This architectural innovation incorporates certain vernacular features into a modernist approach that meets the privacy requirements specific to Moroccan culture, whilst enabling vertical densification. As Avermaete (2010) notes, "The exterior walkways of the Carrières Centrales buildings were designed

as extensions of domestic space, allowing for activities that would traditionally have been carried out in the patios of traditional houses", 'fig. 5'.

Figure 5. Research into affordable housing by Atbat-Afrique: (1) experimental housing estate comprising three standard buildings in Casablanca, designed to rehouse a population "committed to Muslim ethics" (facades incorporating patios and open walkways); (2) housing intended for the Jewish population, whose lifestyle is considered to be similar to that of Europeans, with adaptations to their customs and climate (covered double-height patios and walkways for outdoor circulation); (3) European housing, also designed to meet the climate and social environment requirements of the target populations (integration of outdoor staircases and landings). (L'Architecture d'Aujourd'hui, 1955, no. 60).

However, this conception of intermediate spaces often reflects an overly idealistic and sometimes simplistic view of Moroccan lifestyles. Although they declare themselves to be resolutely modern and progressive, their designers take a critical stance towards Corbusier's doctrine. They consider the Athens Charter to be outdated and advocate introducing a social dimension to modern architecture (Avermaete & Ockman, 2005). This reductive approach tends to freeze complex social systems into stereotypical representations, obscuring their dynamism and ability to adapt to contemporary transformations.

STRATEGIES OF RESISTANCE AND APPROPRIATION

Despite these attempts at adaptation, very early on, residents began to reclaim and transform spaces in ways that did not always correspond to the original intentions of their designers (Hauw, 2004, pp. 97-104), 'fig. 6'. These transformations affected both private living spaces and intermediate spaces: filling in suspended patios to gain space, closing loggias, extending walkways, reallocating communal patios for private or commercial use, installing self-managed communal facilities, and creating additional thresholds through continuous adaptations to social needs.

Figure 6. Individual or collective appropriation and modification of intermediate spaces: (1) and (2) closure of patios and development of a small neighbourhood mosque (Atzeni & Mocci, 2017 and Hauw, 2004), experimental collective housing projects in the central quarries, south building; (3) construction of new living spaces on two levels replacing the suspended patios, east-west building, Carrières Centrales (Hauw, 2004).

This period was also characterised by interventions from the urban planning department, which aimed to address the individual appropriation of spaces adjacent to dwellings. The administration studied population densities, surveyed these areas and proposed plans for the layout and development of green spaces around sanitation facilities and buildings. These interventions reflect the ongoing tension between institutional control mechanisms and residents appropriation practices, 'fig. 7'.

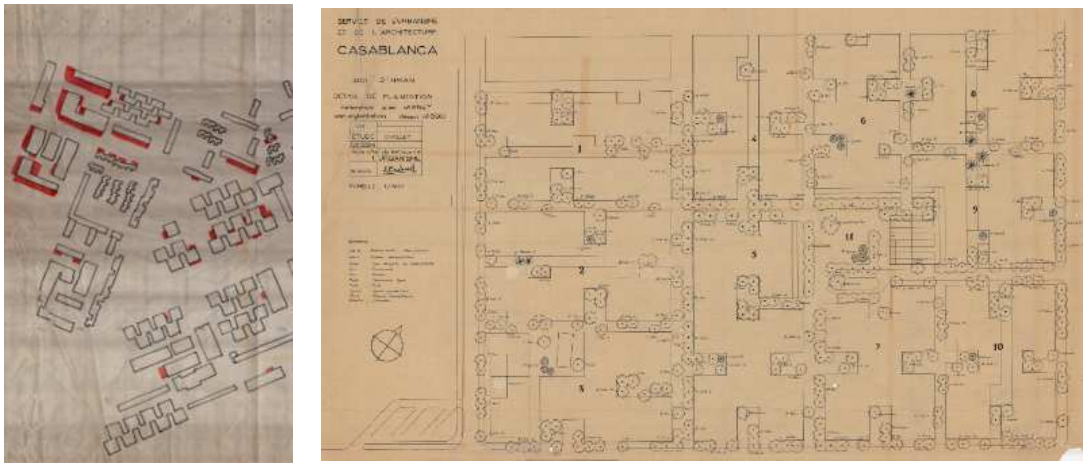

Figure 7. Planting and landscaping of open spaces: (1) survey of "informal" individual appropriations; (2) planting and landscaping plan for the 8x8 grid areas (P5-E0-306, P4-E0-108, DU-MATNUHPV archive).

In terms of the legal framework, the legislation introduced during this period was the first to provide context, they have several shortcomings, particularly with regard to the integration of Moroccan socio-cultural specificities. As Tribillon (2017) points out, as these provisions were directly inspired by French law, they do not sufficiently[7] consider traditional Moroccan ways of living and pre-existing forms of community solidarity.

RESILIENCE OF MODELS BETWEEN HYBRIDISATION AND VERNACULAR CONTINUITY

The resilience of the traditional model in colonial production is expressed through a complex process of hybridisation that does not reproduce vernacular forms identically, but reinvents them in ways that can be summarised as follows: (1) intermediality persists through the reproduction of traditional codes of transition between public and private spaces. Thus, residents occupy thresholds, halls, landings, gardens and communal courtyards according to the logic of appropriation, filtering and social regulation that originates from traditional models of intermediate spatiality(Navez-Bouchanine, 2002, pp. 156-178). This creates additional thresholds and differentiates areas according to gendered activities, reflecting the permanence of horma and joura values, (2) remarkable spatial creativity is used to repurpose intermediate spaces, transforming them into places for informal socialising. Landings become domestic extensions and roofs, courtyards and gardens are turned into meeting places. This "urban bricolage" (De Certeau, 1990, pp. 145-162) is a form of spatial intelligence which draws on collective memory to create new ways of living, and (3) the adaptation of collective regulations reflects the ability of vernacular social structures to adapt to the constraints of collective housing. When possible, residents develop informal systems for managing conflicts and organising maintenance, thereby perpetuating neighbourhood solidarity mechanisms in new architectural contexts. Rather than constituting a dysfunction or replacing regulated management models (Navez-Bouchanine, 1994), these "informal" practices stem from a lifestyle strategy that utilises residents spatial memory to adapt transitional spaces.

However, this resilience has its limits. The analysis reveals several contradictions and tensions. Despite attempts at adaptation, the colonial approach remains characterised by a rigid and essentialist view of Moroccan culture. References to the "indigenous way of life" obscure the actual social practices complexity and dynamism. Conversely, although the transformations carried out by the inhabitants are innovative, they are often constrained by the limitations of the developed models. Functionalist architecture, which is designed according to the principles of standardisation and optimisation, is less flexible than vernacular architecture when it comes to adapting to the changing needs of users. Furthermore, the colonial legal framework, inspired by French law, struggles to integrate traditional forms of community regulation, creating persistent discrepancies between official standards and actual practices.

CONCLUSION

An examination of colonial collective housing production in Morocco reveals the remarkable resilience of the traditional model, which is expressed not through direct resistance, but through subtle strategies of adaptation and reinvention, demonstrating the strength of vernacular models and their ability to mutate while preserving their structural values[8].

Indeed, the colonial period was a laboratory for experimentation, where new forms of collective living were negotiated and invented. Attempts at architectural hybridisation, despite their limitations, opened up avenues for a modern architecture sensitive to local cultural specificities, where the appropriation strategies developed by the inhabitants revealed a remarkable spatial intelligence that transformed architectural constraints into opportunities for social innovation.

This analysis enables us to view housing as a dynamic process of negotiation between designed models and inhabiting practices rather than as a completed product. It also reveals the need to move beyond technocratic, top-down approaches in order to integrate social and cultural considerations into architectural and urban design. The resilience of the traditional model in colonial production demonstrates the adaptability and resilience of societies in the face of imposed changes, and provides valuable insights for designing collective housing.

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[1]In this context, intermediality refers to all spatial devices that enable transition, gradation and regulation between the public and private spheres (Flamand, 2008).

[2]Vernacular design refers to all the techniques derived from traditional architectural production. This anonymous and spontaneous form of architecture is developed in harmony with its local environment and cultural constraints, using local materials and collectively transmitted know-how (Rudofsky, 1964).

[3] This separation, justified by the need not to alter the culture and customs of the "protected", is in reality an instrument of social and political control (Wright, 1991, p. 85).

[4] The urban planning department "addressed the problems posed by rapid urban growth, placing emphasis from the outset on the needs of the Moroccan population and striving to promote social urban planning above all else" (activities-urban planning department, 1954, p. 16).

[5] This model of grid-based master plan organisation originated in Latin America, under the influence of Spanish quadras, and was then imported and developed mainly in North Africa to meet the needs of large populations, notably by M. Ecochard in Morocco (Candilis, 1954).

[6] These projects were developed as part of the Shanty towns clearance programme in the "Carrières Centrales", Casablanca (Hay Mohammadi) and were designed by the architects at ATBAT-Afrique (Candilis, Woods, Bodiansky). Ecochard presents these projects as the first of their kind, experimenting with the development of collective housing that is attractive in terms of its economy, architecture and functionality, and that meets the needs of Moroccans. In a letter, the head of the urban planning department invites other architects to propose collective housing that may be of interest to Moroccans. Correspondence sent by Ecochard to the Housing Department in Casablanca (DU-MATNUHPV Archives, 685-R18/T5/P3).

[7] The road and construction regulations of 3 December 1927 (8 Joumada II 1346), relating to special provisions for indigenous towns, in particular Articles 100 and 101, require compliance with indigenous customs and prohibit direct views of neighbouring terraces or courtyards. (Archive DU S1-1119-2-10-2).

[8] This cultural continuity is consistent with Bourdieu's analyses (Bourdieu, 2008) on habitus and its reproduction in new contexts.

Material–Structure–Design Interactions in Rammed Earth Housing: A Study on Wall Design, Components, and Detail Solutions

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ABSTRACT

This study explores the interplay between material properties, structural systems, and architectural design decisions in contemporary rammed earth housing projects. Focusing on wall design, construction components, and detail solutions, the research investigates how earthen materials influence architectural and structural strategies in an integrated manner. Emphasizing the interdependence of material and structure, the study highlights the performative and aesthetic potential of rammed earth in sustainable housing design. The methodology involves a comparative analysis of selected projects documented in architectural journals and professional websites. Through the examination of wall typologies, material compositions, reinforcement methods, and junction details, the study categorizes different design and construction approaches shaped by local material availability and contextual needs.As part of the analysis, eight main structural materials types were identified across the selected cases: rammed earth, reinforced concrete, wood, stone, metal, steel, brick, glass and other systems. These structural variations are examined in relation to wall thickness, material mix, and detailing techniques to understand how different load-bearing strategies influence the use of rammed earth. These results underline the necessity of a holistic design approach that integrates material logic with construction and spatial thinking. Rammed earth housing, therefore, emerges as a field where architectural expression and structural efficiency are closely tied to material and context.

Keywords: Rammed Earth, Material-Structure Integration, Hybrid Structures, Local Materials

1. INTRODUCTION

In recent years, the growing interest in rammed earth construction techniques has repositioned rammed earth as a viable and promising building material within the framework of sustainable architecture. For this purpose, many architects and companies strive to develop original, distinctive, and context-specific solutions [1]. Beyond its environmental and economic advantages, such as low construction cost, reduced carbon footprint, high thermal performance, and the potential for local material sourcing, rammed earth offers both a theoretical and practical framework through which the interrelations of material, structure, and design can be critically reexamined in contemporary architectural production. Rooted in traditional knowledge yet increasingly aligned with modern performance criteria, this hybrid construction method holds significant potential for the development of place-based and material-driven design approaches. Despite its rising visibility in architectural practice, there remains a limited number of systematic and interdisciplinary studies that investigate the relationships between material properties, structural systems, and detailing strategies in rammed earth architecture. Yet, the applicability of such construction systems in the context of contemporary design must be evaluated not only through structural performance and technical adequacy, but also through the formative influence of material behavior on spatial organization, structural articulation,

and construction detailing. In this regard, the wall is no longer viewed as a mere load-bearing element but rather as a dynamic interface where material, structural, and design decisions intersect. Rammed earth material performance can be enhanced through integrated design strategies including optimized wall composition, strategic window placement, protective overhangs, and night ventilation systems [2]. Based on traditional knowledge yet aligned with contemporary performance criteria, rammed earth holds significant potential for developing integrated design strategies, enabling a critical reconsideration of the interrelations between material, structure, and architecture in contemporary housing practice.

2. THEORETICAL BACKGROUND

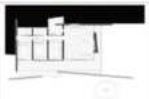
Recent architectural discourse has witnessed renewed interest in rammed earth construction, driven by growing concerns over resource limitations and environmental impacts in the building industry. Unlike traditional approaches rooted in cultural heritage, contemporary rammed earth architecture reflects deliberate design choices by architects adapting these techniques to modern needs [3]. The rammed earth construction technique emphasizes the use of locally sourced materials, offering a more sustainable and environmentally friendly alternative compared to other contemporary building methods. The technical basis of rammed earth construction begins with careful material assessment. Critical to this process is determining whether local soil sources require adjustments to gravel, sand, and clay proportions to meet structural requirements [4]. Following the proper optimization of the soil mixture, modern construction innovations have significantly enhanced the applicability of this traditional building technique. Modern construction innovations have introduced methods such as continuous rammed earth panels and mechanized formwork systems, which address traditional challenges like cracking while improving structural performance [5]. In addition to these developments, studies have demonstrated that rammed earth walls are effective not only in terms of structural strength but also in terms of thermal performance. Research confirms that properly constructed rammed earth walls measuring 50-60 cm in thickness provide effective thermal [6]. Such approaches demonstrate how material properties, structural systems, and architectural decisions interact in rammed earth construction.These developments position rammed earth as a viable contemporary housing design that successfully merges material with structural and spatial considerations, offering both ecological advantages and architectural potential.

3. METHODOLOGY

This study investigates the integration of rammed earth with other building components in contemporary architectural practice across diverse geographical and climatic contexts. For this purpose, eight housing projects constructed between 2014 and 2024 were selected to represent a broad spectrum of climatic and contextual conditions. To ensure programmatic comparability and consistent documentation across cases, housing projects were selected as the primary typology. This is because they reflect design criteria such as user interaction, privacy, comfort, environmental sensitivity and sustainability most intensely. The selected case studies were analyzed through a qualitative and visual assessment framework, focusing on both exterior and interior architectural expressions. The research adopts a methodological framework based on the comparative analysis of selected projects. The selected projects were evaluated based on parameters such as geographical location and climate type, structural systems and material combinations, and architectural and construction materials. The evaluation of material articulation, structural integration, and environmental responsiveness is based on the synthesis of visual data, including photographs, and architectural drawings with contextual information. Where primary technical documents were unavailable, information was cross-checked against architects' official publications and reputable professional outlets to ensure consistency of descriptions, drawings, and photographic evidence.

4. MATERIAL-STRUCTURE-DESIGN INTERACTIONS

This section analyzes the architectural and spatial integration of rammed earth in eight housing projects across Australia, Spain, China, Brazil, Mexico, Ecuador, and the USA.

Project	P1- Earth by the River	P2- Casa de Tapia en Ayerbe	P3- Earth House Yunnan	P4- Casa em Cunha
Exterior View				
Interior View				
Plan				
Year	2024	2014	2016	2019
Location	Allynbrook Australia	Ayerbe Spain	Guangming Village Yunnan, China	São Paulo Brazil
Climate	Humid Subtropical Climate (Cfa)	Oceanic Climate (Cfb)	Subtropical Highland Climate (Cwb)	Oceanic Climate (Cfb)
Area	370 – 560 m²	276 m²	148 m²	140 m²
Architect	Luigi Rosselli Architects	Edra Arquitectura km 0 Àngels Castellarnau	1U1V CUHK	Arquipélago Arquitetos

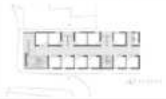
Project	P5- Guesthouse Casa Candelaria	P6- Casa Lasso	P7- Yunnan Village Collective Housing	P8- Marfa Ranch House
Exterior View				
Interior View				
Plan				
Year	2018	2019	2023	2021
Location	San Miguel de AllendeMexico	Lasso, Ecuador	Xialapu Village Yunnan, China	Texas, USA
Climate	Cold Semi-Arid Climate (BSk)	Cold Semi-Arid Climate (BSk)	Humid Subtropical Climate (Cfa)	Cold Semi-Arid Climate (BSk)
Area	2322 m²	350 m²	440 m²	497 m²
Architect	Cherem Arquitectos	RAMA Estudio	No 10-Architects	Lake | Flato Architects

Figure 1. The figure presents the exterior and interior views, plan, year of construction, climate, location, area, and architect of the eight selected projects.P1 [7]; P2 [8]; P3 [9]; P4 [10]; P5 [11]; P6 [12]; P7 [13]; P8 [14]. (Figure by the authors.)

These projects are examined in terms of their architectural design, floor plans, and integration with rammed earth construction techniques. The analysis focuses on the use of materials that create a hybrid rammed earth system and on criteria that vary according to the local context 'Fig. 1'.

Earth by the River (P1) is a farm house which consists of five separate structures, referencing the river's curves, and includes a multi-functional program with housing, outbuildings, a barn, storage, and staff accommodation. Engineering solutions have been developed to address flood risks and temperature fluctuations, suited to Australia's humid subtropical climate [7]. Casa de Tapia en Ayerbe (P2) is a house inspired by traditional local architecture, the design aims to revive sustainable approaches at the village scale. The three-story house is positioned to harmonize with the street level [8]. Guangming Village (P3) is a prototype building designed as part of the reconstruction process in Guangming Village, following the 2014 Ludian earthquake. Built using rammed earth techniques suited to the monsoon climate, the structure aims to provide a low-cost and durable housing solution [15]. The design, based on local materials, local technology, and local labor (the 3L principle), has been shaped according to environmental conditions and the cultural context. Spatial arrangements have been planned to respond to user needs and climatic conditions [16]. Casa em Cunha (P4) is a residence located in Cunha, Brazil. Situated in a mountainous area with heavy rainfall, the structure is partially embedded in the sloping terrain [10].

Guesthouse Casa Candelaria (P5) is located in Mexico's arid region. Reflecting the traditional Mexican courtyard typology, the structure consists of twelve separate volumes. These are arranged around three main courtyards, connected by corridors without direct contact between them. The plan separates public, semi-private, and private zones, with each courtyard formed around spatial units that define distinct functional groups [17]. Casa Lasso (P6) designed for the family's leisure and visitation purposes, this residence prioritizes passive design strategies in its relationship with the natural environment. The structure is designed with an open plan layout, enabling flexible use of space [18]. Yunnan Village Collective Housing (P7) was designed as part of a local government social housing initiative. The project presents a multifunctional settlement model addressing the housing needs of elderly individuals living alone and families with children in remote areas. Designed as a low-cost and functional housing solution, the project features a compact typology comprising 22 living units. Developed in harmony with traditional architecture, the design aims to preserve local identity and sustain collective memory [13]. Marfa Ranch House (P8) is located near the town of Marfa, an area with a desert climate. Designed by Lake Flato Architects, this contemporary ranch house consists of eight separate volumes. Its U-shaped layout, organized around a central courtyard, references the region's traditional ranch houses. Each volume is functionally distinct and supported by open verandas and semi-open transitional spaces [14].

4.1. Wall (Rammed Earth)

Across the selected projects, rammed earth is employed as the primary load-bearing material, with wall thicknesses ranging from 40 cm to 60 cm, adapted to local structural and climatic needs. P2 features 45 cm thick walls composed of lime, sand, gravel, and straw, refined through laboratory testing, while P5 uses 50 cm thick walls incorporating mineral aggregates to enhance thermal performance. P6 adopts 40 cm thick walls with integrated buttresses reaching 80 cm, and P8 presents the thickest walls at 60 cm, built entirely from locally sourced soil. These variations reflect structural strategies tailored to environmental conditions and desired thermal mass. Formwork and compaction methods also vary according to available resources and construction contexts. P3 and P7 utilize metal formworks and mechanical rammers to ensure high-density compaction and surface consistency, whereas P4 omits tie rods and allows the mixture to cure naturally between flat panels. P6 uses wooden formworks capable of resolving complex junctions within single molds, and P2 combines electric compressors with mechanized soil mixing. P1 demonstrates material versatility with custom formworks producing circular columns, arches, and chimneys from rammed earth.

Material compositions were optimized for both structural integrity and environmental performance. P3 includes 3% cement and recycled debris to improve strength in a post-disaster context. P5 and P8 employ natural additives, mineral pigments and native soils respectively to align with local environmental aesthetics and passive thermal control strategies. The thermal mass of thick walls in P5 and P8 helps regulate indoor temperatures by absorbing daytime heat and releasing it at night, while P6's longitudinal wall orientation shields against prevailing winds. P4 reinforces wind

protection with freestanding rammed earth walls. Several projects also highlight community-based construction approaches. P7 integrates granulometric soil analysis and optimized mixes as part of a local skills training initiative, while P3 simplifies construction techniques to enable post-disaster replication by non-specialists. P1, through its expressive architectural elements, illustrates the structural and aesthetic capacity of rammed earth as a hybrid material system.

4.2. Structural Systems of the Projects

In the eight projects, modern materials have been integrated with rammed earth to improve structural stability and enable architectural flexibility. In P1, steel trusses spanning six meters are used to overcome the spatial limitations typically associated with traditional rammed earth construction. In P7, steel is utilized in both the roof and staircase, contributing to improved seismic resistance. In P2, a concealed reinforced concrete beam is embedded within the rammed earth walls, while mass concrete foundations support composite concrete and wooden floors. P4 utilizes reinforced concrete beams at the top the rammed earth walls to support a wood roof system, enabling the incorporation of wide window openings. P5 features reinforced concrete columns and slabs that bear the roof load, in combination with rammed earth walls. P6 incorporates a reinforced concrete ring beam that caps the earthen walls, upon which wooden rafters for the pitched roof are placed. In P7, a reinforced concrete frame is infilled with rammed earth panels, offering a hybrid solution that combines seismic resilience with thermal insulation. P2 employs pine trusses above the reinforced concrete beam to support the roof. Similarly, P4 and P6 incorporate wooden rafters that complement reinforced concrete elements.

The integration of rammed earth with steel, reinforced concrete, and wood demonstrates a coherent architectural approach that effectively addresses both structural performance and environmental conditions. These material combinations not only improve the load-bearing capacity of earthen walls but also provide increased design adaptability, including the accommodation of larger spans, openings, and enhanced thermal efficiency. The selected case studies illustrate the practicality and effectiveness of hybrid construction systems in achieving structural durability, indoor comfort, and contextual responsiveness in contemporary residential architecture.

4.3. Details of the Projects

In the projects examined, both architectural design and construction details reflect a conscious effort to implement passive sustainable strategies, alongside the use of recycled and locally sourced materials. In P1, recycled wood was used for both flooring and roofing elements, while in P2, approximately 80% of the materials were obtained locally, resulting in a 50% reduction in CO_2 emissions. In P8, recycled metal pipes were repurposed to form a canopy structure above an outdoor veranda. P3, built in the aftermath of an earthquake, utilized construction materials salvaged from damaged buildings in the area. Similarly, P5 incorporated local Guanacaste wood, stone, and concrete, minimizing the environmental impact associated with transportation.

At the design level, P3 was developed to support the continuation of rural living practices, embedding resilience within everyday spatial use. Inspired by vernacular architecture, P8 adopted a courtyard-based plan that reflects traditional spatial arrangements. P6 introduced an open-plan layout with no permanent partition walls; instead, mobile wooden panels allow users to adapt the space according to changing needs and functions. In response to climatic conditions, P4 was partially embedded into the ground by excavating about one meter of earth, improving thermal insulation and protecting interior spaces from cold. On the other hand, P7 employed a sloped roof to effectively manage rainwater drainage and enhance natural ventilation through a compact roof structure. Across all projects, a strong focus on detailed design solutions plays a key role in enhancing sustainability by integrating locally adapted strategies with flexible spaces.

4.4. Comparison of the Projects

A comparative analysis of the selected case studies reveals that 'Fig. 2', with the exception of the P6, reinforced concrete was predominantly preferred as the primary foundation system. In the P1, a hybrid foundation composed of reinforced concrete and rammed earth was employed, whereas the P6 utilized a foundation system consisting of natural stone and wood. In the P6, rammed earth was combined with wood in the construction of the walls, while in the remaining cases, rammed earth was used independently as the primary wall material. Regarding structural frames, various combinations were observed: in some projects, reinforced concrete was used in conjunction with rammed earth, wood, or recycled steel for columns and beams; in others, where reinforced concrete was not employed, rammed earth was structurally integrated with wood or metal. As for the roofing systems, the analyzed rammed earth structures featured a diverse range of materials, including metal sheets, ceramic roof tiles, steel roof structures, concrete, wood, and glass tiles.

Project		P1- Earth by the River	P2- Casa de Tapia en Ayerbe	P3- Earth House Yunnan	P4- Casa em Cunha
Exterior View					
Interior View					
Structural System Elements	Fou.	Concrete Rammed Earth	R.Concrete	Natural Stone	R. Concrete
	Slab	Wood	R. Concrete Ceramic Voided Slab	R. Concrete	Wood
	Wall	Rammed Earth	Rammed Earth	Rammed Earth	Rammed Earth
	Column /Beam	Rammed Earth / Concrete	Concrete Rammed Earth Wood	R. Concrete Steel	Rammed Earth /Wood
	Roof	Metal Sheet	Ceramic Roof Tile	Steel Roof Structure	Wood

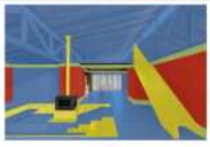
Project		P5- Guesthouse Casa Candelaria	P6- Casa Lasso	P7- Village Collective Housing Yunnan	P8-Marfa Ranch House
Exterior View					
Interior View					
Structural System Elements	Fou.	Concrete	Natural Stone	Reinforced Concrete	Concrete
	Slab	Concrete Wood	Wood	Concrete	Concrete Ceramic Tile
	Wall	Rammed Earth	Rammed Earth Wood	Rammed Earth	Rammed Earth
	Column /Beam	Rammed Earth /R. Concrete	Concrete Rammed Earth /Wood	Steel Reinforced /Concrete	Concrete Rammed Earth /Recycled Steel
	Roof	Concrete	Wood Ceramic Roof Tile	Concrete Glass Tiles	Metal
Lejant		Ram. earth	Concrete	Wood	Stone
		Metal	Steel	Brick	Glass

Figure 2. Foundation, slab, wall, column/beam and roof materials across the eight cases (2014–2024) based on the interior and exterior views of the buildings. (Data compiled from project documents and authors' coding; locations and climates per project sources; figure by the authors.)

5. EVALUATION

The eight housing projects analyzed in this study show that rammed earth is a highly adaptable material, responding to diverse climatic, structural, and spatial requirements. Wall thickness ranges from 40 to 60 cm, tailored to structural needs and thermal performance. In warm or semi-arid climates, thick rammed earth walls ensure thermal comfort through passive heat absorption and release, especially effective where temperature fluctuates significantly. The combination of rammed earth walls with climate-sensitive fenestration and shading contributes to stable indoor environments, while the material's density and impermeability provide flood protection. Rammed earth also aligns with rural and local architectural identities, as seen in projects reinterpreting vernacular forms. Though earth walls may limit height and span, these constraints are addressed through integration with concrete, steel and wood, enabling larger openings, flexible plans, and multi-story construction. Building orientation and wall placement reflect responses to wind and sun exposure. Beyond structure, rammed earth is used as a principal aesthetic element, with exposed surfaces showcasing the material's texture and stratification. Collectively, these projects demonstrate the effective application of rammed earth in contemporary architecture, facilitating sustainable design approaches that integrate environmental, structural, cultural, and aesthetic dimensions.

6. CONCLUSION

In conclusion, this study highlights the versatility and adaptability of rammed earth as a sustainable building material in contemporary housing. The comparative analysis of eight projects across diverse climates and contexts demonstrates that rammed earth can be effectively integrated into a variety of structural and architectural solutions. Its use enables passive thermal regulation, and resilient design, and strengthens connections to local materials, skills, and traditions.

The adoption of hybrid systems, combining rammed earth with materials like concrete, steel, or wood, allow for design flexibility, accommodating larger spans, and complex spatial requirements. Exposed rammed earth surfaces not only provide structural performance but also contribute to the aesthetic expression of buildings.

Ultimately, these findings emphasize the need for context-driven material choices, construction strategies, and passive design principles to maximize the benefits of rammed earth. Continued research into advanced material enhancements, long-term performance, and broader applicability will further expand the potential of rammed earth in sustainable and culturally grounded architectural practice.

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The Unexpected Existence of Earthen Heritage in Industrial Izmit: Challenges of Transmission and Survival

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ABSTRACT

Izmit, known as Nicomedia during the Roman period, is today Turkey's fourth-largest industrial production hub. In such a city, one might be surprised to encounter structures built using traditional methods, let alone adobe walls, earthen floors, or mud-plastered façades.

Dr. Balcı conducted oral history interviews in her doctoral research within 45 rural neighborhoods of Izmit, Kocaeli, Turkey. During these interviews, when asked "what was the oldest house you remember here?" responses frequently included references to earth and adobe. In these narratives, adobe was more than just a building material; it represented a cool interior in summer, warmth in winter, affordability, easy renewal, and healthy living conditions. Examples from these narratives will be highlighted throughout the paper. Motivated by the continued presence of adobe structures in Izmit's rural—and occasionally urbanized—settlements, and the existence of living memories related to adobe production, Dr. Balcı and her colleague Dr. Kishalı decided to deepen their research. The interviews conducted by Dr. Balcı were revisited using keywords "adobe," "earth," and "mud." Identified rural settlements containing adobe-filled structures were examined on-site, and the local inhabitants' perspectives were reassessed.

This paper will provide insights into the architectural and construction techniques of predominantly timber-framed adobe-filled vernacular buildings, material deterioration issues, and the local inhabitants' attitudes toward these structures. Thus, the aim is both to enhance Izmit's visibility within the global adobe inventory and to contribute to the discourse on issues surrounding adobe heritage.

Keywords: adobe, Izmit, earth, vernacular architecture

1 INTRODUCTION

Adobe has long been one of the principal building materials of rural Anatolia, valued for its natural qualities, accessibility, and climatic adaptability. Today, however, rapid urbanization, the widespread adoption of reinforced concrete, and the association of adobe in the social imagination with "backwardness" and "fragility" have relegated it to the background. Nevertheless, recent studies demonstrate that adobe is not merely a building material but also a cultural element that embodies, in collective memory, rural lifestyles, everyday economic relations, notions of healthy dwelling, and the communal solidarity inherent in the practice of *imece* (collective labor) **[1]**.

Izmit—known as Nicomedia in the Roman period and retaining its strategic importance under Byzantine and Ottoman rule—is today Turkey's fourth-largest industrial production hub and a city defined primarily by its industrial identity. In such a context, adobe may initially be perceived merely

as a material of the past; yet oral history interviews and field observations in Izmit's rural neighborhoods reveal that adobe continues to persist both physically and symbolically in collective memory. This article, drawing upon oral history interviews conducted in 45 rural neighborhoods of Izmit, seeks to evaluate the place of adobe and other earth-based building materials in local memory **[2]**. The recurrent image of the "old house" in these narratives illustrates how adobe has come to signify nostalgia, solidarity, and naturalness in collective memory. Field observations further demonstrate that these buildings, often abandoned or converted to secondary uses, expose the fragility of adobe heritage in the face of modernization. The use of adobe in vernacular architecture—as masonry, as infill in timber-framed structures, and as plaster or rendering—has been examined in numerous publications. Several studies have discussed construction techniques, methods, and conservation approaches **[3, 4, 5]**. In archaeology, too, adobe has been investigated in various studies **[6, 7]**.

The Getty Conservation Institute sponsored the Getty Seismic Adobe Project, which analyzed the performance of historic adobe structures during earthquakes **[8]**. More recently, the earthquakes of February 6, 2023 (Mw 7.7 and Mw 7.6), which struck the Pazarcık and Elbistan districts of Kahramanmaraş, Türkiye, caused massive loss of life and widespread destruction. Research assessing the damage to adobe buildings has yielded significant findings. For example, during the Post-Earthquake Cultural Heritage Damage Assessment conducted in Elbistan in August 2023, 32 historic structures were surveyed, of which 28 remained undamaged despite the two catastrophic seismic events **[9]**. Further technical analyses on damage patterns and the structural behavior of adobe buildings have also been undertaken **[10]**. Innovative approaches in material science have been pursued since the early 1990s, particularly through the work of Kafescioglu **[11]** and Işık **[12]**. (1995) on *Alker*, a gypsum-stabilized earth material. Current R&D studies on adobe and rammed earth continue to expand this field **[13]**. New architectural applications in rammed earth demonstrate how traditional construction techniques can be sustained while enhancing resilience, thus ensuring the continuity of adobe architecture **[14]**.

2 HISTORICAL AND RURAL BACKGROUND OF IZMIT

Izmit has long been one of the most important settlements in Anatolia. Founded in the 4th century BCE during the Bithynian Kingdom as Nicomedia, the city became a major center of the Roman Empire in the East. Under Diocletian (AD 284–305), monumental structures, administrative buildings, and military garrisons were built. Known historically as Iznikmid, Izmid, and Ismiid, the city reflects changing territorial boundaries over time. The earliest settlement, Astakoz, was established in Başiskele and later moved to its present location in the 3rd century BCE. Between AD 284 and 330, Izmit served as the Roman capital before suffering invasions and eventually passing into Ottoman rule in 1333 **[15].**

During the Ottoman era, Izmit served both as an administrative center and an agricultural hinterland. From the 16th century, Izmit's sheltered harbor facilitated shipments to Istanbul. The 1776 earthquake led to decline, but the city revived in the 19th century with textile factories producing broadcloth, fezzes, and cotton prints. In 1888, Izmit became an independent *sanjak*, and significant urban development followed. Before the Republic, Izmit's position as a crossroads from the Balkans and Istanbul into Anatolia made it strategically important during the War of Independence. The presence of Manav and arrivial of Muhacir-Mübadil and other migrant groups diversified settlement patterns and architectural typologies **[16].**

Izmit's industrial identity grew stronger following the "national economy" policies of the İzmir Economic Congress in 1923 **[17]**. The SEKA Paper Factory, opened in 1936, transformed the city's landscape, population, and rural livelihoods. Industrialization accelerated in the 1950s with new facilities along the Gulf of Izmit in present-day Kartepe, Başiskele, and Gölcük, making Izmit a predominantly industrial center **[18].** Proximity of rural areas to factories facilitated labor mobility, driving rural transformations. Administrative restructuring that reclassified villages as

neighborhoods further eroded rural identity. In recent years, especially after the Covid-19 pandemic and the 2023 earthquakes, Izmit's closeness to Istanbul has made it attractive to urban residents seeking safe living environments **[2].**

Izmit was designated the central district of Kocaeli province in 1924. Today, it encompasses 12 districts, including Karamürsel, Gölcük, Başiskele, Kartepe, Derince, Körfez, Dilovası, Gebze, Çayırova, Darıca, Kandıra, and Izmit itself. Kocaeli is ranked as Türkiye's fourth-largest industrial and commercial center after Istanbul, Ankara, and Izmir **[19]**. The SEKA factory, one of the first major heavy industrial investments in Türkiye, reshaped the city's profile. Subsequent petrochemical plants, tire factories, and the automotive industry further consolidated Izmit's role as the country's fourth-largest industrial hub from the mid-20th century onward. These processes integrated rural areas into the urban fabric: successive migration waves diversified rural demographics, while traditional material culture weakened.

Despite these pressures, Izmit's rural areas still reflect cultural diversity. Even though the 2012 Metropolitan Municipality Law reclassified villages as urban neighborhoods, fieldwork shows that many settlements have preserved their cultural identity. Villages vary in altitude, topography, agricultural practices, migration histories, and levels of urbanization pressure, yet many still retain distinctive practices **[20]**.

3 CULTURAL AND ARCHITECTURAL CHARACTERISTICS OF ADOBE ARCHITECTURE IN RURAL İZMİT

Traditional construction techniques in the rural settlements of Izmit demonstrate a certain continuity. Chronologically, the timber log technique known as *çandı* was followed by timber-frame systems with adobe infill or the wattle-and-daub method, and later by the use of solid brick as infill material. Except for the timber log technique, all other systems involved the use of earth-based materials in some form. Rural Izmit, situated at the intersection of the eastern Marmara and western Black Sea regions, contains distinctive examples of architecture shaped by earth-based materials **[21]**. These buildings are most commonly composed of timber frames filled with adobe and are typically one or two stories high. The timber skeleton was prepared using wood from local forests, while the infill consisted of adobe blocks **(Fig. 1)** produced by mixing soil and straw from the immediate surroundings. Another widespread method involved weaving thin wooden sticks between structural timbers to form a basket-like framework, which was then coated with a mud plaster.

Figure 1. Examples of walls constructed with adobe blocks in various rural settlements of Izmit. (Balci, 2024)

The rural fabric shaped by *Manav*, *muhacir*, *mübadil*, and other migrant groups provided a cultural basis for different typologies; nevertheless, across the region, the geography and locally available materials consistently informed rural architectural practices in various forms. Accessibility of materials constituted one of the fundamental requirements of vernacular architecture. In oral history

interviews, when asked about sources of building materials, respondents consistently pointed to nearby locations—*behind the village, in a neighboring settlement, along a roadside, or near a water source.*

Figure 2. Use of mud plaster on timber-frame hımış and brick infill walls in rural settlements of Izmit (Balci, 2024)

The spatial organization of traditional houses built with earth-based materials also reflects the cultural practices of rural Izmit. Houses were generally arranged around a central *sofa* (hall) with adjoining rooms. Ground floors typically accommodated storage, cellars, or stables, while upper floors were used as living quarters. Exterior façades were commonly finished with mud plaster and a local lime-earth whitewash known as *yaldız*. Mud plaster served both to protect the adobe and to regulate interior humidity. This simple yet effective system created indoor environments that remained cool in summer and warm in winter **(Fig 2)**.

Today, however, adobe structures are increasingly falling into disuse and abandonment. Many have been converted into barns, storage spaces, or animal shelters. Reinforced concrete houses, associated with "modernity," "cleanliness," and "durability," have become widespread even in rural contexts, while adobe houses are often perceived as symbols of backwardness **(Fig. 3)**. Nevertheless, oral history accounts reveal that adobe continues to be identified with the "old house" image, carrying nostalgic value. Thus, adobe architecture in rural Izmit holds a distinctive significance both for its spatial qualities and its place in collective memory. Produced from local materials, these structures stand as tangible expressions of the relationship between rural communities and their natural environment.

Figure 3. Two examples of lost earthen houses: one from Emirhan (right) and the other from Böğürgen (left). (Balci, 2024)

4 ORAL HISTORY FINDINGS ON THE USE OF EARTH IN RURAL ARCHITECTURE IN İZMİT

The transcripts of oral history interviews conducted with 96 individuals across 45 rural neighborhoods of Izmit were systematically searched using the keywords "adobe," "earth," and "mud." In 28 villages, 44 respondents referred to one or more of these terms when answering the question "What was the oldest house you remember in the village?" **(Fig. 4)**.

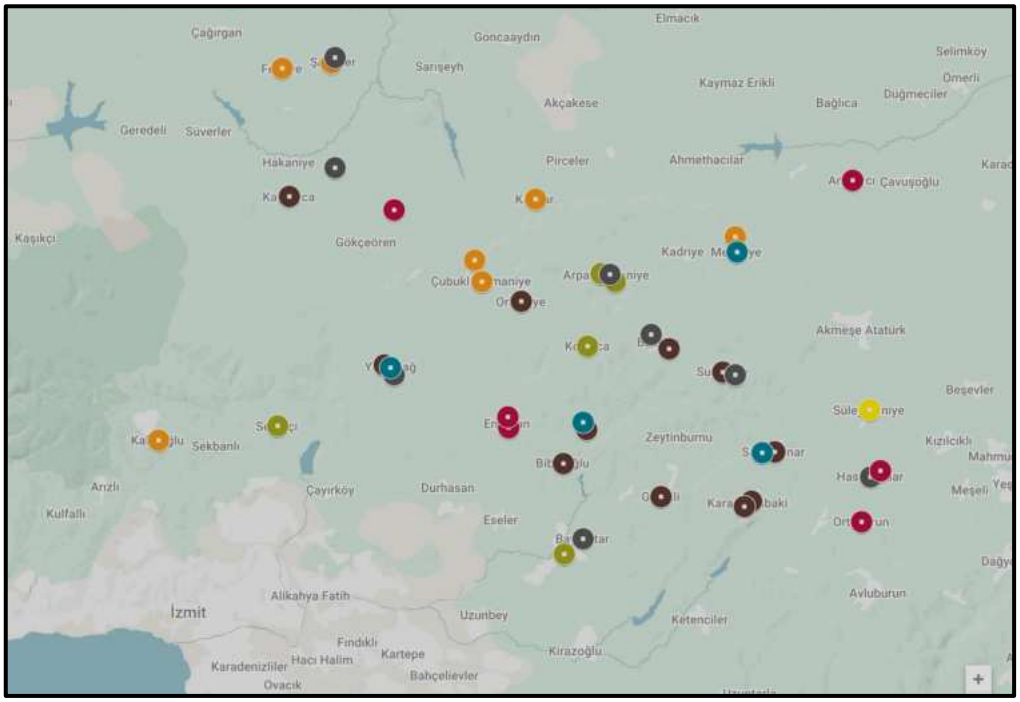

Figure 4. Map of settlements mentioned in oral history narratives where the terms "adobe," "earth," or "mud" appear. (Balci & Kishali, 2025)

Although the interviews were not designed specifically to investigate the use of earth-based materials in traditional architecture but rather to examine broader aspects of cultural identity, the fact that nearly half of the respondents recalled narratives related to earth-based construction demonstrates the continuing significance of these materials in collective memory. Another notable point is that a portion of the participants remembered *çandı*—a timber log construction system in which earth was almost never used—as the oldest building technique, which also accounts for the observed distribution. An analysis of the interview content makes it possible to identify five main themes: climatic comfort, economic accessibility, healthy interior environment, maintenance and sustainability, and rural wisdom and memory.

4.1 Climatic Comfort [22]

One of the most frequently emphasized features by participants was the climatic advantage of adobe houses. Interviewees from nearly every village repeated the expression "cool in summer, warm in winter." As one respondent described, *"In winter we barely lit the stove, yet the house remained warm; in summer, while it was burning hot outside, the interior stayed cool."* These accounts confirm, through everyday experience, the climate-responsive qualities of earth-based materials. In the narratives of local residents, adobe was not regarded merely as a construction material but as an integral part of daily life. A respondent compared the energy required to heat old adobe houses and new reinforced-concrete houses, stating: *"In an adobe house, let's say you burn one ton of wood, but in a concrete house you burn five tons. That's the difference."*

An 85-year-old male interviewee from Hasancıklar village compared the reinforced-concrete house he has been living in after the earthquake with his former adobe dwelling: *"Do not be afraid of being cold in that adobe house during winter. In today's concrete houses, it is hot in summer and cold in winter. My house was timber-supported adobe."* He also expressed his longing for the past by recounting the experience of a guest: *"A friend of mine from Izmit came to visit; there was a wedding here, and he stayed overnight. In the morning he said to me: 'I slept well tonight! I slept warmly; I rested here. In the concrete houses where we live, you cannot sleep. They are cold! If the stove is burning, you get warm;' if not, you cannot!"*

4.2 Economic Accessibility

The economic accessibility of adobe also emerged as a prominent theme. Interviewees emphasized that the material was easy to obtain and that everyone could produce their own adobe. As one participant described, *"We mixed the mud, added straw, poured it into the mold; it cost nothing."* The interviews further revealed that many villages had specific sources of soil for different purposes (adobe blocks, mud plaster, lime wash, earthen ovens, etc.). People literally built their houses with their own hands. One interviewee, who earlier in the conversation spoke of his family's material deprivation following migration, recounted: *"He came here and wove timber poles together like fingers, then plastered them with mud and built a house. My father's house was also a small, low adobe dwelling."*

The interviews also highlighted the widespread use of *imece*, or communal labor, in the construction process. Adobe thus appears not only as a building material but also as a social practice that strengthened solidarity within the village. Narratives frequently described this cooperative method: *"Back then, houses in the old village were built collectively from timber through imece. Neighbors would gather, raise the wooden frame together, weave thin hazelnut sticks in between, plaster them with mud, and cover the roof with what we call 'Gypsy tiles,' the old style of roofing tile."*

4.3 Healthy Indoor Environment

Adobe structures were also associated with healthy living conditions. The breathable nature of earth-based materials, their ability to regulate humidity, and their facilitation of natural air circulation indoors were described by users as positive experiences. In the narratives of the older generation in particular, it was frequently stated that illnesses were less common in adobe houses and that the quality of sleep was higher. As one female participant explained, *"There was no dampness in the adobe house; it absorbed the moisture, and we would not fall ill.* In these dwellings, where the floors were also made of earth, carpets were not used; instead, mats woven from corn husks or reeds were spread over the ground. As one interviewee from Dağköy recalled, *"Women would smooth the earthen floor; it smelled wonderfully of earth."* These accounts also indicate that, along with the walls, the floors were renewed annually.

An elderly male interviewee from the settlement of Çubuklu Osmaniye described their timber-frame, wattle-and-daub houses coated with mud plaster: *"Those houses were very healthy, woven structures. There was a ceiling above, a wooden floor below, and mud plaster inside and out. We lived there, and it was very healthy. Once we moved into these concrete houses—everything is there—but if you don't ventilate, it gets damp. The old houses were better."* Such testimonies highlight striking parallels between local knowledge and contemporary scientific discussions regarding the health and environmental performance of earth-based construction.

4.4 Maintenance and Sustainability

Statements highlighting the disadvantages of adobe houses were also noteworthy. Several participants pointed out that adobe deteriorates easily during rainy weather and therefore requires regular maintenance. One respondent emphasized this issue by stating: *"In the rain, the adobe would*

melt; it always needed repair." In houses that were partially filled with brick and partially coated with mud plaster, the brick sections often corresponded to the facades most exposed to rain and, consequently, to the earthen surfaces most prone to deterioration.

This maintenance process was not perceived solely as a burden but also as a cyclical part of village life. Almost every year, particularly in the spring, the exterior façades of the houses were replastered with mud, an activity that not only helped preserve the adobe but also reinforced neighborly relations. The link between this annual cycle of maintenance and *Hıdrellez*—a seasonal festivity in Anatolia—was made explicit by an elderly female interviewee from Arpalık İhsaniye: *"We plastered before winter, and again after summer because the rain and drizzle would cause the mud to fall off. We plastered again near Hıdrellez so that the houses would hold up well and look nice."*

It was further understood from the interviews that this annual mud maintenance was carried out both in early spring around *Hıdrellez* and again at the end of summer after the harvest. This cyclical practice may thus be interpreted as an intrinsic requirement of adobe architecture, ensuring its continuity while simultaneously sustaining collective solidarity. Today, however, this labor-intensive maintenance culture has gradually weakened; with the transition to reinforced-concrete houses, the preservation of adobe or mud-plastered dwellings has become increasingly difficult.

4.5 Rural Wisdom and Memory

Humanity's relationship with earth extends deep into history. This readily malleable material gradually became the source of shelter. At the same time, people cooked meals in clay pots and earthen ovens **(Fig. 5)**, stored provisions in clay jars, and slept upon earthen floors. Adobe houses also serve as carriers of the "old house" image. Childhood memories, family life, and elements of village culture are frequently associated with adobe dwellings. One participant emphasized the nostalgic value of adobe by recalling, *"Our wedding was held in front of the adobe house; now it lies in ruins."* At the same time, the process of modernization has led to reinforced-concrete houses being perceived as "strong" and "modern," while adobe houses are increasingly seen as "old-fashioned" and "backward."

Figure 5. Examples of earthen stoves and hearths constructed for indoor and outdoor use in rural settlements of Izmit. (Balci, 2024)

These findings indicate that adobe in rural Izmit is not merely a building material of the past but an element intertwined with collective memory, cultural practices, and perceptions of everyday life. In local memory, adobe carries nostalgic value due to its associations with climatic comfort, solidarity, and health, yet it is simultaneously recalled as fragile and outdated. This layered perception represents one of the central tensions in the preservation and transmission of adobe heritage.

5 CONCLUSION

Field surveys conducted in rural Izmit reveal that adobe structures have largely lost their primary function today, yet their traces remain visibly present. In most villages, houses constructed using traditional building techniques with various earth-based materials have been abandoned, left in a state of disrepair, or repurposed as storage spaces, barns, or animal shelters. This situation demonstrates that adobe has lost its former significance as a material for daily habitation, but endures in the rural landscape as a background element, sustained above all by collective memory. These secondary uses contribute, to some extent, to the preservation of the structures while simultaneously allowing adobe to persist as a form of "living heritage" within the rural economy. However, such uses overshadow the cultural value of these buildings, reducing them to mere "functional remnants."

One striking aspect observed during fieldwork was the pronounced material deterioration of adobe structures. In regions with heavy rainfall, erosion, cracking, and surface losses on walls were particularly evident. In neglected buildings, the collapse of roofs further accelerated the decay process, exposing adobe blocks and mud-plastered walls directly to rain and wind.

The attitudes of local residents toward adobe houses reveal a dual perception. For older generations, adobe represents a healthy, natural, and inexpensive way of life, and thus carries nostalgic value. By contrast, younger generations and those more closely aligned with modernization perceive adobe houses as symbols of "backwardness" and "fragility." As one villager remarked, *"Nobody likes adobe houses anymore; people want urban-style houses."* This illustrates that the transmission of adobe heritage involves not only physical conservation but also a transformation of perceptions.

Field observations in rural Izmit reveal the growing impact of urbanization. In neighborhoods closer to the urban core, reinforced-concrete buildings have become increasingly prevalent, while adobe houses are gradually marginalized within the new built environment. In more distant villages, adobe structures have been preserved to a greater extent, yet declining populations and outmigration have weakened the culture of maintenance.

In conclusion, although adobe heritage in rural Izmit has increasingly been pushed into the background under the pressures of industry and modernization, it remains vibrant in collective memory. This article has demonstrated that adobe is not only an architectural element but also a cultural, social, and ecological value. Preserving adobe heritage will contribute both to reconsidering Izmit's industrial identity alongside its rural heritage and to bringing earth-based construction back into focus on a global scale.

4 ACKNOWLEDGMENTS

The doctoral study on which this article is based was supported by the YÖK 100/2000 Doctoral Fellowship Program.

This article is based on oral history interviews and field observations conducted within the scope of the doctoral dissertation entitled *"A Cultural Geography Approach in the Analysis of Rural Settlements: The Case of Izmit, Kocaeli"*, completed in 2024 under the supervision of Prof. Dr. İclal Dinçer at Yıldız Technical University, Department of Urban and Regional Planning. We would like to express our gratitude to Fatma Kaplan Hürriyet, Mayor of Izmit, for enabling the use of these oral history interviews—originally conducted as part of the Izmit Municipality Intangible Cultural Heritage Project—within the dissertation research, thereby allowing their contribution to the scientific field.

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Cultured Embedded in Form: Halawa House by Hasan Fathy

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ABSTRACT:

With the increasing awareness of the necessity of sustainable and culturally relevant architecture, the paper presents a narrow study of the Halawa House in Agamy, Egypt. Designed by Abdel Wahed El-Wakil under the guidance of Hassan Fathy, the Halawa House is a rather illustrative demonstration of how the vernacular principles, based on the values of the community, the adaptation to the environment, and the use of local craftsmanship, can be applied to modern architecture. The aim of the paper is to discuss the means through which spatial organization, material authenticity, and climate-responsive strategies are implemented in the Halawa House and explain what it can teach us about the preservation of earthen architectural heritage. The study takes a qualitative case-study approach and combines contemporary academic literature, architectural analysis, and thematic analysis to unveil the conversation between tradition and innovation that informs the Halawa House. The paper cocludes with a suggestion that the Halawa House is a good example of how vernacular models can address the current issues and at the same time raise important questions regarding the ability of such models to adapt and survive in the fast-changing world.

Keywords: Vernacular Architecture, Hassan Fathy, Climate-Responsive Design, Cultural Identity, and Indigenous Materials.

1 INTRODUCTION

Earthen architecture is a pillar of human settlement in arid and semi-arid areas as is seen in the case of Egypt where mud brick and adobe are continuously used. Their construction practices have been evolving over thousands of years and responding to environmental, social and economic factors (1). The sustainability of such practices is usually attributed to the fact that they help to stabilize harsh climatic conditions, make use of locally available resources, and promote the community living style (2). The recent focus on sustainability and climate adaptation in the world has led to the re-focus on the vernacular traditions that exhibit resilience and adaptability in their own contexts (3).

In this discussion, the works of Hassan Fathy are well known. The practice of Fathy has been marked with the incorporation of local building methods and the clear emphasis on environmental and cultural sensitivity (4). His emphasis on local materials and passive design measures has been seen as a direct reaction to the demands of modernization and environmental change (5). The Halawa House built in Agamy in 1975 under the guidance of Fathy is often referred to as one of the instances when these principles have been put into practice.

In the current study, the Halawa House can be seen as a lens, through which the philosophy of Fathy is projected onto the modern discussions on the earthen architectural heritage. In order to explain this connection, qualitative case-study approach was chosen to examine spatial planning, choice of materials, and environmental measures. This is aimed at explaining the relevance and possible use of earthen architecture in current and future Egypt (6).

2 LITERATURE REVIEW

2.1 Vernacular Architecture: Sustainability, Identity, and Social Practice

Vernacular architecture, which can be considered the material and spatial system created by means of local methods, has long been recognized as a source of sustainable design solutions, particularly in the places where the climate is harsh and the resources are limited. As an example, traditional earth-based building methods in Egypt (i.e., mud brick and adobe) have been empirically demonstrated to provide effective thermal control and reduce reliance on mechanical heating and cooling systems to a great extent (1, 7). Since such approaches are based exclusively on locally available materials and utilize passive environmental modalities, they provide a practical alternative to contemporary environmental goals and the low-carbon construction agenda (2). The current studies have further positioned the vernacular as a dynamic, adaptive system, which can guide the current sustainability efforts instead of being considered historical artifacts (8).

The combination of cultural identity and social practice is a fundamental attribute of earthen architecture in Egypt. Structural elements such as courtyards, transitions and privacy gradations are direct reflections of local customs, family structure and the life of the community (1). These spatial arrangements allow interaction, privacy and hospitality hence making the built environment to incorporate intangible cultural values (9). Empirical evidence also shows that revival of vernacular architectural typologies can help in reinforcing community cohesion especially when participatory design processes are adopted in incorporating local knowledge and community involvement (8).

2.2 Hassan Fathy's Legacy and Contemporary Adaptation

With the ongoing discussion of culturally embedded and sustainable design, the philosophy of architecture as developed by Hassan Fathy has become a point of reference to modern architects. The advice of Fathy on the use of indigenous materials, passive cooling methods, and the involvement of the community anticipates some of the main sustainability goals that are currently being explored. Such case studies as New Gourna and the Halawa House are illustrative of how environmental, social, and cultural needs are incorporated into an all-inclusive design paradigm. Recent research also recognizes the method of Fathy as an intermediate between the traditional vernacular knowledge and the new practice needed in the contemporary settings.

Modern research in vernacular architecture finds several barriers to the more widespread use of earthen construction methods. Three of these barriers are commonly mentioned: oppressive regulatory regimes, the loss of traditional craft knowledge, and unstoppable modernization (2). Despite the size of these barriers, a growing amount of literature suggests that they can be addressed by specific policy measures, well-designed educational initiatives, and careful application of vernacular principles to modern requirements (8). The literature available highlights the fact that only those projects that are selectively re-interpretation of vernacular precedents in such a way that they achieve both cultural resonance and technical feasibility in the changing socio-economic scenarios succeed.

3 METHODOLOGY

The study has adopted a qualitative, case-study approach in the analysis of the operationalization of the architectural philosophy of Hassan Fathy in the Halawa House. This decision is consistent with

current trends in recent architectural thought, which emphasize context-sensitive interpretation and spatial analysis in the study of vernacular and earthen architecture (1, 6). In that regard, the Halawa House was chosen as a prototype of the vernacular revival and culture-integrated design in Egypt because it retained the traditional spatial organization, climate-responsive design, and native building material.

The information has been collected using various secondary sources- published architectural records, peer-reviewed journal articles and critical reports that explain the spatial, material and environmental features of the Halawa House. Comparative insights have also been developed using recent literature on vernacular architecture, climatic adaptation as well as cultural continuity (1, 3). The combination of these various materials will aim at increasing the depth as well as the validity of analysis.

İn published documentation and the existence of analyses that could affect the interpretation of architectural features and social practices. Furthermore, the study is limited to one case, and thus the results may not be applicable to other examples of earthen architecture in Egypt or similar situations. Despite these limitations, triangulation of various sources and careful cross-validation of information have been used to increase the validity of the study, as per current methodological standards (1, 6)

4 ANALYSIS OF THE CASE STUDY

4.1 Fathy's Philosophy in Architecture

The philosophy of architecture of Hassan Fathy is based on three issues; cultural heritage, environmental adaptation and social responsibility. He is best known for reviving and reinterpreting indigenous building traditions, a project that presupposes that architecture has to respond to the specific needs, climatic conditions, and social practices of the environment. Fathy is always in support of the use of local materials, passive environmental solutions, and spatial arrangements that support communal lives. Concisely, his holistic vision in perspective would place the built environment as a tool that would enable social interaction, ensure cultural continuity, and uphold an ecological balance. Modern criticism observes that Fathy was ahead of his time in his advocacy of passive cooling, natural ventilation, and the involvement of the community in the design process, as those are some of the sustainability concerns that are currently in the spotlight of architectural discussion (1, 4).

4.2 The Halawa House

Located in the Agamy village of Egypt and completed in 1975, the Halawa House, which was constructed under the guidance of Hassan Fathy, is a perfect example of a culture-based design. El-Wakil has achieved a building that has successfully balanced climatic and social demands by reimagining conventional spatial forms, exploiting climate-responsive techniques, and prioritizing locally produced craft. The Halawa House is therefore an example of how vernacular interpretations can be re-arranged to fit modern day living, and serve as a model of a sustainable and culturally satisfying architecture. (11)

4.3 Key Aspects of Fathy's Philosophy in the Halawa House

4.3.1 Spatial and Social Organization:

In the architectural discourse, the Halawa House is a case study of a systematic space approach that is aimed at reflecting and supporting the cultural activities and social life of the people that are living in it. The general plan is divided into separate zones, i.e., the areas of privacy, semi-publicity, and the threshold loggia, in such a way that the privacy is guaranteed, and, at the same time, the hospitality and the interaction with the community are also possible (1, 12). The loggia

itself functions as a crucial intermediary between the interior and the exterior, providing versatilely sized environments suitable to both day-to-day operations and mass social events.

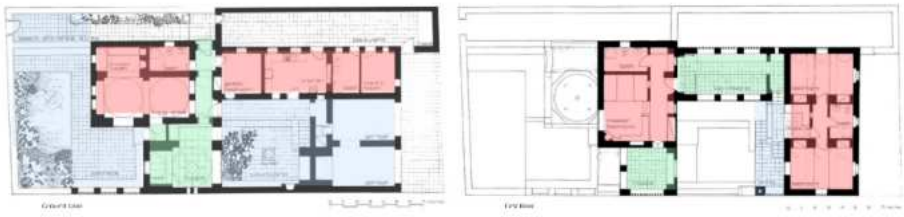

Figure 1. The Ground and First floor plans of the Halawa House, illustrates the transition between private(red), semi public(green) and public zones(blue). (Source: authors, 2025)

The spatial layout of Halawa House centres on the courtyard, which is thought of as the intellectual and social hub of the residency. This room serves as a climatic moderator at the same time, as well as the main place of family activities and the reception of guests due to natural ventilation and daylight that it provides. The enclosure of the court encourages security and the feeling of belonging, but the openness encourages social interaction and the sharing of experience.

Figure 2. View into the corutyard(green) and the circulation zone around the courtyard connects bedrooms and services (Source: Authors, 2025) (Source: 11, 1980)

Internal features, alcoves, masonry benches, and so on, have been tactfully incorporated to facilitate cultural practices of conversation, rest and the presentation of valued objects. These elements by no means are intended to be decorative elements; they are all extensions of the social tissue, and they make room for the informal social life and strengthen the rhythms of domestic life. These aspects are arranged by the local traditions, and the built environment is sensitive to the needs and values of the people that live there.

Figure 3. Showing the alcoves and benches in the different zones of the house. (Source: 11, 1980)

Through this socially aware design, Halawa House shows how the spatial design, transitions spaces and interior elements can be staged to create privacy, hospitality and continuation of cultural identity. The courtyard, especially, is a social and climatic center, a vivid example of the combination of environmental adaptation and co-existence.

4.3.2 Vernacular Construction and Materiality

The Halawa House's construction has been noted for the integration and reinterpretation of Egypt's architectural heritage vernacular building methods. The application of mud-brick vaults and domes has been improved to meet modern structural standards as well as climate control needs (4, 10).

Such techniques are derived from centuries of knowledge responding to the local environment, affording the creation of thermally efficient enduring spaces devoid of contemporary energy-intensive materials (2).

The deliberate selection of indigenous materials, particularly mud brick and locally quarried limestone, has served multiple purposes. On a practical level, these materials have provided excellent thermal mass, contributing to the regulation of indoor temperatures and reducing the need for mechanical cooling (2, 7). On a cultural level, the use of local materials has reinforced a sense of place and continuity, while also supporting local economies and traditional craftsmanship (8).

By grounding the Halawa House in its immediate environment through material choices and construction methods, Fathy's philosophy has demonstrated that environmental suitability and cultural resonance can be achieved simultaneously. The validation of indigenous craftsmanship has not only preserved valuable building knowledge but has also empowered local builders, ensuring that the construction process remains connected to the community (1). This approach has illustrated how vernacular techniques, when thoughtfully adapted, can meet contemporary standards of comfort, sustainability, and identity.

Figure 4. construction work of Halawa House (Source: 11, 1980)

4.3.3 Climate-Responsive and Aesthetic Features

The integration of Fathy's climate-responsive and aesthetic approaches in The Halawa House shows his commitment of culture and environment adaptation. Traditional methods of belvederes and malqafs have been incorporated to enhance passive cooling techniques. The malqaf is thermally driven in the sense that it reduces mechanical ventilation by capturing breezes and directing airflow through interior spaces enhancing comfort during hot periods. As open-sided promenades, belvederes contribute to shaded outdoor spaces whilst providing cross-ventilation.

Figure 5. Views of the house showing the malgaf and belvederes. (Source: 11, 1980)

With regards to the privacy and modesty mashrabiya screens uphold, these intricately carved wooden features serve a dual purpose beneficial for ventilation as well as protection from direct glare and heat gain. Consequently, ensuring interiors remain well-lit without overheating . Moreover, The Halawa House draws attention with its balanced blend of traditional aesthetic values alongside functional design necessity which helps create a refined contrast between interior and exterior environments. (10, 12).

Figure 6. Features of traditional craftsmanship include: a built-in cupboard, typical for Cairene homes; mashrabiyya screens on windows; and a ceiling of wood beams and battens, which is very effective insulation. (Source: 11, 1980)

By a careful integration of passive environmental systems and culturally expressive motifs, the Halawa House shows that the architectural form can effectively serve both practical purposes and symbolic purposes at once. The deliberate convergence of climate-responsive strategies and refined aesthetic vocabulary not only augments occupant comfort and environmental performance but also affirms the edifice's character as a contemporary expression of its spatial context and historical moment (1, 10).

Figure 7. Vault and domes used in the roof. (Source: 11, 1980)

5 RESULTS

From the examination of the Halawa House, several results have come to light, showcasing how Hassan Fathy's architectural philosophy is still relevant and effectively implemented today. Visual evidence supports these conclusions as detailed below.

5.1.1 Cultural Integration Through Spatial Design: privacy, hospitality, and cultural perpetuation practices are evidenced within the spatial organization of the Halawa House. The zoning of private and semi-public spaces together with transitional spaces like the loggia offers adaptable enforced structured utilization aligned with familial and societal biological rhythms. The nucleus or core focal point which all essential activities converge is the central courtyard as a climatic social hub and thus enables both intimate and collective gatherings, illustrating traditional layouts tempered with enduring value throughout time.

5.1.2 Integration of Traditional Interior Elements: Design elements such as niches and masonry benches have been specifically added for purposes of dialogue, resting, and the careful showcasing of treasured items. They serve as acclimatization to social and cultural activities, making daily routines more meaningful.

5.1.3 Revival of Vernacular Construction Techniques: The use of Nubian mud-brick vaults and domes has affirmed local craftsmanship as well as addressed ecological concerns. These

techniques have provided structural strength along with greater thermal efficiency which decreases the need for mechanical systems and foreign materials.

5.1.4 Effective Climate-Responsive Strategies: Natural ventilation and daylight are utilized through passive cooling features like the malqaf (wind catcher) as well as belvederef. Light and airflow coupled with privacy have Mashrabiya screens regulated while serving a culturally important design purpose increasing environmental performance.

5.1.5 Material Honesty and Local Identity: The Halawa House is situated within environment and culture due to locally sourced limestone and mud brick used, placing it within eco geography construction ethnography intersections. This strategy diminishes ecological harm while sustaining heritage building practices alongside artisans.

All these results together prove that the Halawa House is a good example of the comprehensive approach of Sayed Fathy and provides valuable lessons to the future maintenance of the earthen architecture.

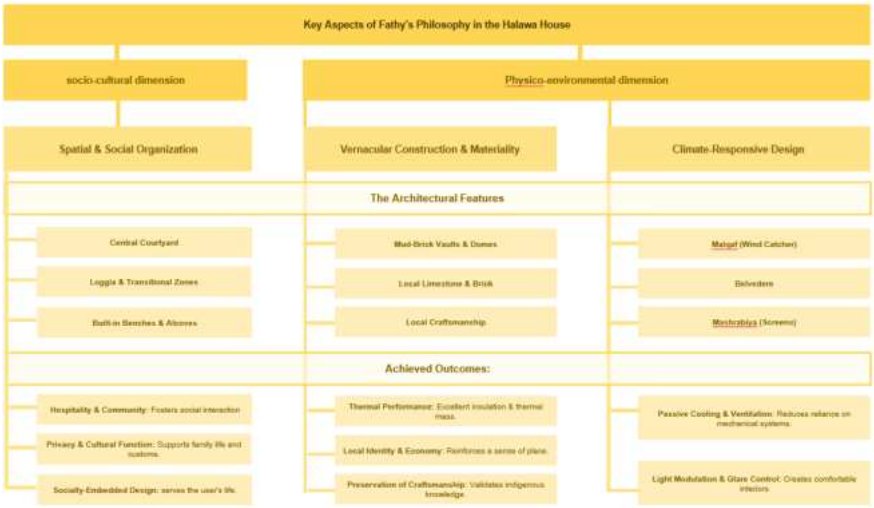

Figure 8. Conceptual diagram of the Halawa House's design philosophy, connects key architectural features to their socio-cultural and environmental outcomes. (Source: Authors).

6 CONCLUSİON

The Halawa House presents a compelling example of the ideology of Hassan Fathy, which proves that a purposeful revival and modification of vernacular architecture can produce spaces that are both environmentally sustainable and culturally relevant. As the case study reveals, the socially conscientious spatial arrangement of the house, with the central courtyard and reinforced by the transitional spaces, has been quite effective in promoting privacy and hospitality in the shared community setting. The use of Nubian mud-brick vaults, domes, and local materials like limestone has resulted in physical benefits in thermal comfort and energy efficiency, which can be seen in the reduced use of mechanical cooling and the universal positive response of users on the quality of the indoor climate and spatial perception. The environmental performance is further strengthened by passive design features, most prominently the malqaf and the mashrabiya screens, which do not undermine cultural continuity or aesthetic integrity.
Despite the success of the model proposed by Fathy as a sustainable, culturally-sensitive architectural approach, its broader applicability is challenged by issues that lie deeply embedded in

the regulatory system, loss of traditional craft skills, and challenges of adapting vernacular strategies to the small areas of dense urban tissue. In addition, the fact that the work has not been much involved with primary data and relied on only one case study, indicates the need to conduct further empirical field studies and comparative analysis to further explain the economic feasibility and scalability of such approaches.

Based on the Halawa House, a number of practical implications to architects, educators, and policymakers can be made. The participation of the local communities and artisans in the design process is vital as it will be impossible to guarantee that the spatial organization and material choices are actually representative of the cultural practices and needs without it. Policy change is also necessary to revise the building codes and regulations so that vernacular materials and techniques can be used and thus spread the application of sustainable practice. Educational and apprenticeship programs need to be invested in to reinvigorate and pass on traditional building knowledge to maintain a dialogue between the past and the new. Vernacular projects need to be documented visually systematically and this is where the Aga Khan Award for Architecture comes in as it preserves and shares architectural knowledge with future generations. Lastly, architects are advised to treat vernacular precedents as a flexible approach rather than a strict model, thus triggering an innovative combination of modern requirements and technologies.

To conclude with, the Halawa House proves the statement that architecture is not only about the construction of a building but also about the creation of the cultural identity and the increase of environmental sustainability of communities. Through a combination of the wisdom of precedent and a sharp sense of the current need, the practitioner can think through creating a place that is at once innovative, sustainable, and highly contextual, a goal that is both timely today as it was to Hassan Fathy in his time.

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Kerpic'25 – Earthen Architectural Heritage
13th International Conference
Rabat, Morocco, 25-27 September / 2025

Building with Earth in Seismic Zone: Case Study of Nepal

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ABSTRACT

Nepal lies in a seismically active and subtropical climactic zone with average rainfall as high as 1 meters a year. Yet according to Nepal's Living Standard Survey 74% of the Nepali houses are made of earthen material. In 2015, there were multiple earthquakes with over 7.5 rector-scale. All the structures, that the author designed using materials like earth and survived unscathed- including structures built at the epicenter.

Those structures gave lots of confidence to local population who were told that earthen structures are not stable. Aftermath of the earthquakes, author has designed and build over a dozen school, public spaces, monasteries, temples, hotel and homes. In this paper, the author will share his experience of rebuilding using the local resources. Author will discuss building an enterprise, creating a supply chain, involving university for research, lobbying for policy change and the process of building using rammed earth, adobe, compressed earth blocks, wattle and daub, lime bricks and bamboo trusses.

Keywords: Earthquake reconstruction, earth construction, rammed earth, bamboo, Nepal, Gorkha Earthquake.

BACKGROUND

Two-thirds of Nepal's terrain is mountains including the Himalayas. Mountains are hard to navigate, therefore in earlier times, communities separated by mountains had very limited exchange. Such conditions gave rise to hyper-local, context specific indigenous knowledge systems within a few square miles. It is for this reason the small county of Nepal, that is only 1400 km wide and in average 300 km wide, has more than 100 languages and corresponding means of articulating their worldviews through arts, crafts, agricultural systems and architecture.

The materials available at their disposal- mostly timber, stones, bamboo and earth are utilized by the communities to design and build extraordinary structures. Some of them are multi storied structures designed to be earthquake resistant and cope with the harsh winter. Some of the wood joineries and stone carvings embedded in the walls or structural members are among the most extraordinary in the world (Tiwari, 2023, Tiwari, 2009, Bernier 1997).

The materials for these houses were locally sourced from the commons, so they were virtually free. Timber was typically sourced and managed from local forests, stones were harvested from local quarries (which were abundant in the mountains) and soil procured from their own site. Labor was bartered, in other words if A helped in construction of B's house for 10 days then B would have to reciprocate in

construction of A's house by working for same amount of days. This system of barter of labor is called "*parma*". If the owner is disabled or old, the neighbors would help in the spirit of community.

As 'development' creeped in the 1950's, these independent communities began to be regulated. The common resources like the local forest, quarries, rivers became state property (Regmi,2000). In other words, the government started monetizing materials which were hitherto free. The communities were left with no other choice but to buy industrial materials for construction and maintenance.

When the government began to regulate the commons and imposing building codes even in rural and remote Nepal, the vernacular architecture of yesteryears began to diminish in numbers. Many of the building traditions that were thousands of years old were also deemed unfit in the light of renewed building codes.

Earthquake of 2015

In 2015, there were two massive earthquakes on April 12th and May 22nd of Richter scale 7.8 and 7.3 magnitude. It claimed casualties of over 8856 people (NDRRIP, 2015). Considering the magnitude of the earthquake, the casualty was considered to be low. Earthquake of similar magnitude in Pakistan and Turkey killed more than 80,000 people. Despite media and the government claiming that vernacular houses are weak and unsafe, it was observed that properly built traditional structures survived the earthquake even at the epicenter (Adhikary, 2017).

In a country where majority of the buildings are made with earth and stone, the new regulation from the government, in the light of the natural disaster, made it very difficult to rebuild with the existing materials and skills. Hundreds of high paying consultants from abroad flew in with different agendas for reconstruction. Even after a year of the devastation and the lack of initial disaster response, the government did not lean towards the ideas of rebuilding homes, schools and communal spaces which were needed urgently using local materials. They supplanted a renewed building code, uninspired by the possibilities with natural materials and local craftsmanship. Interestingly, the older code allowed for vernacular construction. The new government approved designs had no resemblance to any traditional building style (see DUDBC 2015). The government engineers seemed to have been inspired by foreign laws, codes, materials and designs. They lacked the creativity and finesse to contemporize vernacular buildings. Even in the odd case that some designs that utilized natural materials and traditional aesthetic were assessed and selected to be passed by law, the criteria for legally executing such a construction were that it be reinforced heavily with the usage of cement and steel.

The average cost of building a house before the earthquake was around 5000 USD but with the new building laws of the government (with the mandate to reinforce every room using RCC), a similar house would cost more than 20,000 USD.
Many home-owners emigrated to middle eastern countries to work in a very harsh conditions to earn the money necessary to rebuild their homes destroyed by the earthquake. In a short span of less than a few decades, owing to modernization and hastened by the earthquake, a previously self-sufficient common man in Nepal, who could build using resources from the commons, was forced to work in foreign lands (with very poor working rights) to pay for their shelter.

Not building back better.

In many instances the Government turned very authentic villages with a unique vernacular architecture into a cookie cutter design that looked very trite and non-functional. One such example in Barpak, which was the epicenter of the earthquake. The village had beautiful cobble stone streets with intimate stone structures roofed with stone slates (Fig. 1). The new rebuilt houses, built with lots of government and

foreign help, are bereft of any authenticity to the place. There are many such government rebuilt settlement which are abandoned, wasting billions of tax-payers money (NepaliTimes, 2016).

Photo of Barpak before the earthquake Photo Source: Nepali Times

Barpak after the earthquake. Photosource: Nepalitimes

Government implement cookie cutter design, which is now abandoned. Photo: Nepali times.

By forcing cement and steel down peoples throat with their earthquake reconstruction effort, the government managed to reduce the amount of vernacular Nepali architecture that used locally available materials from 74% in 2011 down to In 2021. (CBS 2011 and 2021)

ABARI

In 2006, after returning from Northern New Mexico college with specialization in Adobe Earth Construction, the author set up a private social enterprise called ABARI, that would reappropriate earth based traditional materials into contemporary architecture. Author was inspired by Northern New Mexican architecture which celebrated the ancient adobe techniques in the modern context.

In 2007 author met a group of Norwegians who wanted to build a learning center based on the Scandinavian *folkschule*, where they would demonstrate different sustainability techniques. Author led ABARI to design and built adobe domes, two story dormitory with rammed earth, office space with compressed earth blocks, canteens and training halls which had to house 100 people each with bamboo and adobe. In the process, the team trained hundreds of builders both men and women in sourcing, processing and finishing. The communal projects led to economic opportunities for the local communities who not only shared a beautiful space, but also subsequently generated income by hosting tourists in these buildings. People from different parts of the countries came there to learn about sustainability when programs were organized at community, municipality and national and international level. They offered courses on natural earth construction, permaculture, social mobilization, women empowerment etc.

The public infrastructure cost lots of money and generally always uses modern industrial material, which have to be imported. The government schools, however limited they are, are not satisfactory. They are made of cinder blocks, metal trusses and tin sheet. They are basic without any insulation whatsoever. These schools would close if the weather is too hot or cold or when it rained because the tin roof would make so much noise that it is impossible to hear what the teachers were saying.

ABARI's second project was construction of small pre-primary school. It was designed a demonstration so it could be replicated across the country. Fortunately, Justin Wickham, an English builder and a friend of ABARI, had already started building a school with stone in a remote village of Gorkha. It was so remote that the closest hardware store was five hours away. ABARI team volunteered to build the roof with bamboo and stone. With limited budget and it took almost three years to build the school. Just after ABARI had finished the building, a huge earthquake hit Nepal. The school was only 12 km from the epicenter. The devastation was very intense and our school was one of the very few schools that survived the tremor.

Though it was a tragic event, it was a vindication that buildings that are built with earth bamboo and stone can survive big tremors. It proved that using local resources one can build beautiful spaces that can meet the needs of the local people with its own vernacular flavor. Furthermore, it demonstrated that one does not need imported industrial technologies or materials to make safe, comfortable and beautiful structures.

After the earthquake, around 40,000 schools had to be rebuilt. It was a perfect opportunity to pitch a new idea to the government. Government immediately approved ABARI's prototype design of a modular school that would work in Nepali terrain. It was one of the rare moments, even internationally, where government had approved earth and bamboo as construction materials for public schools. The designs were very popular and the team got so many offers to build schools all over the country. ABARI did not have the bandwidth to build all those schools, therefore they put the design on their website as opensource documents. Over thirty schools were built using the documents and there were almost a million downloads.

Politics of Construction.
After the earthquake people were scared that the government would come up with prescriptive design that would create cookie cutter structure all over the country, undermining thousands of years of vernacular architectural tradition. Unfortunately, that is what happened. Government, funded by World Bank, made construction with natural buildings very difficult. Even if it was allowed, it had to be done

by adding tons of cement and steel in the mixture. Even though so many people wanted to build in ABARI style, the regulations made it difficult to do so. The building codes which were pretty favorable to natural construction before the earthquake was changed in order to prioritize concrete and steel. 10 years after the earthquake, one can see traditional vernacular architecture being cannibalized by modern cookie cutter concrete and steel construction.

Nevertheless, there were some pockets of opportunities that open up among a small group of alternative thinking individuals and organizations. A big commission after the earthquake was an immediate reconstruction of a public archive. It was a public building right at the center of Kathmandu Valley. A public building out of earth and bamboo in an urban area would have been almost impossible before the earthquake. ABARI finished the library in 9 months using rammed earth, wattle and daub and bamboo trusses. The two story structure exposed all the bamboo members that form a complex spider web like trusses. It was instantly embraced by the public. The slender, lightweight and ductile bamboo roof was psychologically comforting to the public who had witness heavy concrete structure come down like house of cards.

The building is now reaching its 10 years and is now a public attraction, where many tourists come just to see the building. Instead of doing mass housing projects ABARI does small projects that can redefine the earth and bamboo construction in modern context. ABARI get clients from various spectrums of life, they have designed public halls, monasteries, schools, residence, house of worships. One of the biggest achievement so far has to been to challenge the biases that people had regarding vernacular materials.

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A Systematic Review of Clay and Earth-Based Mixtures for 3D Printing

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ABSTRACT

This paper presents a systematic review of clay and earth-based mixtures in 3D printing. From the Web of Science database, 251 publications were initially retrieved; 64 full texts were screened, and 33 provided extractable data on mixture compositions. Bibliometric analyses indicate a sharp rise in research activity since 2016, peaking in 2024, with major contributions from the United States, China, India, and European countries. Citation patterns further confirm the growing impact of this field and its emergence as a research domain.

The reviewed studies highlight mixture design -covering binder and aggregate types, mix ratios, and additive incorporation- as the key factor in balancing fresh-state with hardened-state properties. Additives such as cellulose microfibres, xanthan gum, sodium alginate, and nanomaterials strongly influence extrudability, buildability, and strength. In addition, sustainable strategies -including the reuse of waste, valorization of industrial by-products, and integration of natural fibers- contribute to reducing environmental impact. Overall, the review shows that while interest in clay and earth-based 3D printing is rapidly increasing, mixture design constitutes an area open to further advancement through experimental research.

Keywords: 3D printing, clay-based mixtures, earth-based mixtures, mixture design, printability, buildability.

1. INTRODUCTION

Earth has recently gained renewed attention as a sustainable building material for additive construction, offering advantages such as low environmental impact, affordability, and high local availability. In the context of 3D printing, its performance is strongly tied to printability, which depends on achieving a balance between extrudability and buildability [1]. Within this framework, mixture design becomes a decisive factor. The proportions of binders, aggregates, and additives govern rheological behavior, layer stability, and the ultimate mechanical performance of printed elements. Even minor adjustments in composition can markedly affect printability, often requiring trade-offs between fresh-state and hardened-state [1-4]. A deeper understanding of these relationships is therefore essential for tailoring materials to the practical demands of extrusion-based construction.

For this reason, the present study conducts a systematic review to examine how variations in mixture design influence the printability of clay- and earth-based mortars. By compiling and analyzing recent research, the review emphasizes the central role of material composition (i.e., the type and nature of constituents) and the modifications introduced through additives, thereby providing insights into the current state of research and highlighting emerging directions for the development of more reliable approaches to earth-based 3D printing.

2. METHODOLOGY

This study presents a systematic review of the performance of earth-based materials in 3D printing. Publications were retrieved from the Web of Science (WoS) database, chosen for its comprehensive, peer-reviewed, and multidisciplinary coverage. A total of 251 records were initially identified. Abstract screening eliminated duplicates, studies unrelated to the research scope (e.g., biomedical or artistic applications), non-3D printing studies, and those focused solely on cement-based mixtures. This filtering process reduced the pool to 64 full-text articles. Of these, 33 studies provided extractable data on mixture designs, including material compositions and additives, and were systematically analyzed. The remaining studies were excluded due to missing proportion data, inaccessible full texts, or incomplete reporting of mix parameters. These 38 articles formed the basis for analyzing mixture design parameters and their relationship to printability and performance outcomes.

3 BIBLIOMETRIC ANALYSES OF LITERATURE

This section presents a bibliometric analysis of the 251 publications included in the systematic review. The analysis is structured into three main parts. First, a time-series evaluation is conducted to illustrate trends and developments in publication output over the years. Second, a geographic analysis maps the contributions of different countries, highlighting the global distribution of research on the 3D printability of earth-based materials. Finally, a publication-based analysis examines citation metrics, including the most highly cited articles, the evolution of citation counts over time, and h-index trends, providing insight into influential studies and key contributors in the field.

3.1 Time Series Analysis

The field of 3D printability of clay- and soil-based materials has undergone substantial expansion over the past decades, reflecting a growing academic and practical interest in this area. Figure 1 illustrates the temporal evolution of research between 1997 and 2024. In the initial phase (1997–2005), publication activity was minimal, with only a single study emerging annually. From 2006 onward, a gradual increase became evident, followed by fluctuations between 2007 and 2018, during which annual outputs ranged from three to eight publications. A notable acceleration in research activity occurred after 2018, with a sharp upward trajectory that culminated in a peak of 43 publications in 2024. This sustained growth underscores the rising importance of the field and the progressive diversification of its research scope.

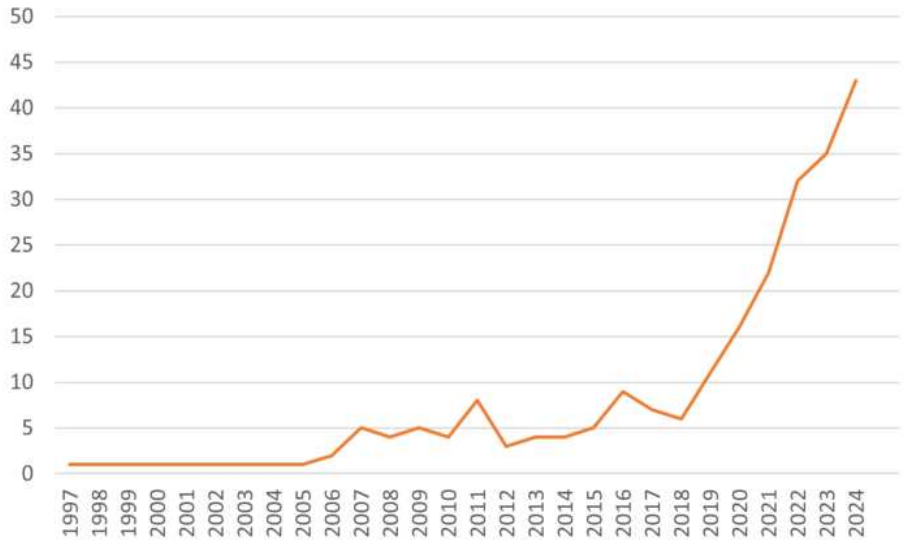

Figure 1. Annual Distribution of Publications (1997–2024).

3.2 Location Analysis

The research on the printability performance of clay and earth-based mixtures in 3D printing is geographically widespread, with notable contributions concentrated in specific regions (Figure 2). The United States leads with the highest number of publications (45), followed by China (28) and India (24), reflecting their strong and growing interest in additive manufacturing technologies applied to sustainable construction materials. European countries, particularly England (16), France (15), Spain (15), and Italy (13), also show significant involvement in this research domain. In South America, Brazil (15) emerges as a prominent contributor, while Australia (10) represents a key player in the Asia-Pacific region. Contributions are further enriched by active participation from Germany, Iran, South Africa, Canada, Türkiye, and several Middle Eastern countries. Overall, the distribution of studies demonstrates that while North America and Asia dominate in terms of volume, Europe and emerging economies provide essential complementary perspectives, highlighting the global relevance of developing optimized clay- and earth-based mix designs for 3D printing.

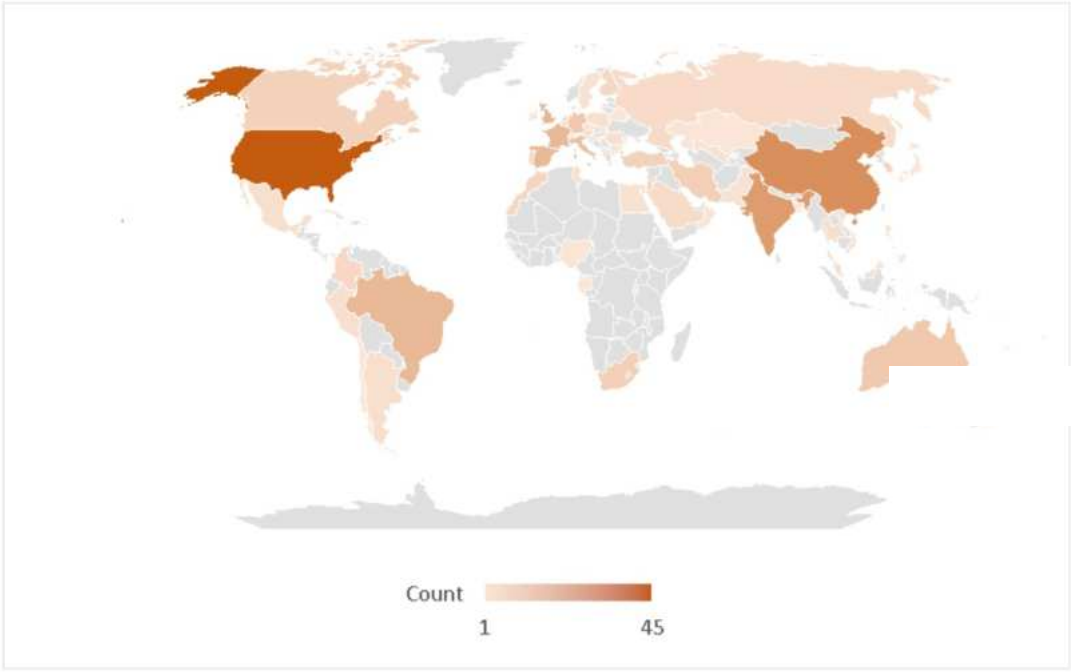

Figure 2. Geographical Distribution of Publications by Country.

3.3 Citation and Impact Analysis

The citation analysis of the reviewed literature provides valuable insights into the academic impact of studies on the printability performance of clay and earth-based mixtures in 3D printing. As illustrated in Figure 4, the field exhibits an H-index of 42, indicating that at least 42 publications have each received a minimum of 42 citations. This reflects a substantial and growing body of influential research. Moreover, Figure 3 demonstrates a sharp upward trend in annual citations, particularly after 2018, with a notable peak in 2024 where citations exceeded 1,400. Despite minor year-to-year fluctuations, the overall trajectory underscores increasing scholarly attention and recognition of this research domain. Together, these findings highlight not only the expanding scope of publications but also their rising influence within the broader scientific community.

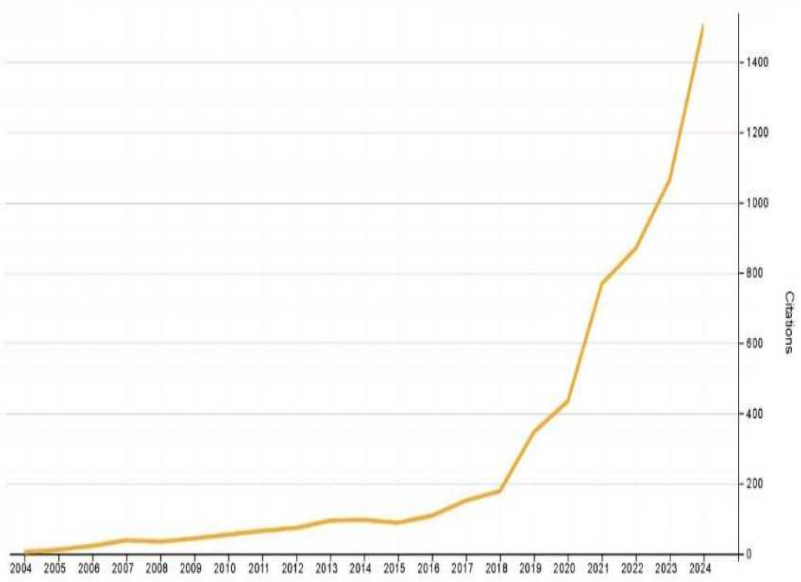

Figure 3. Annual Citation Trends (2004–2024).

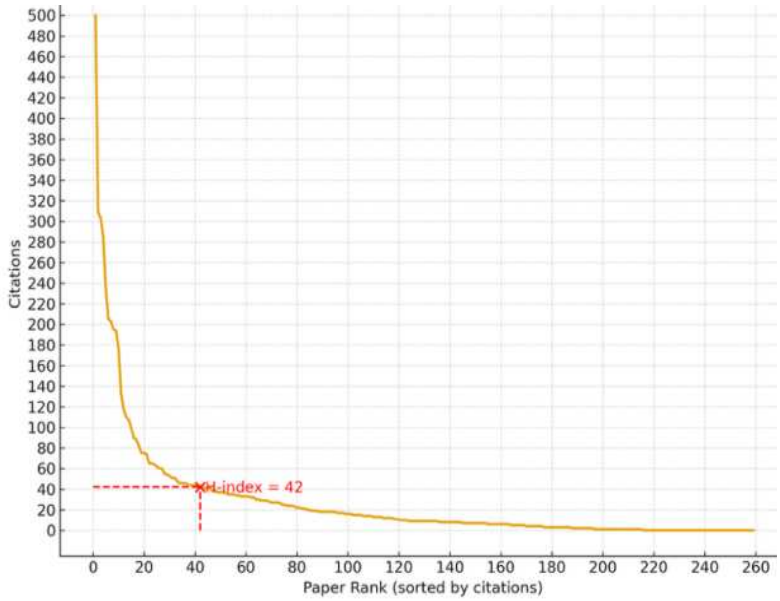

Figure 4. H-index graph. The included studies collectively yield an h-index of 42.

3.4 Keyword Co-occurrence Analysis

The keyword co-occurrence network presented in Figure 5 highlights the main research themes related to the printability performance of clay and earth-based mixtures in 3D printing. The central position of terms such as 3D printing, additive manufacturing, rheology, and extrusion indicates that these constitute the core research focus of the field. Closely connected clusters emphasize complementary themes, including sustainability, buildability, and printability, which reflect the increasing attention toward environmentally responsible and structurally viable construction materials. The prominence of keywords like soil-earth, concrete, geopolymer, and waste underscores the importance of raw material selection and recycling strategies in developing optimized mix designs.

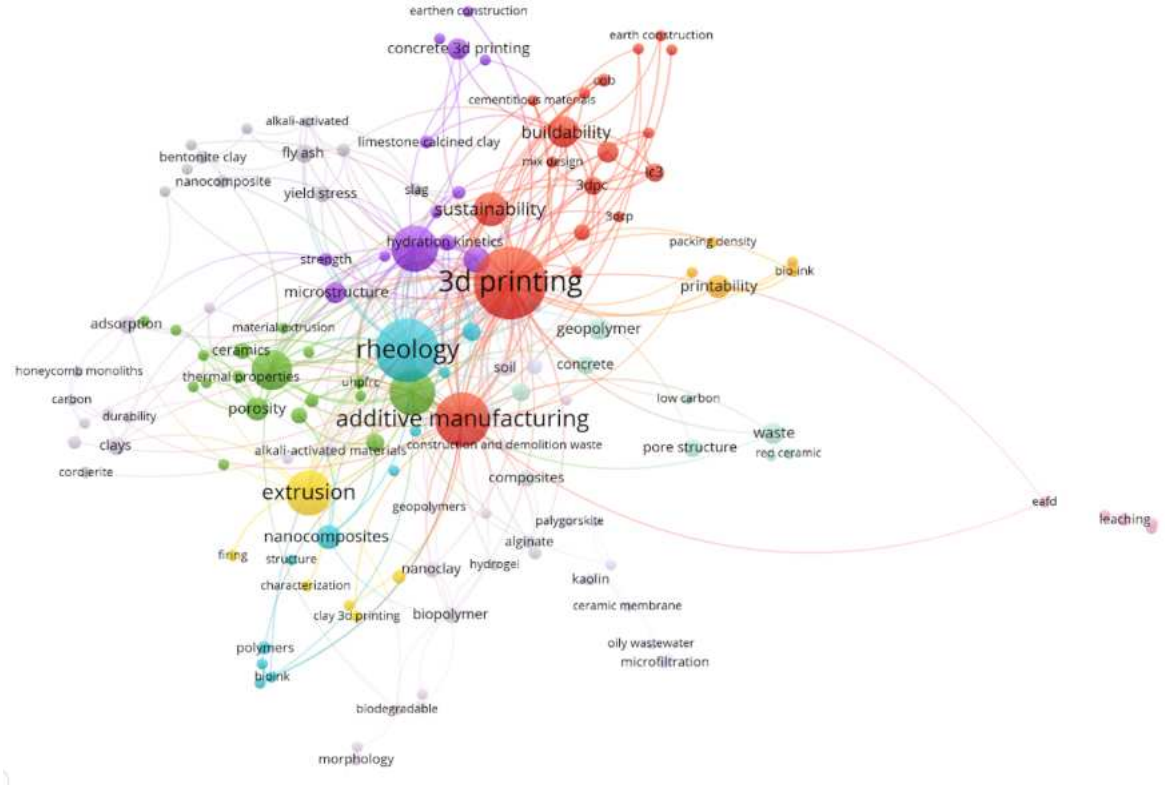

Figure 5. Mapping 3D Printing Research via Keyword Co-Occurrence.

Furthermore, the occurrence of terms such as nanocomposites, biopolymers, and ceramics suggests a growing interdisciplinary approach, linking material science with construction technology. Peripheral but connected keywords such as hydration kinetics, porosity, and microstructure highlight the role of fundamental material properties in influencing printability outcomes. Overall, the network reveals that the research domain is characterized by a strong integration of sustainability considerations, material innovation, and process optimization, pointing to a comprehensive and multi-dimensional exploration of clay and earth-based 3D printing.

4 GENERAL INSIGHTS ON MIX DESIGN

The reviewed studies in Table 1 demonstrate a broad range of approaches to mixture design in clay- and earth-based 3D printing. A primary emphasis is placed on binder–aggregate systems and substitution strategies. Various binders, including clays, lime, cement, ground granulated blast-furnace slag (GGBS), fly ash, and metakaolin, are frequently combined with aggregates such as sand, recycled brick powders, or earth. Substitution with industrial by-products (e.g., quarry washing mud, marble dust, municipal solid waste incineration ash) reflects an increasing effort to reduce environmental impact while enhancing structural performance. These strategies are aimed at optimizing strength, durability, and sustainability.

Another central research focus involves the incorporation of additives for tuning fresh-state behavior. Both natural and synthetic modifiers have been tested, including cellulose microfibres, xanthan gum, sodium alginate, hydroxypropyl methylcellulose (HPMC), and dispersing agents such as sodium hexametaphosphate (SHMP). Chemical admixtures, such as superplasticizers, nano-silica, nano-clay, and alkaline activators, have been widely explored. In parallel, organic and mineral fibres -such as straw, hemp, sisal, coconut, banana, and goat hair- are integrated to improve crack resistance and ductility. These studies consistently show that even small dosages of additives can exert a significant influence on rheology, cohesion, extrudability, and mechanical strength.

Table 1. Mix Contents, Investigated Parameters, and Key Findings from the Reviewed Studies.

Mix Contents	*Investigated Parameters*	*Findings*	*Ref.*
B: Clay A: Sand Add: Cellulose microfibre	Cellulose microfibre	-Cellulose microfibres improve flowability, plasticity, and strength, making mixtures more cohesive and easier to extrude.	[5]
B: Cement+GGBS A: Sand+Soil Add: SP+VMA	Water/Binder Ratio GGBS Substitution Soil Substitution	-Non-expansive clay improves extrusion, flow, and buildability, enabling taller prints. -GGBS enhances layer stability and reduces moisture sensitivity. -Higher clay content increases porosity and lowers strength.	[6]
B: Kaolinite Clay A: Sand Add: Xanthan Gum	Xanthan Gum	- At low concentrations, XG disperses kaolinite particles, reducing yield stress, viscosity, and storage modulus. - Compressive strength increased steadily with higher XG content. A printable mixture was achieved at 5% XG	[7]
B: Earth Add: Cimalgin HS3	Cimalgin HS3	- Alginate enabled successful printing of earth-based structures with high productivity (e.g., 3 m wall in one day). - It significantly enhanced green strength, with rapid improvement confirmed by penetrometry.	[8]
B: Earth Add: $NaOH+Na_2SiO_3+Ca(OH)_2$+HPMCB	$Ca(OH)_2$ HPMC	- Adjusting solid–liquid ratio, Ca^{2+} content, and HPMC content allows control of rheology, mechanical properties, and extrudability	[9]
B: Clay A: Sand	Binder/Aggregate Ratio Water/Binder Ratio	- Kaolinite increases thixotropy; coarse particles raise static yield.	[10]
B: Clay Add: Sodium Alginate	Water/Binder Ratio Sodium Alginate	-Sodium alginate enhances electrostatic interactions, stabilizing kaolinite suspensions. -Increased alginate reduces storage modulus and yield stress, but excessive content (>0.12–0.6%) forms a polymer network reversing this trend. -Alginate shifts the printability window to higher solid contents, improving strength and reducing shrinkage.	[11]
B: Earth +Lime + Quarry Washing Mud+Plaster+GGBS A: Sand	Quarry Washing Mud Substitution Plaster Substitution GGBS Substitution	-Improved textile–matrix bonding enhanced load distribution and structural integrity. -Second mixing significantly reduced torque, enabling lime-based mortar printability. -Textile reinforcement increased strength by 142.8% and ductility by 1130.3%, confirming its effectiveness for sustainable 3D printing.	[12]
B: GGBS+FA A: M-Sand+Soil Add: Na_2O	Binder/Aggregate Ratio Na_2O	-Clay increased dynamic yield stress but reduced plastic viscosity. -Increasing NaOH concentration (4M → 8M) enabled lower binder content. -Lower layer deformation (0.09%) and higher buildable height confirmed structural stability.	[13]
B: Clay A: SiC Add: PEG + PVA + CMC	PEG PVA CMC	-Optimal mix (10% PEG, 1% PVA, 0.6% CMC) achieved best printability and firing results. -Developed a printable paste with high solid loading (80% wt).	[14]
B: OPC+FA+GGBS A: Dredged Sand Add: NAC+PCE+SD	NAC PCE	-Nano clay reduced the negative effects of PCE on yield stress and viscosity. -Reduced macropores (>1000 nm) from 19.31% to 18.82%. -Increased hydration products and maintained acceptable compressive strength.	[15]
B: Cement+Lime A: Sand+Soil Add: Rice Husk+Shredded Rise Husk+Marble Dust+MSWI	Soil Substitution Rice Husk Shredded Rise Husk Marble Dust MSWI BA	-Mixes achieved relatively good strength with limited shrinkage. -Multi-criteria evaluation (mechanical, economic, carbon footprint) identified the most efficient mix. -Lime + sisal fibers yielded compressive strength	[16]

BA+Juta+Coconut+Sisal+Goat Hair	Juta, Coconut, Sisal, Goat Hair	of 1.26 MPa, embodied carbon 0.05239 $kgCO_2eq/kg$, and cost 0.137 €/kg. -Optimized real-scale mix reached 11.04 MPa compressive and 1.26 MPa flexural strength.	
B: GGBS+FA A: M-Sand+Soil Add: Sucrose	Soil Substitution Sucrose	-Provided a potential approach to control printing time of geopolymer-stabilized earthen materials. -Reduced embodied carbon while enhancing mechanical performance.	[17]
B: Clay Rich Earth Add: Hydrated Lime+Wheat Straw Fiber	Hydrated Lime Wheat Straw Fiber	-Pure soil mix showed good print quality and strength but high shrinkage and cracking from nontronite content. -Fiber addition mitigated cracks and reduced shrinkage to 2.6%. -Lime and pozzolana stabilizers did not improve strength, shrinkage control, or printability.	[2]
B: FA+OPC A: Fine River Sand Add: Sodium Sulfate+Nano Clay+Pozzolana	Nano Clay (NC)	-0.1–0.5% NC increased static yield stress via re-flocculation and thixotropy, with little effect on viscosity. -0.5% NC improved viscosity recovery and structural build-up under varying rest times and shear rates. -Enabled extrudable and buildable HVFA mortars for 3D printing. -Demonstrated successful 20-layer printing.	[3]
B: Cement+Silica Fume A: Silica Sand+Silica Flour Add: Superplasticizer (ADVA-190) +Nano Clay	Nano Clay (NC)	-Shape stability of UHPC mixes depended strongly on the printing system rather than solely on material properties.	[18]
B: GGBS A: Sand Add: Liquid Sodium Silicate+ NaOH+Nano Clay+Na_2O	Liquid Sodium Silicate NaOH Nano Clay	-Nano clay improved structural build-up of AAS mixtures. -Higher Ms value reduced yield stress but increased compressive strength and lowered flexural strength. Increased Ms value lowered porosity but caused more micro-cracks.	[19]
B: Earth A: Sand Add: SHMP	Sand as Aggregate SHMP	- Zero-crack formulations achieved with 50% soil replacement by fine sand and SHMP addition (0.55–2.20%).	[20]
B: Metakaolin Add: Bentonite + Fiber	Bentonite Fiber	-Bentonite improved plasticity, cohesion, and green-state strength of metakaolin pastes. -Minimum 5% bentonite required for printability; >7.5% caused excessive shrinkage.	[4]
B: GGBS+Calcium Hydroxide+Gypsum+Solid brick powder A: Concrete+Solid Brick Add: H ES910i + Nano-silica + Nano clay	Nano-silica Nano-clay	-Nano-silica and nano-clay contributed to optimizing the mixture's performance and printability.	[21]
B: FA+GGBS A: River Sand+Quartz Sand Add: Natural Halloysite+Calcined Halloysite	Natural Halloysite Calcined Halloysite	-CH-1.5 mixture improved shape stability, buildability, and mechanical properties. -Flexural and compressive strengths were 88% and 40% higher than the control, respectively. -Enabled printing of a twisted column, confirming suitability for complex structures. -Demonstrated halloysite clays as low-cost additives for enhancing AAMs.	[22]

B: Earth Add: Fiber + Straw + Hemp + Kenaf + Banana	Water/Binder Ratio Fiber Straw Hemp Kenaf Banana	-Novel earthen mixtures with 2–13% fiber content were successfully developed. -Fiber addition (straw, hemp, banana, kenaf) enhanced compressive strength by up to 125%. -Thermal conductivity reduced by up to 86% compared to earthen mixes.	[23]
B: Clay Add: EAFD	EAFD	-Established the potential of EAFD hazardous waste as a sustainable material for 3D printing.	[24]
B: Clay A: Sand	Clay Types	-Intraparticle and interparticle swelling strongly influenced strength and cohesiveness. -Organic matter and mineral content significantly impacted overall properties	[25]
B: Recycled Clay Brick+Tile+Hollow Brick+Glass Powder Add: $Ca(OH)_2$+NaOH+Na_2SiO_3	$Ca(OH)_2$ NaOH Na_2SiO_3	-Combined benefits of green material development and waste upcycling were demonstrated. -Enabled reduced raw material use with easy, fast, and accurate producibility.	[26]
B: Cement A: Clay Ceramsite Sand+Fine River Sand Add: Nano-Silica + Superplasticizer	Binder/Aggregate Ratio Fine River Sand Substitution Superplasticizer	-Printing process induced anisotropy, lowering specific strength compared to cast samples. -Increased pre-wetted CCS reduced matrix porosity and improved pore circularity. -Findings provide guidance for preparing 3DPLWC at varying density levels.	[27]
B: Clay A: Alumina+Micro Silicon Powder Add: Sodium Dodecyl Sulfate+Polycarboxylate	Sodium Dodecyl Sulfate Polycarboxylate	-Heating corundum–mullite refractory from 1200 °C to 1500 °C enhanced thermal conductivity (0.35 → 1.65 W/m·K) and compressive strength (20.1 → 45.5 MPa). -Acid corrosion resistance improved, with corrosion rates dropping below 3.4% after 12 h at 1500 °C. -Minimal microcracks and pores were observed after acid exposure at high temperature.	[28]
B: OPC+Silica Fume A: Fine Aggregate Add: Nano-Kaolin Clay+DHE-SFs+HRWRA	Nano-Kaolin Clay DHE-SF	-Optimizing NKC and DHE-SF content significantly improved UHPC performance. -Enhancements ensured greater durability and structural integrity.	[29]
B: BFS+GGBS+LP A: Sand Add: NaOH Pellet+Nano Clay+SP	LP Substitution NaOH Pellet Nano Clay SP	-Alkali-activated slag mixtures enabled fast phase transition for set-on-demand applications. -Higher NaOH concentration or nano clay addition improved structural build-up and buildability.	[30]
B: Clay+GGBFS A: Sand Add: NaOH+Waterglass+Soil Disperser	Binder/Aggregate Ratio GGBFS Substitution	-Geopolymer solidification improved compressive (↑2378%) and flexural strength (↑3448%) of EC. -Solidification inhibited cracking and reduced porosity, especially pores >1 mm^3. -Thermal conductivity increased by 43.7% but remained 9.6–10.4% lower than cast EC. -3DPEC showed potential for low-rise buildings due to enhanced mechanical/thermal properties and low environmental impact.	[31]
B: Clay Add: GNP	GNP	-Low GNP content (0.1 wt.%) improved compressive and flexural strength. -Higher GNP contents (0.2–0.3 wt.%) resulted in reduced strength performance.	[32]
B: Yellow Clay+Gray Clay Add: Sawdust+Rice-Peel+Seed-Shell	Sawdust Rice-Peel Seed-Shell	-Increasing organic byproducts in clay significantly reduced thermal conductivity, enhancing insulation. -Only minor reductions in mechanical strength were observed. -Sunflower seed-shell additive produced the greatest decrease in thermal conductivity.	[33]

** B: Binder, A: Aggregate, Add: Additive*

6. CONCLUSION

This systematic review highlights that research activity in the field of clay and earth-based 3D printing has grown rapidly since 2016, peaking in 2024, with major contributions from the United States, China, India, and several European countries. Citation trends confirm the growing academic influence of this topic and underline its emergence as a multidisciplinary research area.

The review further demonstrates that mixture design is a decisive factor influencing the performance of clay- and earth-based materials in 3D printing. The type and proportions of binders and aggregates, together with the type and dosage of additives, strongly affect both fresh and hardened properties. In addition, sustainability-oriented strategies such as the valorization of industrial by-products, the reuse of waste materials, and the integration of natural fibers contribute to lowering environmental impact while maintaining or even enhancing material performance.

Overall, the review shows that while interest in clay and earth-based 3D printing is rapidly increasing, mixture design remains a promising research area. Experimental studies, particularly focusing on binder–aggregate interactions, additive optimization, and waste valorization, are highly important for advancing mixture design into more standardized and environmentally responsible solutions.

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Kerpic'25 – Earthen Architectural Heritage
13th International Conference
Rabat, Morocco, 25-27 September / 2025

Reconciling Contemporary Performance Standards and Cultural Heritage in Earthen Architecture of Morocco

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ABSTRACT

Morocco holds a remarkable heritage of earthen architecture, ranging from adobe and rammed earth (pisé) dwellings to kasbahs and ksour in the southern valleys and the High Atlas. These architectural forms embody centuries of adaptation to a specific context: harsh climate, while expressing deep-rooted socio-cultural, environmental, and economic values. Today, however, earthen architecture faces critical challenges, including accelerated urbanization, shifting climate conditions, the demand to meet evolving thermal and acoustic performance standards as well as preserve it symbolic meaning and cultural value.

This paper explores Morocco as a living laboratory for bridging ancestral wisdom with innovative solutions—ranging from stabilized earth and bio-based composites to digital fabrication and 3D printing. Drawing on literature review, fieldwork in Aït Benhaddou, Ouarzazate and Marrakech, and experimental design investigations, the study assesses material performance (thermal, acoustic, and structural) across diverse architectures. Results reveal that hybrid materials—integrating lime, hemp, palm fibers, and phase-change components—greatly improve environmental performance while lowering embodied energy. Moreover, digital tools enhance efficiency without compromising cultural identity. Ultimately, Morocco's case illustrates how tradition and innovation can converge to position earthen construction as a global model for sustainable, resilient and sustainable architecture.

Keywords: Morocco, earthen architecture, heritage, thermal and acoustic performance, sustainable construction.

1 INTRODUCTION

Earthen architecture, practiced across millennia, remains a central expression of Morocco's cultural and architectural identity. Whether in the rammed earth medinas or the kasbahs of southern oases, this architecture responds intelligently to specific environmental and social contexts (Fathy, 1973; Houben & Guillaud, 1994). By relying on local materials, passive thermal strategies, and shared community practices, it creates an architecture that is not only sustainable but also socially embedded (CRATerre, 2016).

Today, however, Moroccan earthen architecture is under strain. Rapid urban growth is creating immense housing needs; climate change is exacerbating environmental risks; and building standards increasingly demand higher performance in terms of energy efficiency, acoustics, and structural resilience (UNESCO,

2019). These pressures raise a pivotal question: can earthen architecture evolve to meet contemporary demands while safeguarding its symbolic and cultural depth?

This paper examines that question by exploring how Morocco can leverage material innovation, hybrid methods, and digital tools to sustain and adapt earthen architecture in a way that remains both viable and meaningful.

2 METHODOLOGY

2.1 Literature Review

A review of foundational and contemporary works on earthen construction was conducted. Key references include Hassan Fathy's Architecture for the Poor (1973), Houben & Guillaud's Earth Construction (1994), CRATerre and UNESCO reports on sustainable earthen practices, and recent studies on hybrid and digitally-fabricated earthen systems (Morel et al., 2017).

2.2 Field Studies

The fieldwork component of this research was conducted across key sites representative of Morocco's earthen heritage and contemporary experimentation, with the aim of capturing both the tangible performance characteristics and the intangible social and cultural dimensions of this building tradition. The sites examined are: ksar Aït Benhaddou, Ouarzazate, and Marrakech medina. They illustrate the breadth of earthen construction techniques, ranging from monumental fortified settlements (ksour and kasbahs) to urban housing and construction (medinas).

Ksar Aït Benhaddou: Living vernacular heritage

The ksar of Aït Benhaddou, a UNESCO World Heritage site, epitomizes the architectural genius of southern Moroccan communities. Constructed primarily with rammed earth (pisé) and adobe, the site demonstrates how earth was used not only for structural efficiency and thermal comfort but also as a medium of cultural expression (Figure 1). Its tiered, compact urban fabric reduces solar exposure and maximizes shading, while thick walls and small openings regulate indoor climates naturally, keeping interiors cool during intense summer heat and retaining warmth during cold desert nights.

Field surveys highlighted the role of communal maintenance practices, where annual repairs—taught and shared among generations—preserve the site's longevity. This form of living heritage is a critical social dimension, as the act of collectively maintaining structures reinforces community identity and knowledge transmission (Houben & Guillaud, 1994). Yet, the fieldwork also documented challenges: erosion caused by flash floods, depopulation due to rural exodus, and pressures to replace traditional techniques with modern, less sustainable materials such as cement.

Figure 1. Ksar Ait Ben Haddou Landscape

Marrakech: Experimental site
In Ouarzazate and Marrakech, the fieldwork shifted to experimental and hybrid projects designed to bridge ancestral techniques with contemporary performance standards. Pilot housing units were constructed, as villas in the suburbs of Marrakech, using stabilized earth blocks (CSEB), lime-hemp composites, and palm fiber reinforcement (figure 2). These interventions are designed to address Morocco's increasingly stringent thermal (RTCM regulation) and acoustic performance codes (in preparation), while maintaining a symbolic landscape continuity with vernacular architecture.

Figure 2. Example of SEB Villas in Marrakech

Measurements conducted on-site demonstrated that lime-stabilized CSEBs improved compressive strength by up to 40% compared to untreated adobe, without sacrificing breathability or low-carbon benefits (Morel et al., 2017). The use of phase-change materials embedded in walls moderated temperature fluctuations by up to 6°C, enhancing comfort and reducing energy demand for heating or cooling (Riza et al., 2019) (Figure 3).

Figure 3. interior design of an earth villa in Marrakech

Just as important as technical gains, the projects explored how to preserve the tactile and visual identity of Moroccan earthen architecture. Wall textures were left rough or subtly patterned, echoing traditional kasbahs, while natural pigments replicated the chromatic language of the region's landscapes. These choices were validated through informal interviews with local residents, tourists and artisans, who expressed a strong preference for architectural solutions that feel rooted in place rather than alien or imported.

A Human-Centered Dimension
The fieldwork underscored that earthen architecture's value lies not only in its material sustainability and climatic adaptation but also in its ability to anchor communities within a shared cultural narrative. The architecture of ksour and kasbahs functions as a symbolic landscape, reinforcing a sense of belonging and continuity amidst Morocco's rapidly changing urban and environmental contexts. Any innovation, therefore, must tread carefully—enhancing performance while ensuring that these structures continue to embody the collective memory and identity they have carried for centuries (UNESCO, 2019).

2.3 Experimental Design Investigations
Laboratory and pilot-scale tests explored stabilization techniques using lime, fibers, and phase-change materials. Compressed Stabilized Earth Blocks (CSEB) and prefabricated panels were tested, alongside digital fabrication methods including 3D printing prototypes for housing modules. Performance metrics included thermal inertia, acoustic attenuation, and structural durability under various climatic conditions.

3 RESULTS AND DISCUSSION

Stabilized earth incorporating lime and plant fibers demonstrated up to 35% improvement in tensile strength and compressive performance compared to untreated adobe (Morel et al., 2017). Thermal inertia surpassed Moroccan building regulation thresholds, enabling year-round comfort with minimal mechanical cooling.

Phase-change materials embedded in wall assemblies reduced indoor temperature swings by up to 6°C in hot climates and improved sound insulation by 8–12 dB, contributing to acoustic comfort (Riza et al., 2019).

3D printing and prefabricated earth panels (even if the sample was very small) reduced construction timelines by 40% while retaining the tactile, expressive qualities of vernacular forms. These methods also allowed for structural precision, facilitating compliance with seismic codes (Nguyen et al., 2020).

Community engagement revealed strong acceptance when innovations preserved traditional textures, color palettes, and symbolic motifs, underscoring that technological advancements must remain culturally legible (UNESCO, 2019).

4 CONCLUSION

This research illustrates how Morocco's earthen heritage can serve as a foundation for sustainable, high-performance architecture. By combining hybrid materials, phase-change systems, and digital tools, it is possible to meet modern standards without eroding cultural and symbolic significance. Morocco thus holds potential to become a reference in low-carbon, resilient architecture rooted in local identity. Future efforts will focus on lifecycle analysis and the development of regulatory frameworks to scale these hybrid approaches.

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6 FIGURES

Fig. 1. Ksar Aït Benhaddou Landscape
Fig. 2. SEB villa in Marrakech
Fig. 3. Interior design on an earth villa in Marrakech

From Tradition to Hybridization: Contemporary Challenges of Architectural Reconstruction in Earth within Morocco's Southern Disaster-Affected Areas

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ABSTRACT

This article interrogates the contemporary dynamics of vernacular earthen architecture in the provinces of Al Haouz and Chichaoua, in light of reconstruction efforts undertaken following the September 8, 2023 earthquake. Through critical analysis of pre- and post-disaster architectural interventions, it elucidates the structural tensions between heritage preservation logics and modernization imperatives induced by public policies of rehousing and securitization. Field investigations reveal constant recomposition of the built environment, characterized by the juxtaposition of ancient vernacular constructions and new realizations with heterogeneous morphologies.
Prior to the seismic event, local architecture, founded on the use of earth and stone foundations, embodied centuries-old constructive intelligence adapted to regional climatic and topographical constraints. However, post-seismic reconstruction strategies, despite their grounding in discourses valorizing local architecture and traditional materials, manifest on the ground through increasing typological and material hybridization.
The massive integration of industrialized materials introduces a rupture in constructive continuity, questioning the aesthetic, cultural, and environmental coherence of built landscapes. This evolution reflects a profound ambivalence within local communities, torn between attachment to inherited constructive practices and aspirations toward a modernity associated with safety and social recognition.
Confronted with these profound mutations, the article calls for rethinking architectural reconstruction models to reconcile security imperatives, heritage preservation, and community aspirations within a critical approach to post-disaster normative paradigms.

Keywords: Vernacular architecture, earthen construction, post-disaster reconstruction, architectural hybridization, Moroccan mountains.

1 INTRODUCTION

The earthquake of September 8, 2023, which struck the provinces of Al Haouz and Chichaoua with devastating force, constitutes a veritable open-air laboratory for understanding contemporary developments in Morocco's vernacular earthen architecture. This catastrophe, through the magnitude of destruction it wrought and the reconstruction dynamics it triggered, illuminates the tensions between heritage preservation and modernization imperatives within these Moroccan mountain regions.

The disaster-affected areas are distinguished by their rich vernacular architectural heritage, the result of centuries of adaptation to local climatic and topographical constraints. Traditional architecture

was grounded in proven constructive intelligence, intimately linked to natural resources and communal ways of life. However, reconstruction processes reveal complex architectural hybridization dynamics that raise fundamental questions about the sustainability of these traditions when confronted with contemporary demands for safety and comfort.

This article aims to elucidate how public reconstruction policies that reconcile heritage valorization with security imperatives influence these transformations, while exploring the conditions for post-disaster reconstruction that harmoniously combines heritage authenticity, territorial resilience, and local community expectations.

2 BETWEEN PRESERVATION AND TRANSFORMATION : THE PARADOXES OF CONTEMPORARY VERNACULAR RECONSTRUCTİON

The seismic catastrophe that recently affected the provinces of Al Haouz and Chichaoua exacerbates structural tensions surrounding the preservation and evolution of Moroccan vernacular architecture. It highlights the contradictions between official valorization of traditional built heritage and modernization imperatives dictated by post-disaster reconstruction policies.

While institutional discourses advocate the use of traditional materials and techniques, field practices reveal increasing hybridization, marked by the integration of industrialized materials such as reinforced concrete and concrete blocks (Figure 1). This dichotomy between heritage intentions and concrete realizations questions the architectural and environmental coherence of territories, fostering the emergence of a fragmented built landscape where vernacular constructions (Figure 2) and new forms coexist with difficulty. Within this context, local communities find themselves divided between transmission of inherited know-how and aspiration toward a modernity that promises safety and social recognition.

Figure 1a. Example of local vernacular architecture, Douar Tamdeghoust, Timezgadouine commune, Chichaoua province. Source: White Paper of the National Council of the Order of Architects, 2023 [1].

Figure 1b. Current hybridization, Imintanoute. Source: photo by workshop students of the author, 2025.

The central problematic resides in the capacity to reconcile vernacular materials and techniques with contemporary security requirements. This reflection calls for transcending normative heritage preservation and interrogating the transmission and evolution of architectural legacies in the face of new challenges of resilience, spatial justice, and sustainability.

3 VERNACULAR ARCHITECTURE AND POST-DISASTER RECONSTRUCTION: BETWEEN INSTITUTIONAL LOGICS AND LOCAL PRACTICES

Vernacular architectural reconstruction in disaster-affected areas mobilizes a vast interdisciplinary field, intersecting architecture, anthropology, geography, and political sciences. Since the pioneering work of Hassan Fathy (1973) [2], which initiated reflection on participatory adaptation of traditional constructive techniques, the question of earthen architecture in the Maghreb has experienced constant growth. The research of Paccard (1981) [3], followed by Naji (2006, 2010) [4], documented the diversity of techniques and highlighted the systemic dimension of vernacular architecture, articulating constructive choices, social structures, and environmental constraints.

Regarding post-disaster reconstruction, international literature addressing this question, initiated by Ian Davis (1978) [5], has demonstrated the importance of persistent gaps between public policies and local needs. The analyses of Boano & Hunter (2012) [6] and Dunn (2017) [7] emphasize the "reconstruction gap" resulting from tension between technocratic approaches and field realities. This finding aligns with critical work on heritage preservation, such as that of Choay (1992) [8] and, for Morocco, Lahbil Tagemouati (2001) [9] and Lakhsassi (2009) [10], which examine the paradoxes of conservation policies between tourist valorization and authenticity..

Concurrently, the notion of architectural hybridization - a process of métissage between traditional techniques and contemporary innovations - has developed, with contributions from Bourdier & AlSayyad (1989) [11], Vellinga (2013) [12], and Tlemçani (2025) [13] explicating its concrete modalities and identity stakes.

Thus, research on the Moroccan context in this regard, still rare, illuminates the transformations and tensions specific to rural habitat and modernization policies (Hadda, 2003 [14]; Benraouane, 2016 [15]; Mourad, 2018 [16]).

4 BETWEEN EXPERTISE AND INVESTIGATION : METHODOLOGICAL CHALLENGES OF PARTICIPANT OBSERVATION IN POST-DISASTER CONTEXT

This article draws upon a qualitative approach of participant observation developed within the framework of technical expertise missions deployed by the National Council of the Moroccan Order of Architects following the September 8, 2023 earthquake. This singular methodological position, articulating professional engagement and scientific investigation, enables apprehension of architectural transformation dynamics through a longitudinal approach combining technical analysis of constructions and documentation of morphological mutations. The empirical investigation was structured around two distinct temporal sequences in the provinces of Al Haouz and Chichaoua (Figure 3), the most severely affected territories.

Figure 2. Location of Al Haouz and Chichaoua provinces. Source: ALERTE – "An ecological catastrophe threatens the Haouz," according to L'Économiste https://article19.ma/accueil/archives/89238

The first phase (September 2023) focused on the evaluation of seismic damage and characterization of vernacular architectural heritage before reconstruction. The second phase (September 2024) aimed at comparative analysis of architectural transformations that occurred during the first year, offering a diachronic perspective on ongoing processes.

The observational corpus comprises constructions examined during official missions, complemented by new constructions erected within the framework of rehousing programs. Technical documentation relies on classical tools of architectural expertise: photographic surveys, dimensional measurements, material characterization, and conservation state evaluation. This approach was enriched by ethnographic observation of local constructive practices and informal exchanges with inhabitants and architects responsible for construction sites.

Data analysis proceeds through multi-temporal comparison, mobilizing morphological analysis tools to characterize architectural hybridization processes. Interpretation crosses technical approach and anthropological perspective, attentive to social logics underlying constructive choices. Validation proceeds through source triangulation, confronting technical data, field testimonies, and institutional documentation to identify convergences and divergences in observed representations and practices.

5 RESULTS: ARCHITECTURAL TRANSFORMATIONS AND POST-SEISMIC RECONSTRUCTION DYNAMICS

Field investigations reveal complex architectural transformation dynamics articulated around three principal phenomena: the differential vulnerability of vernacular constructive typologies, the emergence of technical hybridization processes, and the morphological recomposition of built landscapes.

5.1 Constructive Vulnerabilities and Damage Patterns

Technical evaluation establishes a significant correlation between traditional typologies and seismic damage patterns. Earthen constructions manifest particular vulnerability at corner chaining levels, with a majority of examined buildings presenting major structural fissures (Figure 5).

The analysis reveals that a significant proportion of damaged constructions present disorders linked to the progressive introduction of industrialized materials into vernacular systems, creating mechanical incompatibilities that amplified seismic effects (Figure 4).

Figure 3a. Example of construction presenting corner fissures, Chichaoua province. Source: Photo CNOA mission,

Figure 3b. Hybrid structure, earthen wall fissures. Imin ouassif. Source: Photos CNOA mission 2024.

5.2 Reconstruction Strategies and Technical Hybridization

Comparative analysis identifies three distinct strategies adopted by local communities. Identical reconstruction constitutes a minority approach using exclusively traditional techniques. Controlled hybridization represents the dominant strategy, selectively integrating innovations into vernacular systems: concrete foundations associated with earthen elevations. Complete rupture favors standardized typologies with industrialized materials (Figure 6).

Figure 4. From left to right, construction using stone foundations, controlled hybridization of construction materials, and post-and-beam construction with concrete block walls. Source: Photos CNOA mission 2024.

5.3 Morphological and Material Mutations

New constructions manifest notable evolution in building scales, with significant increase in habitable surfaces and systematic elevation of heights. Hybridization processes generate unprecedented typologies that partially preserve traditional spatial organization while adopting mixed constructive systems. However, local constructions included a livestock component that has disappeared in most post-earthquake constructions.

Material analysis reveals diversification of the constructive palette and increasing hybridization of mortars, associating local earth with industrial binders. This evolution is accompanied by new pathologies linked to incompatibilities between traditional materials and technical innovations, questioning the durability of adopted hybrid solutions.

Figure 5. The photos show from left to right, systematic elevation of heights, hybridization of styles, and livestock spaces in constructions. Sources: photos by workshop students of the author, 2024.

5.4 The Reconstruction Specifications: Between Heritage Injunctions and Security Imperatives

Analysis of dynamics observed in the field cannot be dissociated from the normative framework that governs them, notably the official Specifications [17] which constitute the reference document framing post-seismic reconstruction operations. Official orientations and declared objectives aim to reconcile structural security, regulatory compliance, inhabitant aspirations, and heritage authenticity within a single normative framework.

5.4.1 *Architectural prescriptions: The codification of the vernacular*

The document establishes a detailed prescriptive system aimed at "framing" vernacular architecture. Provisions concern typo-morphology (optimal orientation according to geographical situation, maximum heights not exceeding R+1), dwelling modes (space separation, privacy preservation, thermal comfort), and exterior envelope (use of earth, stone, and wood, preservation of natural material appearance).

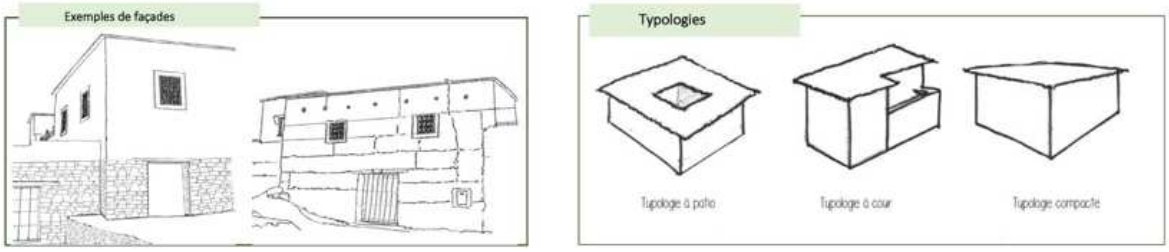

Figure 6. Facade typology and examples established by official reconstruction specifications. Source: Specifications for reconstruction operations following the September 8, 2023 earthquake.

5.4.2 *The dual constructive regime: Controlled tradition and framed modernity*

The Specifications institute a dual construction regime reflecting the tension between preservation and modernization. On one hand, it meticulously details prescriptions for "construction with local materials" (pisé, adobe, stone masonry), establishing precise rules for geotechnical reconnaissance, constructive provisions, and reinforcement systems. On the other hand, it provides for "constructions with load-bearing structure in reinforced concrete and steel," subject to conventional seismic standards.

This normative duality translates the ambivalence of public authorities toward vernacular architecture, valorized in discourse but framed by technical devices that substantially transform its nature. The mandatory introduction of reinforced concrete chains, metallic reinforcement systems, and standardized foundations profoundly modifies traditional constructive logics.

5.4.3 *Institutionalized hybridization*

Significantly, the document explicitly legitimizes architectural hybridization by providing for a "hybrid mode," "reinforced concrete post-and-beam structure and masonry and coating with local materials." This provision institutionalizes the hybridization practices observed in the field, while framing them within a normative framework that privileges structural performance over constructive authenticity. It thus reveals the paradoxical nature of post-disaster heritage policies while displaying a will for preservation.

It methodically organizes the transformation of vernacular practices through the introduction of modern technical standards. This tension between displayed conservation and effective modernization constitutes the normative framework within which the dynamics observed in the field

are inscribed, illuminating the mechanisms by which public policies participate in the recomposition of contemporary vernacular architecture.

6 ANALYTICAL DIGRESSIONS: ISSUES AND PERSPECTIVES OF VERNACULAR RECONSTRUCTION

Post-seismic reconstruction in the provinces of Al Haouz and Chichaoua invites in-depth analysis of tensions between vernacular heritage, contemporary requirements, and social evolutions. Far from constituting a simple technical process, it engages complex dynamics where heritage preservation, adaptation to modern standards, and transformations of habitat practices intersect.

6.1 Tensions between Vernacular Heritage and Modernization Requirements

Analysis of reconstruction policies reveals the difficulty of reconciling preservation of vernacular architecture, the fruit of long adaptation to local conditions, with imperatives of security, durability, and compliance with contemporary technical standards. Institutional discourses certainly valorize earthen built heritage, but their operational translation confronts the necessity of integrating new requirements that often exceed the capacities of traditional systems.

6.2 Constructive Hybridizations: Between Innovation and Loss of Coherence

In this context, the introduction of modern materials such as reinforced concrete, concrete blocks, or steel, mixed with traditional techniques, generates hybrid forms whose structural compatibility and bioclimatic performance remain uncertain. This hybridization, frequently operated without profound adaptation of local know-how, can result in a loss of architectural coherence, even an alteration of the intrinsic qualities of vernacular construction.

6.3 Social and Identity Mutations of Rural Habitat

The evolution of constructive systems accompanies a transformation of habitat practices and representations. Driven by modernization logics and the influence of external actors, local populations tend to progressively distance themselves from traditional models in favor of standardized habitats, thus uniformizing landscapes once imbued with strong territorial identity. This phenomenon raises the question of preserving cultural anchors in the face of comfort and security imperatives.

Beyond its academic and operational implications, this article contributes to broader reflection on contemporary modalities of preserving and transmitting cultural heritage in a world undergoing accelerated transformation. It suggests that the vitality of vernacular architectural traditions resides less in their integral conservation than in their capacity for creative adaptation to contemporary challenges, a questioning that transcends the architectural domain to more broadly interrogate the conditions of cultural continuity in contemporary societies.

7 CONCLUSION

This article on reconstruction dynamics in the provinces of Al Haouz and Chichaoua following the September 8, 2023 earthquake illuminates the complexity of transformation processes affecting vernacular architecture in these Moroccan mountains. Beyond the triggering event, reconstruction modalities reveal structural issues relative to the sustainability and evolution of vernacular heritage in a context of mutation.

The analysis distinguishes three major reconstruction strategies: preservation, hybridization, and rupture. It thus demonstrates the limits of binary oppositions between tradition and modernity. The majority adoption of hybrid solutions enriches reflections on post-disaster cultural adaptation, revealing the living and evolutionary dimension of constructive traditions.

The results of this investigation, though anchored in a Moroccan context, more broadly interrogate international paradigms of reconstruction aid. They suggest the necessity of rethinking dominant models, often marked by the imposition of technical standards inadequate to local realities, in favor of differentiated approaches valorizing endogenous dynamics.

Finally, this theoretical contribution illuminates the concrete mechanisms of architectural hybridization, emphasizing that it can emerge from both cultural choices and external constraints. It thus opens new perspectives on forms of built environment adaptation in crisis contexts.
Far from advocating for frozen conservation, this article proposes a vision of heritage as a living system, capable of evolving without losing its cultural anchorage. This stance invites fruitful dialogue between tradition and innovation, in favor of more just, sustainable, and resilient territorial development.

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Sustainable Development of Morocco's Ksour And Kasbah: An Integrated Territorıal Model

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ABSTRACT

The Sustainable Development Program for Ksour and Kasbah of Morocco (PVD2K) represents a pioneering initiative for preserving architectural heritage in oasis zones. Launched in 2015 with a budget of 251.8 million dirhams, this program rehabilitates 22 pilot sites housing 23,000 inhabitants across three regions through integrated approaches combining heritage restoration, socio-economic development, and capacity building. This mixed-methods study, based on documentary analysis, field observations across 18 sites, stakeholder interviews, and detailed case study analysis, demonstrates the viability of sustainable territorial development models combining heritage preservation with improved living conditions in arid zones. Results show 73% completion rates, creation of 1,400 direct jobs, and mobilization of 21 million dirhams in complementary local funding, validating heritage-based development as an effective territorial development strategy.

Keywords: Ksour, kasbah, heritage preservation, territorial development, sustainable development.

INTRODUCTION

In Morocco's southeastern oasis ecosystems, where ancient earthen fortresses have weathered centuries of storms, the Programme de Valorisation Durable des Ksour et Kasbah du Maroc (PVD2K) challenges conventional wisdom about cultural preservation and economic development. This program proposes that heritage assets can serve as catalysts for territorial transformation rather than mere conservation obligations, representing a practical response to complex challenges facing arid zone communities worldwide.

These monumental structures, constructed using traditional adobe brick techniques and pisé (rammed earth) wall systems, represent sophisticated earthen construction knowledge developed over centuries. The ksour and kasbahs showcase remarkable diversity in earthen building methods, employing adobe masonry with clay-straw mixtures, pisé construction creating monolithic earthen walls, and tadelakt lime plaster finishes that protect the underlying earthen substrates.

Heritage-based development has emerged as a significant paradigm in contemporary development discourse, representing the intersection of cultural preservation imperatives and socio-economic development needs. This approach recognizes cultural heritage assets as potential drivers of sustainable development, aligning with UNESCO's 2011 Historic Urban Landscape Recommendation. In arid regions, vernacular architecture represents both invaluable cultural heritage and accumulated climate adaptation knowledge developed over millennia.

The earthen wall systems employed in Morocco's ksour demonstrate sophisticated understanding of thermal regulation and moisture management, with thick adobe walls (typically 50-80 cm) providing

excellent thermal mass while pisé construction techniques create durable monolithic structures using locally sourced clay and organic binders. Morocco's southeastern oasis ecosystems exemplify this phenomenon, housing exceptional architectural heritage through ksour (fortified villages) and kasbahs (fortified dwellings) that have sustained communities for centuries.

However, these heritage assets face unprecedented threats including environmental pressures intensified by climate change, socio-economic marginalization through rural exodus, erosion of traditional technical knowledge, and institutional inadequacies. Traditional conservation approaches often fail to address the interconnected nature of these challenges, necessitating innovative models that combine heritage preservation with territorial development strategies. Despite growing recognition of heritage's development potential, limited empirical evidence exists regarding the effectiveness of integrated heritage-based territorial development approaches in arid zones.

Morocco's PVD2K program represents a unique opportunity to examine an integrated heritage-based territorial development model operating at significant scale across diverse contexts. The program's comprehensive approach, substantial budget allocation, and multi-year implementation period provide an exceptional case for evaluating such integrated strategies. The central research question asks: To what extent does the PVD2K model successfully integrate heritage preservation with sustainable territorial development in arid zones, and what mechanisms enable or constrain this integration?

This research evaluates the effectiveness of Morocco's PVD2K program through five objectives: assessing program effectiveness across heritage preservation, socio-economic development, and capacity building dimensions; analyzing integration mechanisms; evaluating sustainability and scalability potential; identifying critical success factors; and providing policy recommendations. The study employs a mixed-methods approach encompassing all 22 PVD2K pilot sites (Fig. 1) across three regions through documentary analysis, field observations, stakeholder interviews, and detailed case study examination of Ksar Igoulmim'n rehabilitation in Goulmima.

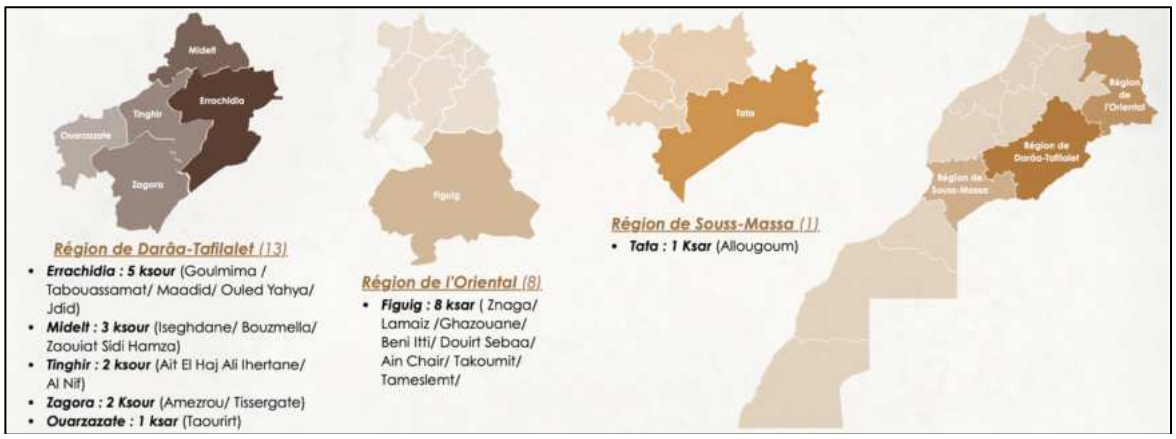

Figure 1. Geographic Distribution of PVD2K Pilot Sites Across Three Regions

1 HERITAGE ASSETS AS CATALYTS FOR TERRITORIAL DEVELOPMENT: BRIDGING CULTURAL PRESERVATION AND ECONOMIC GROWTH

Heritage-based development emerges from the convergence of cultural preservation and sustainable development paradigms, challenging the perception of heritage as an economic burden. Throsby's cultural capital theory provides a foundational framework, conceptualizing heritage assets as generating dual value streams: cultural value through identity and symbolic significance, and economic value through tourism, employment, and market mechanisms [2]. This dual value creation potential repositions heritage as a strategic asset for territorial development.

The "living heritage" paradigm, advocated by ICOMOS and UNESCO, emphasizes dynamic preservation approaches enabling continued habitation while maintaining authenticity [3]. This proves particularly relevant for occupied settlements like Morocco's ksour, where conservation must balance preservation imperatives with residents' livelihood needs. UNESCO's Historic Urban Landscape approach emphasizes landscape-level integration of heritage with contemporary development through participatory governance mechanisms [1].

Territorial development theory addresses spatial dimensions of development processes, emphasizing place-based approaches that leverage local assets rather than imposing external models [4]. This framework recognizes territory as encompassing social relationships, cultural identities, economic networks, and institutional arrangements constituting territorial capital. Heritage assets contribute to territorial resilience by providing identity anchors, diversified economic opportunities, and knowledge repositories for managing environmental and social challenges [8].

Despite extensive literature on heritage conservation and territorial development, limited research addresses their integration in arid contexts. Arid zone heritage faces distinctive challenges including extreme environmental conditions, water scarcity, and limited economic diversification opportunities. Traditional building systems embody sophisticated climate adaptation strategies relevant for contemporary sustainability challenges, yet their preservation requires specialized knowledge and approaches.

2 METHODOGICAL CHALLENGES IN EVALUATING COMPLEX HERITAGE INTERVENTIONS: A MIXED-METHOS APPROACH

Evaluating integrated heritage-based development programs presents unique challenges requiring innovative approaches capable of capturing quantitative outcomes and qualitative transformation processes. This study employs a concurrent embedded mixed-methods design where qualitative insights contextualize quantitative findings [5]. The research encompasses all 22 PVD2K pilot sites distributed across Drâa-Tafilalet (13 ksour), Oriental-Figuig (8 ksour), and Souss-Massa (1 ksar), spanning seven provinces with 23,000 inhabitants.

Sites were selected based on heritage significance, conservation urgency, community organization capacity, and development potential. All sites are located in frontier zones highly exposed to climate change effects, with poverty rates among Morocco's highest, sometimes exceeding 44%. Field research focused on 18 accessible sites during March-September 2024, with Ksar Igoulmim'n selected for detailed case study analysis (Fig. 2).

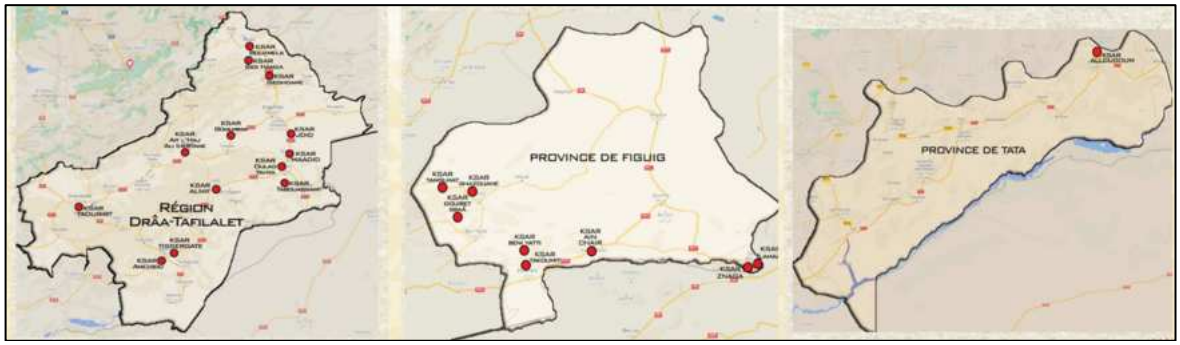

Figure 2. Detailed Geographic Coverage- Drâa-Tafilalet (13 ksour), Oriental-Figuig (8 ksour), and Souss-Massa (1 *ksar)*

Data collection employed documentary analysis of official program documents, field observations, semi-structured interviews with stakeholders across four categories (program management, technical teams, local government, community representatives), case study analysis of Ksar Igoulmim'n, and

quantitative data compilation with cross-source validation. Analysis applies OECD-DAC evaluation criteria and thematic analysis approaches with triangulation through multiple sources enhancing validity and reliability.

3 DEFENDING SUCCESSS IN HERITAGE-BASED DEVELOPMENT: MEASURING MULTIDIMENSIONAL OUTCOMES

Success in integrated heritage-based development requires comprehensive assessment frameworks capturing tangible infrastructure improvements and intangible community empowerment. By December 2023, 16 of 22 sites reached completion representing 73% overall completion rate, with regional variation: Drâa-Tafilalet (77%), Oriental-Figuig (63%), and Souss-Massa (100%) (Table 1, Table 2).

Table 1. Regional Distribution of Rehabilitation Completion Rates

Region	*Total sites*	*Completed sites*	*Completion Rate*
DRAA-TAFILALET	13	10	77%
ORIENTAL-FIGUIG	8	5	63%
SOUSS-MASSA	1	1	100%
TOTAL	*22*	*16*	*73%*

Table 2. Program Budget Distribution by Funding Source (251.8 million Dirhams)

Source	*Amount in DH (MDHS)*	*Contribution (%)*
MATNUHPV	243	96,50%
PROVINCIAL CONCIL OF FIGUIG	3	1,20%
PNUD	5,8	2,30%
TOTAL	*251,8%*	*100,00%*

Rehabilitation encompassed structural consolidation, roof renovation using traditional palmier wood techniques, façade restoration maintaining original elements, and infrastructure integration. Infrastructure improvements included water supply (18 sites), electricity (16 sites), access roads (14 sites), and waste management (12 sites), benefiting 23,000 inhabitants, with solar installations in 8 sites demonstrating renewable energy integration.

Structural interventions specifically addressed earthen construction requirements, including adobe wall consolidation using compatible clay compositions and pisé wall repairs employing traditional compaction methods. Surface treatment restoration focused on traditional finishing systems including tadelakt application over adobe substrates, ensuring weather protection while maintaining authentic earthen construction performance.

Employment generation created 1,400 direct jobs across construction (60%), services (25%), and artisanal activities (15%), with 35% female participation. Income-generating project financing reached 26 projects with 6.28 million dirhams, benefiting 1,000 individuals including 450 women (45% participation). Projects spanned handicrafts (38%), agricultural processing (27%), tourism (19%), and commerce (16%) (Fig. 3), (Table 3).

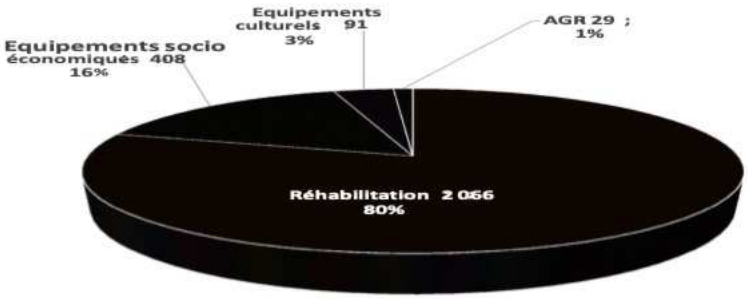

Figure 3. Five-Year Plan 2024-2028 Budget Allocation by Sector

Table 3. Income-Generating Projects by Sector

Sector	*Projects*	*Percentage*	*Beneficiaires*
HANDICRAFTS	10	38%	380
AGRICULTURAL PROCESSING	7	27%	270
TOURISM	5	19%	190
COMMERCE	4	16%	160
TOTAL	*26*	*100%*	*1,000*

Local economic mobilization exceeded expectations with communities contributing 21 million dirhams (11% additional resources), demonstrating extraordinary community ownership. Technical training engaged 50 artisans in traditional construction techniques, while administrative capacity building reached 120 local officials (Fig. 4). Community organization strengthening established 22 local monitoring committees incorporating diverse representation.

Figure 4. Traditional Building Techniques Training- Pisé Construction, Stone Work, and Tadellakt Finishing

The Ksar Igoulmim'n Case Study provides detailed implementation insights. Located in Goulmima, this agricultural oasis houses 400 families (Fig. 5).

Figure 5. Ksar Igoulmim'n General Views- Traditional Fortified Village in Goulmima Oasis

The 8-month 2018 project involved architect consortium LEMCHERFI, AMEZIANE and JARRAR, with CERKAS supervision. Challenges included 12 critical deterioration points, structural instabilities, and inappropriate previous interventions, resulting in 10% cost overruns (Fig. 6).

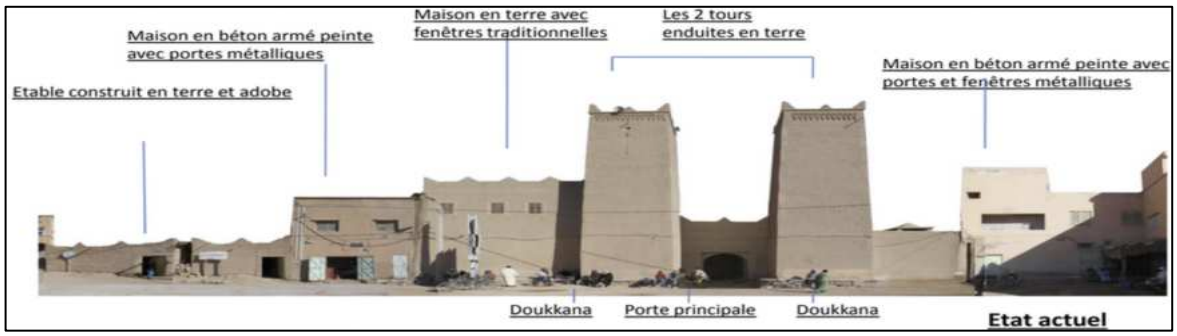

Figure 6. Inappropriate Previous Interventions at Ksar Igoulmim'n- Failed Restoration Attempts and Modern

Solutions emphasized participatory engagement, traditional pisé construction, and specialized artisan training, creating a replicable model while enhancing community conservation awareness (Fig. 7).

Figure 7. Ksar Igoulmim'n Restoration Results- Before and After Traditional Pisé Construction Techniques

The rehabilitation prioritized authentic earthen construction techniques, training local craftsmen in traditional adobe brick production using regional clay sources and proper pisé wall reconstruction methods. Technical challenges included addressing typical earthen construction deterioration patterns such as foundation undermining and wall face erosion while maintaining the structural integrity of the original pisé system.

4 CRITICAL SUCCESS FACTORS AND IMPLEMETATION CHALLENGES: UNDERSTANDING HERITAGE PROGRAM OUTCOMES

The PVD2K program demonstrates significant effectiveness, providing empirical validation of heritage-based development frameworks. The 73% completion rate, 1,400 jobs created, and 21 million dirhams local mobilization confirm Throsby's cultural capital framework through dual value creation [2]. The integrated approach successfully extends UNESCO's paradigm to rural arid contexts, demonstrating comprehensive strategies can function beyond urban environments [1].

Methodological innovations including participatory frameworks with 22 local monitoring committees represent departures from traditional top-down approaches (Fig. 8). Traditional construction training addresses knowledge preservation while generating employment opportunities, with the Ouarzazate pilot demonstrating scalable approaches for maintaining vernacular architecture knowledge.

Specialized training in earthen construction techniques engaged artisans in adobe brick manufacture, pisé wall construction, and traditional surface treatments essential for maintaining Morocco's earthen architectural heritage. These programs addressed the critical shortage of craftsmen skilled in working with traditional earthen materials and techniques.

Figure 8. Participatory Approach Implementation- Provincial Consultation Meetings for 2024-2028 Strategic Planning

Implementation challenges include the complete absence of kasbah valorization, highlighting difficulties with privately-owned heritage assets reflecting tensions between individual property rights and collective heritage value. While ksour benefit from collective ownership facilitating decisions, kasbahs' private ownership creates legal barriers. The Goulmima case study reveals additional complexities including unexpected technical challenges and cost overruns, demonstrating that heritage conservation requires substantial contingency planning.

Technical capacity constraints persist with limited availability of specialized architects and traditional artisans. However, the program demonstrated adaptive capacity through the Majorelle Kasbah valorization project (20 million dirhams), envisioning multifunctional facilities integrating museum functions, workshops, services, and accommodation (Fig. 9).

Figure 9. Proposed Majorelle Kasbah Multifunctional Development- Museum, Workshops, and Tourist Accommodation

Sustainability depends on institutionalization mechanisms and sustained political support. Local committees and territorial planning integration provide positive indicators, though heavy national funding reliance (96.5%) raises questions for the 2024-2028 expansion (88 sites, 2.5 billion dirhams). The program's capacity building shows promising sustainability through certified artisan networks, though limited training scope suggests need for substantial scaling.

This research contributes to heritage studies by demonstrating living heritage principles in rural arid contexts while validating place-based approaches leveraging cultural assets as territorial capital. Findings challenge conventional conservation approaches separating heritage from development

objectives, demonstrating integrated approaches achieve superior outcomes. Unexpected findings include higher-than-anticipated local mobilization and successful renewable energy integration exceeding expectations.

CONCLUSION

This examination of Morocco's PVD2K program provides compelling evidence that heritage preservation can effectively anchor sustainable territorial development through integrated, participatory approaches achieving measurable outcomes across cultural, economic, and social dimensions. The research validates theoretical frameworks emphasizing heritage's dual value while identifying mechanisms enabling effective integration in challenging arid zone contexts.

The program demonstrates effective integration through comprehensive approaches combining physical rehabilitation, socio-economic development, and capacity building while maintaining cultural authenticity and generating community benefits. Critical success factors include sustained political commitment, technical expertise in traditional construction, and meaningful community engagement through participatory mechanisms. Implementation constraints involve capacity limitations, legal framework gaps regarding private heritage assets, and complexity of working with aged vernacular architecture requiring adaptive management.

Policy recommendations include establishing specialized legal frameworks balancing property rights with collective heritage value, expanding technical training through permanent regional centers, developing diversified financing mechanisms reducing state dependency, establishing documentation systems building institutional memory, and implementing comprehensive monitoring tracking conservation and development impacts.

The 2024-2028 expansion will test scalability and sustainability while potentially establishing Morocco as a leader in arid zone heritage-based development. Future research should examine expansion processes, long-term sustainability outcomes, and comparative analysis with similar initiatives. Research priorities include longitudinal studies, comparative analysis against international practices, and examination of scaling mechanisms. Heritage-based development's climate adaptation potential appears particularly relevant given increasing climate pressures.

This research demonstrates heritage preservation can anchor sustainable territorial development through participatory approaches prioritizing local ownership and economic opportunity creation alongside conservation objectives. The PVD2K program provides a valuable model highlighting the importance of adaptive management, technical capacity development, and sustained community engagement. The success suggests that with appropriate design, heritage can serve as foundation for building resilient and prosperous futures in challenging environments, offering insights for heritage-based development initiatives worldwide.

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The Transformation of the Souani in Salé: From Vernacular Agro-Landscape to Informal Urban Absorption - A Lever for Territorial Resilience and Urban Cohabitation

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ABSTRACT

The city of Salé, located on the right bank of the Bouregreg River, preserves in its urban memory the legacy of the souani—irrigated orchards shaped by a vernacular agro-landscape deeply rooted in traditional hydraulic and social practices. This article examines their transformation into informal urban fabric through an interdisciplinary approach combining historical archives, morphological surveys, oral histories, and spatial modeling. The case study of the Sidi Moussa neighborhood highlights the gradual disappearance of agrarian frameworks due to land pressure and the lack of institutional recognition. However, hydraulic structures, relict plant species, and local memory narratives reveal the resilience of these landscapes. The article argues for reconsidering the souani as levers for sustainable urbanism and grounded city-making, by reintegrating these landscape matrices into planning and regulatory tools. This work contributes to a vision of urbanism where heritage and ecology are meaningfully intertwined.

Keywords: Souani, Salé, informal settlements, vernacular resilience, ecological heritage

1 INTRODUCTION

Located on the right bank of the Bouregreg River, facing Rabat, the city of Salé presents an urbanized territory where the layers of a long history intertwine rural and urban dynamics[1]. During his exile in Salé between 1360 and 1363, the famous Andalusian vizier, historian, and poet Lisan al-Din Ibn al-Khatib left a remarkable testimony about the city. Forced to flee the Nasrid court of Granada due to political tensions, he found refuge in this Moroccan city, then flourishing both culturally and spiritually. In his writings, he described Salé as follows:

[1] Mahfoud, Mohammed. (2003). *La ville dans l'histoire du Maroc : étude globale* (Thèse de Doctorat d'État en Histoire, Université Mohammed V de Rabat, Faculté des Lettres et des Sciences Humaines) pp. 377

"Endowed with beauty and freshness, combining both the features of Bedouin life and urban civilization… The zawiya resembles a garden, and the river, with its many sources, embraces it with its arms." [2] **(**ذات الوسامة والنضارة، والجامعة بين البداوة والحضارة... والزاوية كأنها البستان، والوادي المتعدد الأجفان**)** This quote reflects not only the author's wonder at the harmony between nature and civilization but also the social and urban richness of 14th-century Salé, perceived as a model of coexistence between rural tradition and urban refinement.

Figure 1. Location of the city of Salé on the map of Morocco.
Source : https://www.collectivites-territoriales.gov.ma/sites/default/files/pnct/2022-08/Les%20r%C3%A9gions%20du%20Maroc%20en%20chiffres.pdf

Until the mid-20th century, Salé housed agricultural forms interwoven with the city: the souani. These irrigated orchards, fed by basins or springs, formed a sustainable agro-urban fabric, ensuring food production, thermal regulation, and leisure spaces (nzaha) [3]for residents. Gardens, aguedals, basins, orchards, and even the smallest neighborhood green spaces contributed to a civic urbanity where landscape acted as a vector of social cohesion, memory, and identity.[4]

In Moroccan tradition, green spaces go beyond modern public parks or gardens. They encompass a variety of inherited forms, each with specific functions—such as agdals, arssas, and souani[5]. Agdals are large, sometimes wooded enclosures, often communal or royal, protected and left fallow for part of the year, combining agriculture, seasonal leisure, and spirituality. Souani are irrigated orchards, generally located on the outskirts of medinas or ksour, fed by hydraulic systems like norias or khettaras[6]. These served both for fruit production and pleasure, embodying a harmonious articulation between built environment and nature[7]. In addition, it is important to recall that souani were not merely irrigated orchards. They formed part of a vernacular fabric in which earthen architecture played a central role: perimeter walls built in rammed earth (pisé), agricultural annexes in adobe, and basins and norias integrated into earthen enclosures. These built elements demonstrate the close relationship

2 Lisan al-Din Ibn al-Khatib, Miʿyār al-ikhtiyār fī dhikr al-maʿāhid wa-l-diyār, éd. Mohamed Kamel Chabana, Rabat, Institut Universitaire de la Recherche Scientifique, 1977 pp. 152.
3 Ahmed Khalid Ben Omar. Islam, vie collective, organisation sociale et politique dans la ville de Salé : (1792-1930). Histoire. Université Panthéon-Sorbonne - Paris I, 2017. Français. ⟨NNT : 2017PA01H120⟩. ⟨tel-01886105⟩, pp. 193.
4 **Mouline, S.** (2007, 12 avril). *De l'importance des jardins pour une urbanité citoyenne* [PDF]. Marocpluriel. https://marocpluriel.com/content/publications/de-limportance-des-jardins-pour-une-urbanite-citoyenne.pdf. Pages 2,3,5.
5 **Mazirh, K.** (2024). *Repenser la ville pour faire face au changement climatique : Cas de Marrakech* (Thèse de doctorat, Faculté des Sciences Semlalia, Université Cadi Ayyad). N° d'ordre : 880. Spécialité : Géo-environnement, Urbanisme et Télédétection Spatiale.page 102
6 El Faïz Mohammed. Marrakech : de l'enclos de l'Agdâl a l'idée du « jardin planétaire ». In: *Horizons Maghrébins - Le droit à la mémoire*, N°45, 2001. Paysages et jardins des Méditerranéens. pp. 87-90. DOI : https://doi.org/10.3406/horma.2001.1989 www.persee.fr/doc/horma_0984-2616_2001_num_45_1_1989
7 El Faïz Mohammed. Marrakech : de l'enclos de l'Agdâl a l'idée du « jardin planétaire ». In: *Horizons Maghrébins - Le droit à la mémoire*, N°45, 2001. Paysages et jardins des Méditerranéens. pp. 87-90. DOI : https://doi.org/10.3406/horma.2001.1989 www.persee.fr/doc/horma_0984-2616_2001_num_45_1_1989.

between cultivated landscapes and earthen architectural heritage, underlining that the memory of the souani is inseparable from Morocco's earthen architectural heritage.

It is important to recall that souani were not merely irrigated orchards. They belonged to a vernacular fabric where earthen architecture played a central role: perimeter walls in rammed earth (pisé), adobe annexes, and basins or norias within earthen enclosures. These features illustrate the close relationship between cultivated landscapes and Morocco's earthen heritage. This classification confirms that traditional green spaces formed a plural system rooted in socio-religious, climatic, and agrarian dynamics. In this perspective, vegetation is not only ornamental or ecological but a structuring principle of urban space[8]. In Salé, toponymy with names like "Sania" or "Swani" still preserves their memory[9] .

In Salé, souani—vernacular agro-hydraulic systems once fully integrated into the urban fabric—have been gradually erased by land pressure, informal dynamics, and institutional neglect. This disconnection between landscape memory and current urban production raises a profound tension between the rural past embedded in the city and contemporary logic of planned growth[10]. In this context, how can we rethink the revitalization or reactivation of the souani as hybrid structures—between nature, memory, and the city—at a time when issues of climate resilience, controlled density, and social justice demand new ways of envisioning urbanity in Morocco?

2 THEORETICAL AND CONCEPTUAL FRAMEWORKS

The analysis of the *souani* of Salé is based on an interdisciplinary approach structured around six main axes. First, the works of Hassan Fathy and Bernard Rudofsky rehabilitate vernacular architecture as a system of resilience rooted in local know-how. The *souani*, irrigated orchards located within the urban fabric, embody this logic of territorial intelligence. Second, Besim Selim Hakim demonstrates that Arab-Islamic cities were historically structured around customary principles for managing resources—particularly water. The *souani*, as productive and climate-regulating spaces, reflect this Islamic morphogenesis founded on land solidarity. The analyses of Janet Abu-Lughod and Kenneth Brown shed light on the impact of colonization on ancient agrarian structures. In Salé, this resulted in the marginalization of the *souani*, which were excluded from modern urban planning strategies. Professor Mohammed Naciri emphasizes the contemporary crisis in the relationship between city and nature, highlighting the disappearance of territorial heritage in an urbanism disconnected from citizens' expectations. He interprets the *souani* as carriers of urban memory erased by modernization. Finally, the contributions of Arsalan (2020), Gillot (2020), and El Adlouni (1994) advocate for the reintegration of vernacular landscape frameworks into urban planning tools (SDAU, PA, green plans). The *souani* appear here as ecological, social, and heritage resources for imagining the sustainable city of tomorrow.

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[8] Khadija Karibi, *La mixité urbaine et l'espace public à Rabat*, Paris, L'Harmattan, 2015, coll. « Histoire et perspectives méditerranéennes », p. 97.

[9] Gaëlle Gillot. Ces autres espaces. Les jardins publics dans les grandes villes du monde arabe : politiques et pratiques au Caire, à Rabat et à Damas. Géographie. Université François Rabelais - Tours, 2002. Français. ⟨NNT : ⟩. ⟨tel-00685241v2⟩ pp. 35

[10] El Adlouni, A. (1994). *Mécanisme de formation et de régularisation de l'habitat clandestin. Cas de Sidi Moussa à Salé* (Mémoire de Diplôme d'Études Supérieures en Aménagement et Urbanisme). Bibliothèque de Institut National d'Aménagement et d'Urbanisme (I.N.A.U.), Rabat.p1-3

3 METHODOLOGY

The adopted methodology relies on an interdisciplinary approach that combines architectural tools, historical research, fieldwork, and morphological analysis to reconstruct the transformation dynamics of the *souani* in Salé. Four complementary components structure the investigation. First, a historical and archival analysis was conducted using cadastral plans and colonial maps (1906–1941), as well as urban planning documents from the 1970s to the 1990s, to trace the progressive integration of the *souani* into the urban fabric—particularly through regularization files of informal settlements in Sidi Moussa. Second, morphological surveys were carried out in the field, including freehand sketches, diagrams, observations of hydraulic remnants, and the identification of relict trees, which were then modeled using Archicad to reconstruct original agricultural layouts and neighborhood densification dynamics. In parallel, eight semi-structured interviews were conducted with ten informants (former farmers, residents, local association members, and municipal technicians), guided by an open thematic framework focusing on past uses, appropriation processes, and perceptions of the *souani*'s disappearance. Finally, a diachronic cartographic comparison was conducted, overlaying historical maps with current urban forms modeled in Archicad, to visualize the gradual erasure of the *souani* by crossing spatial data with oral testimonies. This methodology enables a precise, cross-disciplinary, and contextualized reading of an evolving urban landscape.

4 THE CASE OF THE SOUANI OF SALÉ: A DYNAMIC OF SPATIAL DISINTEGRATION

Figures 2, 3, 4, and 5 illustrate the disappearance of vegetated spaces (*souani*) in the city of Salé over a very short period between 1906 and 1941. In fact, the area occupied by *souani* in Salé was estimated, up to around 1890[11], at 35 hectares out of the 90 hectares constituting the surface of the Salé medina[12] —representing 38.88%[13]of the total area of the medina. At the beginning of the 19th century, 44 *saniat* were counted within the medina walls (*intramuros*). Today, only one remains: *Saniat Zniber*.[14]

This data highlights how inherited spaces—including gardens, orchards, and hydraulic networks—are often erased or marginalized by urban planning policies in the name of efficiency or standardized development. [15]This *"crisis of the desire for the city"* (*crise du désir de ville*) manifests notably in the loss of territorial anchorage and collective memory, directly linked to the disappearance of *souani* on the outskirts of Salé.

This perspective reinforces the central argument of this article: *souani* represent forms of vernacular urbanity, bearing witness to an alternative way of "making the city"—a way that is rooted, ecological, and socially inclusive.

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[11] Saâdiyn, M. (2023). *Al-mujtamaʿ al-salāwī, 1666–1822 / 1076–1238 H*. Rabat: Imprimerie Rabat Net.pp 29

[12] Naciri(M) ,salé, étude de la géographie urbaine, RGM, n3 -4,1963, pp 18-22

[13] Saâdiyn, M. (2023). *Al-mujtamaʿ al-salāwī, 1666–1822 / 1076–1238 H*. Rabat: Imprimerie Rabat Net.pp 29

[14] ibn Ali Doukkali, M. (1996). Al-Ittiḥāf al-wajīz: Tārīkh al-ʿAdwatayn (M. Būshaʿrā', éd.). Al-Khizāna al-ʿIlmīya al-Ṣubayḥīya bi-Salā. pp79, foot page note N°80

[15] Naciri, M. (2018). *Désirs de ville* (Préface de F. Damette, Postface de M. Fadili, Rabat : El Maarif Al Jadida. pp. 24–26.

Figure 2. Gardens (*saniat*) of Salé in 1906

Figure 3. Gardens (*saniat*) of Salé in 1917

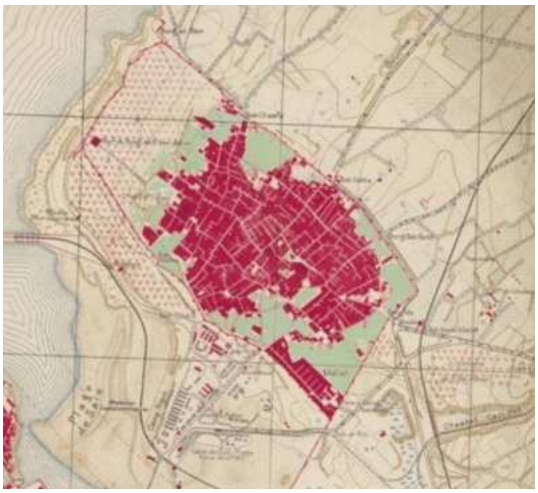

Figure 4: Gardens (*saniat*) of Salé in 1927

Figure 5: Gardens (*saniat*) of Salé in 1941

Sources: Maps sourced from the Bibliothèque national de France (Gallica), dated between 1906 and 1941. Selection, graphical processing, and analysis by the author.

5 SIDI MOUSSA: A CASE STUDY OF THE TRANSFORMATION OF SOUANI INTO INFORMAL URBAN FABRIC:

Represents a key case of the gradual transformation of *souani* into informal housing zones. A cross-analysis of historical maps, field survey data, and semi-structured interviews conducted on-site reveals an active dynamic of illegal land reallocation.This process has been driven by increasing pressure on urban land, a housing shortage, and the absence of inclusive planning frameworks.

Figure 6. Sania ABBAS (Garden) surrounded with construction

Source: authors 24/07/2025

Archived data on the creation of *amicales* (neighborhood associations involved in land regularization) allows us to trace the intensity of this dynamic. This analysis is based on tables documenting the status of these *amicales* at the Salé Court of First Instance and survey data from 1993[16]:

- 1985 stands out as the most significant year, accounting for 35.1% of the *amicales* created.
- 1989 follows with 24.3%, marking a second wave of land appropriation.
- The years 1990, 1992, and 1988 confirm the persistence of the phenomenon (between 8% and 11%).
- Other years, such as 1984, 1986, 1991, and 1993, appear marginal (2.7% each).

The 1985 peak corresponds to a period of institutional vacuum or administrative tolerance that enabled the expansion of illegal subdivisions. These *amicales* later played a decisive role in land regularization requests and in the social structuring of the emerging neighborhoods.

Figure 7. Cherry tomateos cultivated in Sania ABBAS

Source: authors 24/07/2025

The gradual transformation of the territory led to the disappearance of the collective agrarian model (irrigated orchards, water basins, fruit trees), replaced by an irregular urban fabric largely lacking in public facilities, roads, and infrastructure (figure 7). Interviews with former farmers and long-time residents emphasize a strong collective memory attached to the *souani*, seen as places of leisure, subsistence farming, and community solidarity.

Morphological surveys carried out on site made it possible to identify surviving plant relics (orange trees, pomegranates, pear trees, apricots, and lemons once planted during the *souani* period[17])(figure6), bearing witness to the area's former agricultural use[18]. Moreover, some traditional hydraulic structures

[16] El Adlouni, A. (1994). *Mécanisme de formation et de régularisation de l'habitat clandestin. Cas de Sidi Moussa à Salé* (Mémoire de Diplôme d'Études Supérieures en Aménagement et Urbanisme). Bibliothèque de Institut National d'Aménagement et d'Urbanisme (I.N.A.U.), Rabat.pp 92-95.

[17] BrownKenneth L., People of Salé Tradition and Change in a Moroccan City, 1830–1930 (Cambridge, Mass.: Harvard University Press, 1976). Pp. 265, Illus., tables. - Volume 10 Issue 2 - C. C. Stewart. pp25

[18] El Adlouni, A. (1994). *Mécanisme de formation et de régularisation de l'habitat clandestin. Cas de Sidi Moussa à Salé* (Mémoire de Diplôme d'Études Supérieures en Aménagement et Urbanisme). Bibliothèque de Institut National d'Aménagement et d'Urbanisme (I.N.A.U.), Rabat.pp23

(channels, basins) are still visible within private plots, though often in an advanced state of degradation. The traditional irrigation system of the *souani* was organized around the *noria* (animal-powered waterwheel), typically installed at the entrance to the garden on an elevated platform measuring approximately 8 m × 8 m and raised 1.5 m above the ground[19]. This device, often shaded by four trees, illustrates the age-old adaptation of vernacular hydraulic engineering to local conditions—combining technical efficiency, energy sobriety, and respect for the natural water cycle.

6 GENERAL DISCUSSION

The case of Sidi Moussa in Salé reveals a broader dynamic of disintegration affecting agro-hydraulic landscapes in Moroccan cities. This erosion reflects the marginalization of urban agrarian heritage under pressures of land expansion, informal planning, and inadequate regulatory frameworks. *Souani*—identified here as hybrid spaces (agricultural, urban, and landscape-based)—have been progressively excluded from urban planning instruments (SDAU, PA, landscape charters), largely due to their ambiguous legal status. This exclusion signals a deeper rupture in the relationship between city and nature, where inherited landscapes with ecological, social, and memorial functions are sacrificed for densification and land value. The disappearance of the souani entails both the weakening of agro-hydraulic landscapes and the erosion of earthen know-how, as perimeter walls, annexes, and hydraulic components were traditionally built in rammed earth (pisé) or adobe. This loss of vernacular heritage, however, coincides with a renewed appreciation of earthen techniques for their ecological and bioclimatic value. Field surveys and interviews show that traces persist—hydraulic remnants, relict vegetation, and collective memory—providing resources whose reactivation could foster resilient, inclusive, and ecological urbanism. The case of Sidi Moussa illustrates the urgency of reintegrating these matrices as tools of urban repair beyond rigid city–countryside binaries.

7 CONCLUSION

- This research demonstrates that the souani of Salé, although largely erased from the contemporary urban fabric, remain legible through land structures, persistent plant elements, residual hydraulic networks, and collective memory. Their disappearance results not merely from neglect, but from the intersection of informal land transformations, institutional voids, and the undervaluation of vernacular landscape knowledge, including the constructive traditions of earthen architecture such as rammed earth (pisé) and adobe. Recognizing this dual loss—of landscape frameworks and of earthen building know-how—underlines the need to address the souani as both ecological and architectural heritage.
- Using diachronic cartographic analysis (1906–1941), morphological fieldwork, oral interviews, and archival documents, the study uncovers the *souani*'s rich landscape, ecological, and social dimensions, and affirms that their loss is neither linear nor irreversible. Opportunities for reactivation or reinterpretation remain possible—if supported by grounded, participatory local policies attentive to memory and place.
- From a territorial sustainability perspective, *souani* can serve as climate resilience infrastructures, urban biodiversity hubs, and social and memorial anchors in rapidly transforming neighborhoods. The case of Salé invites a rethinking of the relationships between

[19] Georges Séraphin Colin, *La noria marocaine et les machines hydrauliques dans le monde arabe*, Paris, Larose, 1932, 40 pp..3

city, soil, water, and society, especially in the context of Mediterranean socio-environmental transitions.

- Therefore, the study advocates for:
  • A national inventory of historical urban agricultural and hydraulic systems;
  • Their integration into urban planning tools (SDAU, PA, green and climate plans);
  • The recognition of vernacular knowledge as a valuable resource for future urban design.

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Revitalizing Vernacular Earthen Architecture: The Case of Ksar Aourir in the Tafilalet Region, Morocco

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ABSTRACT

Earthen construction holds a fundamental place in Morocco's traditional vernacular architecture, embodying centuries-old techniques that are deeply adapted to the country's climate, culture, and landscape. From historic medinas to fortified mountain villages, these construction methods including rammed earth, adobe, and sun-dried bricks have been developed in harmony with local environmental conditions, offering both functional and aesthetic qualities.

However, over the past few decades, this heritage has been in sharp decline. Traditional earthen construction techniques are being progressively abandoned, replaced by industrialized materials and modern models that often lack sensitivity to local identity. This shift has led to the degradation and desertion of many architectural forms, particularly ksour and kasbahs, which represent invaluable cultural and architectural heritage. These structures are not only testimonies to ancestral knowledge but also integral parts of Morocco's tangible heritage and collective memory.

The Ksar of Aourir, located in one of the country's historically rich regions for earthen architecture, is a striking example of this phenomenon. Now in a state of neglect, Aourir embodies both the fragility and resilience of vernacular heritage. Through its historical layers and architectural evolution, the Ksar offers an opportunity to study, understand, and reflect on the challenges and strategies related to preservation.

This research proposes a critical and integrated approach to the Ksar's revitalization, highlighting the need to safeguard such heritage as a living, usable, and meaningful part of contemporary Moroccan society.

Keywords: Earthen architecture, vernacular heritage, ksour, kasbahs, construction traditions, tangible cultural heritage.

1. INTRODUCTION

Earthen architecture in Morocco represents not only a construction technique but a deeply rooted cultural and environmental expression. The vernacular structures of the Tafilalet region, particularly the Ksour (plural of Ksar), serve as material testimonies to centuries of adaptation to a harsh environment and a complex social fabric. However, this architectural heritage is now under threat.

Massive rural exodus, economic reorientation, and the perception of modernity linked to concrete and industrial materials have accelerated the abandonment of these heritage sites. This article

focuses on Ksar Aourir, a fortified village emblematic of the pre-Saharan earthen architectural tradition, which suffers from advanced degradation but retains potential for sustainable regeneration.

The research investigates both the tangible and intangible dimensions of Aourir's decline and recovery. It proposes a comprehensive reconstruction strategy that reintegrates vernacular knowledge into contemporary practice. The paper is structured to present the historical and architectural context, the causes of degradation, and a concrete framework for reconstruction and revitalization. It aims to contribute to the scientific discourse on heritage, sustainability, and climate-resilient architecture in arid regions. By drawing from both ethnographic data and comparative architectural analysis, it anchors the project in real-world constraints and culturally embedded strategies. It also outlines how traditional knowledge systems can inform sustainable urbanism and offer climate-resilient models relevant beyond Morocco.

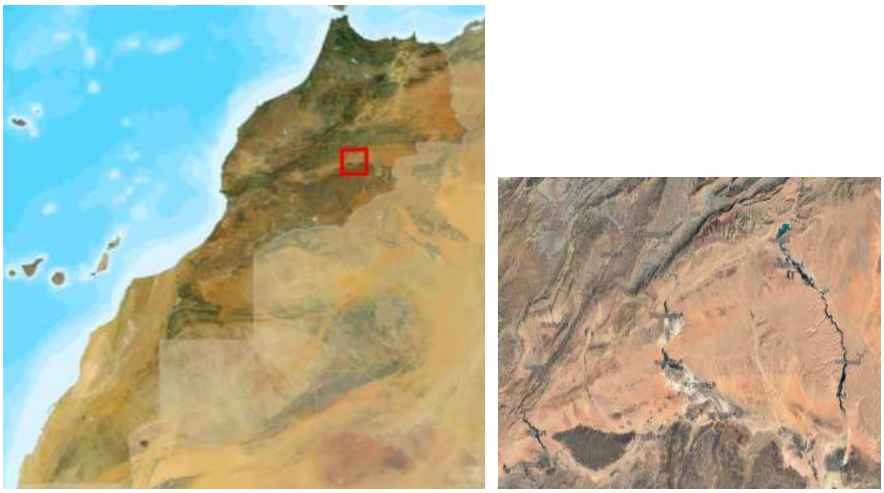

Figure 1. Location of Ksar Aourir in Tadighoust region

2. VERNACULAR EARTHEN ARCHITECTURE IN MOROCCO

The architectural culture of Morocco has historically relied on the intelligent use of local materials. In southern oases, pisé (rammed earth) and adobe (mudbrick) were employed not out of necessity alone, but because of their remarkable bioclimatic properties and renewability. The Ksour were built as collective, enclosed settlements that responded to social and environmental imperatives. Their compact morphology, narrow alleys, and introverted facades minimized solar exposure and maximized thermal comfort.

In Tafilalet, the earthen building tradition evolved through centuries of experimentation. Walls of up to 60 cm thick provide substantial thermal inertia (up to 10–12 hours), moderating temperature swings in desert climates. Openings are minimized and oriented based on prevailing winds. Structural components include palm trunks (used for horizontal beams), tree branches, reeds, and multiple layers of earth mixed with straw for waterproofing and insulation.

These techniques are not arbitrary: they reflect a sophisticated, cumulative understanding of form, function, and material behavior. Construction processes involve community labor, gender-specific roles such as women plastering internal surfaces, and seasonal rhythms. Rituals accompany the completion of structural elements such as the roof or main door lintel. Such embedded cultural practices reinforce architecture as a social act, not a technical product. However, these practices now face challenges from modern regulations, which often overlook their capacity to meet thermal, seismic, and durability requirements. The perception of vernacular construction as backward or unfit for contemporary use contributes to a profound rupture in its transmission.

Figure 2. Rammed Earth method of construction

2.1 Bioclimatic Performance

The thermal inertia of earth walls delays indoor temperature fluctuations by 8–12 hours, providing natural cooling in hot climates and insulation in cold nights. Their hygroscopic properties help maintain indoor humidity levels between 50–70%, ensuring comfort without the need for mechanical systems. Earth also has excellent acoustic insulation properties, reducing echo and external noise.

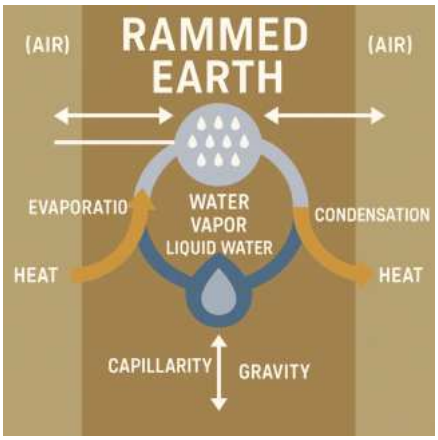

Figure 3. Thermal and physical characteristics of rammed earth

2.2 Legal and Institutional Framework

Organizations like CERKAS (Center for Restoration and Rehabilitation of Architectural Heritage of Atlas and SubAtlas Zones), Morocco, and regulations like RTCM (Thermal Construction Regulations in Morocco) promote preservation and adaptation. However, implementation is inconsistent and often lacks funding. The absence of national heritage listing for many Ksour complicates access to restoration support. Seismic risks have led to stricter building norms, but without adequate adaptation for earthen contexts.

3. CAUSES OF ABANDONMENT OF KSOUR

The decline of Ksar Aourir and similar settlements stems from a combination of socio-economic, cultural, and regulatory factors. The rural exodus that intensified in the 1980s was driven by lack of employment, inadequate services, and the lure of urban amenities. Families who moved to nearby urban centers or emigrated internationally often left homes abandoned, leading to the gradual collapse of unmaintained structures.

Culturally, the association of earthen buildings with poverty led to their replacement by concrete constructions, even when these lacked climatic or structural adequacy. Policies promoting 'modern' building materials marginalized vernacular systems. Furthermore, the loss of local artisanship due to generational disconnection meant that traditional techniques became inaccessible or deemed obsolete.

The lack of integration of Ksour into national heritage registers and the absence of adapted restoration funding mechanisms further reinforced this decline. As walls crumbled and roofs caved in, the collective spaces, such as the central space called Anrar (pl. Inourir) or communal granaries, lost their function, breaking down the social cohesion once central to the Ksar's vitality.

In addition, administrative and legal uncertainties such as unclear land titles or inheritance conflicts often prevent communities from initiating rehabilitation. These layers of dysfunction result in not only physical erosion, but also the erosion of memory and belonging. Aourir is no longer seen by many as a viable living space, but merely as a ruin visited during holidays or commemorations.

Figure 4. Damaged structures of Ksar Aourir

4. CASE STUDY: KSAR AOURIR

4.1 Site and Morphology

Located in the Tadighoust valley, Aourir is a compact Ksar, surrounded by agricultural, fertile lands and date palms. The layout follows topographic lines, with narrow alleys, enclosed patios, and inward-facing facades. Its compactness responds to the desert climate and collective security needs.

4.2 Construction Logic

Buildings rest on stone foundations, with walls in rammed earth, roofs supported by palm beams, covered with reed and finished with a mud-straw mix. Openings are small and strategically placed for ventilation and lighting. The repetition of modular elements ensures scalability and ease of repair.

4.3 Typologies

There are three main typologies: family dwellings, mainly a two-story building, collective storage units, and public facilities like the mosque and central square (Anrar). These reveal a system based on mutualism and resource efficiency. The central square was used for drying dates, marriage celebrations, religious festivities, or meetings during the cool evening.

4.4 State of Degradation

The totality of homes is uninhabited. Roofs have collapsed, wooden beams are rotting, and rainwater has eroded the walls. The central square is used only sporadically. Several entrances are blocked by rubble.

Figure 5. Ruins of Ksar Aourir. Partially ruined in red and totally ruined in blue

5. RECONSTRUCTION STRATEGY

The reconstruction strategy for Ksar Aourir is based not on the conservation of ruins, but on the revival of a functional, inhabited, and structurally sound settlement using vernacular principles.

Recognizing that most of the built fabric has collapsed or is irreversibly deteriorated, the intervention proposes a full reconstruction of key urban and architectural components guided by historical evidence, local materials, and cultural logic.

The aim is not a pastiche reproduction, but a process of architectural regeneration: rebuilding from memory, respecting traditional morphologies, while ensuring compliance with modern comfort and safety standards. The reconstructed Ksar will maintain its original compact fabric, narrow alleys, inward-facing housing typologies, and central square. Construction methods will follow traditional techniques using rammed earth, palm wood, and natural finishes, but enhanced by modern knowledge on seismic resilience, structural durability, and environmental performance.

Foundations will be rebuilt with stone and lime mortar. Walls will use stabilized earth compacted in formworks. Roofing systems will combine palm trunks, reed mats, and layered earth, with improved water evacuation. Openings will respect original proportions, with added protections such as wooden shading devices. Technical networks (electricity, sanitation, water) will be integrated discreetly to avoid visual pollution. Passive design remains the core strategy, reinforced with optional solar energy systems and natural ventilation corridors.

The project is organized in thematic clusters: residential zones, public services (mosque, cultural center), productive spaces (craft workshops, cooperative spaces), and touristic components (guesthouses, heritage route). Each zone will be reconstructed as a coherent ensemble, ensuring continuity in materiality, scale, and urban grammar.

Figure 6. Master plan of Ksar Aourir

6. SOCIAL AND ECONOMIC DIMENSIONS

No architectural reconstruction is meaningful without social reactivation. The proposed strategy for Ksar Aourir explicitly integrates local populations, return migrants, and regional stakeholders in the reconstruction process. Before launching works, several participatory diagnostics were conducted: mapping exercises, family surveys, memory workshops, and skills inventories. These allowed the definition of priorities rooted in lived experience and collective aspirations.

To ensure sustainability, the project proposes a hybrid economic model. Local masons will be trained in seismic-resistant earthen techniques. A fabrication yard will be installed near the site to produce adobe blocks, mortar, and timber joinery. This site will also function as a training platform for vocational education and research. Community cooperatives will manage maintenance, hosting, and cultural programming.

Economically, the reconstructed Ksar will offer multiple revenue streams: seasonal tourism, agroecological production, cultural events, and educational residences. A governance committee composed of local elders, youth representatives, and technical advisors will supervise decisions. Indicators of success include occupancy rate, employment generation, number of restored houses, and reintegration of traditional practices into daily life.

Figure 7. Rendered pictures of the project

7. CONCLUSION

The reconstruction of Ksar Aourir offers a new paradigm in heritage intervention, one that does not merely preserve remnants but boldly rebuilds continuity. In arid rural Morocco, where urban migration and climate pressures threaten entire landscapes of memory, reconstruction can be a tool of dignity, sovereignty, and sustainability. It is not about turning the Ksar into a museum but reinhabiting it as a productive, adaptive, and proud community core.

Through vernacular knowledge, ecological materials, and collective engagement, Aourir can rise not as a replica, but as a renewed symbol of resilience. Its reconstruction will serve as a regional precedent, inspiring new approaches to cultural and environmental stewardship in earthen settlements across the Maghreb.

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Examining the Building Forms Provided by Terracotta Through Examples

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ABSTRACT

Terracotta has a rich history of use throughout human history, valued not only for its durability, accessibility, affordability, and sustainability, but also for its adaptability to human nature. Terracotta, which improves indoor air quality and creates healthy spaces, has become one of the most culturally significant contemporary building materials with its attractive color diversity, light and shadow effects, and flexible forms. The versatility made possible by terracotta's shaped geometry has allowed for an infinite variety of forms and textures in architecture. With the advancement of technology, the understanding of architectural design is constantly evolving; as a result, new construction methods are emerging, and the possibilities for using traditional building materials are increasing. The use of digital technologies and tools is pushing the boundaries of traditional forms and construction, enabling new approaches to the creation of non-standard forms. As designers' digital thinking skills increase, the search for new materials and structures has begun, and traditional materials are being reinterpreted through innovative techniques. These innovative techniques have enhanced the physical properties of terracotta, enabling its application in today's design approaches and enabling the material to be considered a contemporary building material.

This article examines various building forms created with terracotta, alongside the construction methods that have emerged through advancing technologies and digital tools, while also discussing the material's potential applications and production methods in contemporary architecture.

Keywords: Terracotta, Terracotta Building Forms, Terracotta and Technology, Contemporary Terra Cotta Architecture, Digital tectonics

1 INTRODUCTION

Terracotta is one of the few building materials that has survived since ancient times and has never lost its value over the years. Its popularity as a building material continues strongly even in the 21st century. Thousands of years before terracotta technology was developed in ancient Rome, Egyptians and Mesopotamians used adobe brick to build shelters and later terracotta for temples and shrines. This technology spread to the Roman Empire, Europe, India, China, and eventually the rest of the world. This was made possible by terracotta being made from the most abundant material available to us: earth itself. Terracotta is not only an economical, durable, and sustainable building material with a wide geographical reach, but also has the potential to create diverse forms in building design. Throughout the history of architecture, its compositions have been influential in creating new forms, both structurally and aesthetically [1].
Terracotta is a building material hand-cut and hand-cut. Throughout history, terracotta has been one of the most versatile and widely used materials for construction. Terra Compared to other

building materials, cotta has always provided the most beautiful surfaces, the most attractive color variations, and the most brilliant light and shadow effects. No other material can so broadly express the designer's genius [2].

The use of digital tools in the architectural discipline is becoming increasingly widespread. The use of digital technologies and tools has pushed the boundaries of traditional understandings of form and structure, enabling new approaches to the creation of non-standard forms. As designers' digital thinking skills have increased, new material and structure explorations have begun, and traditional materials have been approached with innovative techniques. The potential of terracotta building material has been frequently explored through the use of digital technologies and tools. This study examines the potential offered to designers by using brick through digital design and production tools, and explores examples of the unique forms and design processes created. In light of the results obtained, we examine how the relationship between form, structure, and material has evolved through the digitalization of terracotta. The role and impact of brick in contemporary architectural practice is demonstrated.

2 LITERATURE REVIEW

Terracotta is a dough generally made from a mixture of clay soil and water. It is formed by shaping and firing it in specific molds [3]. Terracotta is the oldest and most widely used building material made from natural soil, produced near water where suitable soil is available. It is inexpensive, environmentally friendly, and abundant [4]. Throughout history, people have preferred readily available building materials for their structures for shelter. Therefore, stone and timber, or adobe and brick, were used as the primary building materials in certain time periods and settlements. Unlike stone and timber, adobe and brick are not used in their natural state and require a specific technical knowledge and preparation process. Therefore, these materials were the first to be produced according to the required forms and dimensions [5].

Bricks have been produced since ancient times, serving as a primary building material in the Mesopotamian, Egyptian, and Roman periods. The best examples are found in Mesopotamia, Syria, and Iraq before the fourth century [6]. The use of clay bricks increased during the Roman period, and their production and application were further specialized, leading to their maximum utilization. The first industrially fired bricks were produced and used by the Lydians in Anatolia in the fourth century BC [7].
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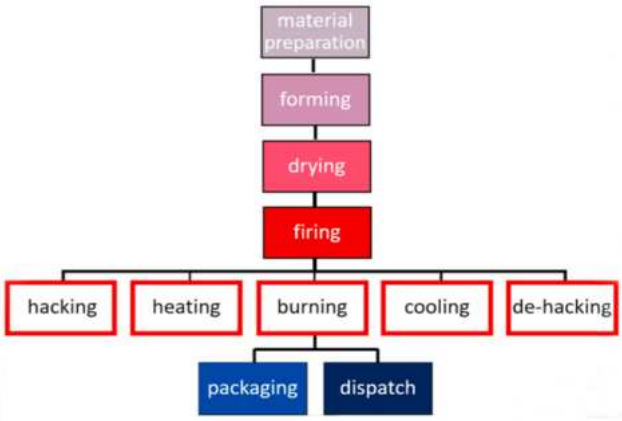

Figure 1 Terracotta production scheme

The firing of clay bricks has a history of over 5,000 years and has evolved over time into a highly complex and highly controlled production process (Figure 1). The first significant change in brick production was the firing of molded bricks in specialized drying mechanisms. This process gave the brick the durability of stone while also providing greater flexibility for creating architectural surfaces [8]. Brick production has witnessed many innovations throughout history; however, the shaping process remained dependent on molding or extrusion.
The production of firebricks, which are still in use today, accelerated with the invention of brickmaking machines in the second half of the 19th century [9]. With the increasing demand for housing in the 20th century, brick was gradually supplanted by steel, concrete, and glass for reasons of durability and cost-efficiency. Due to its light weight and fire resistance, brick became a material primarily used for facades[10]. Although its popularity declined in the 19th and 20th centuries, its potential allowed brick to continue to be used structurally by master architects and engineers of the time. Over time, brick has evolved in terms of production, assembly, and detailing techniques, and its advantageous geometry continues to create building compositions through improved construction techniques.

3. ANALYSIS OF TERRACOTTA IN ARCHITECTURE THROUGH EXAMPLES

This section highlights the significance of brick in architecture and demonstrates its evolution from traditional to contemporary use. The impact of innovative technologies is evaluated through examples, demonstrating how current advancements continue to transform its applications.

3.1. Traditional Terracotta Architecture

The Red Madrasa; the madrasa belongs to the group of single-storey, two-iwan madrasahs with open courtyards. The structure was constructed predominantly from terracotta, without the use of basalt or other stone materials. Architectural elements such as arches, vaults, and domes were systematically employed throughout the building. While it employs traditional architectural elements such as arches, vaults, and domes, the building also demonstrates the material's full potential as a structural and expressive material: it supports a two-story configuration with an octagonal plan and five exterior façades, accommodates significant height variations between the upper (5.15 m) and lower (2.15 m) floors, and features a convex inverted inter-floor dome, illustrating the material's versatility, load-bearing capacity, and ability to realize complex geometries [11].

Figure 2 View from the Red Madrasa Courtyard

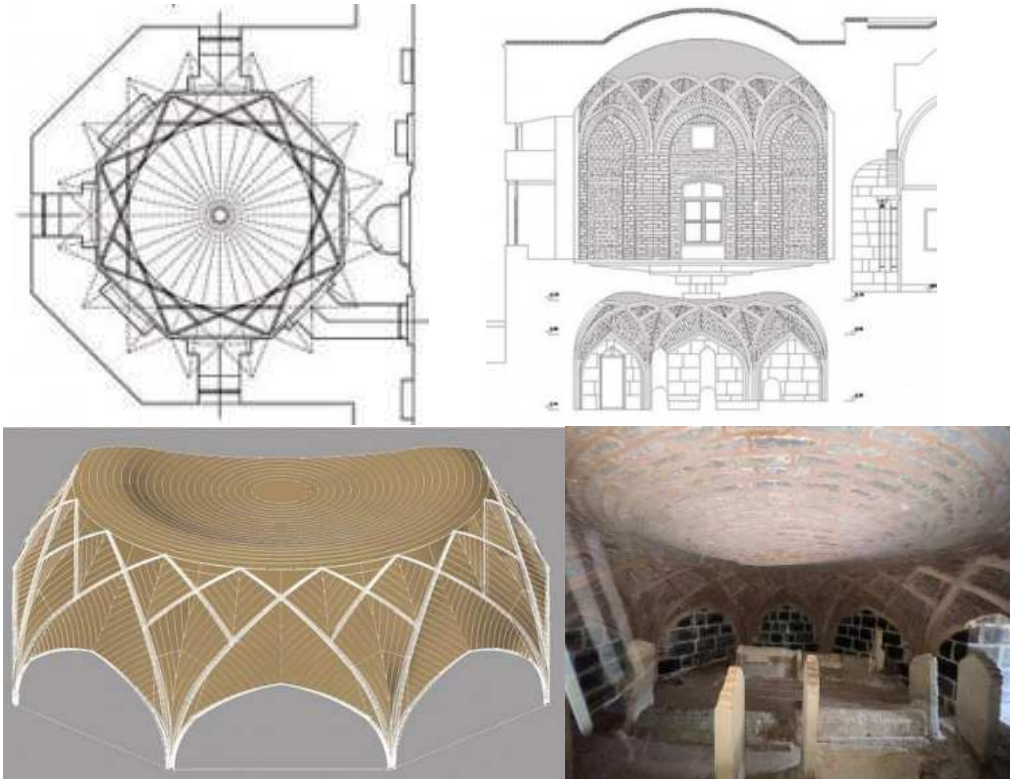

Figure 3. Convex upper cover structural element found in the rejection Madrasah [11].

3.2. Contemporary Architecture Transformed by Digital Tools

Tarang Arts Center; located in Gandhinagar , Gujarat , India , the Tarang Pavilion is a testament to the seamless integration of contemporary architectural design with traditional construction techniques. As its name suggests, it reflects the essence of waves with fluid forms and organic materials, challenging traditional architectural norms.
Completed in 2023, the Tarang Pavilion seamlessly integrates contemporary design principles with traditional craftsmanship, establishing a distinctive dialogue with the surrounding landscape. Defying conventional architectural norms, the expansive, cornerless, harmonic-wave structure comprises a series of vaults constructed entirely from locally sourced terracotta tiles, without the use of support beams or reinforcement. At 279 square meters, it is one of the largest vaulted structures of its kind in India.

Figure 5. Tarang Art Center general view [12].

Tarang creates a timeless environment by encouraging a meaningful dialogue between different eras. Its design fosters a sense of continuity and connection that transcends the present, encouraging a dialogue that extends beyond time[12].

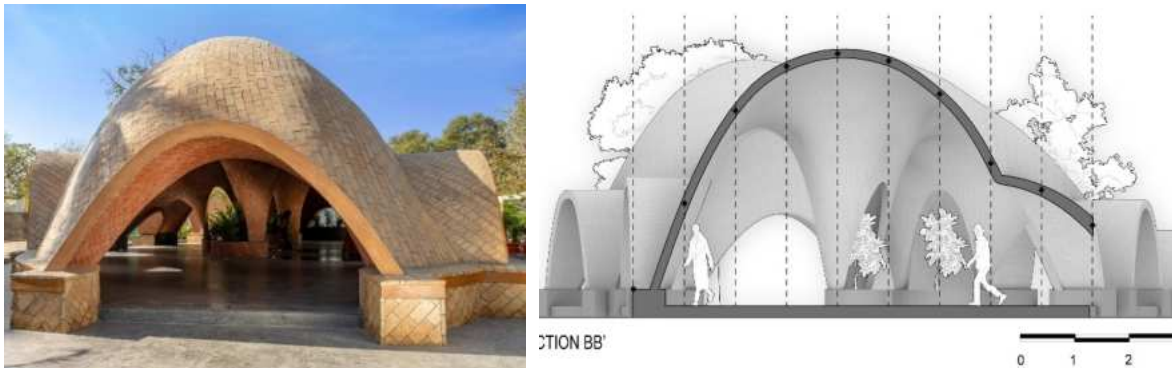

Figure 6. Tarang Art side view and section

Brick-topia Project; bricktopia is a multifunctional, custom-built vaulted structure designed for events, combining traditional construction techniques with digital technologies. It is the first free-form, human-scale vault structure of its kind constructed entirely from brick at this scale.

Figure 7. General view of the project [13].

What makes Brick-topia Project unique is its integration of digital tools to optimize structural performance: the building's behavior was analyzed digitally to achieve the most efficient form. Thus, by combining terracotta and the ancient technique of vaulting with structural analysis provided by digital tools, Brick-topia demonstrates how traditional building methods can be applied innovatively in contemporary architecture [14].

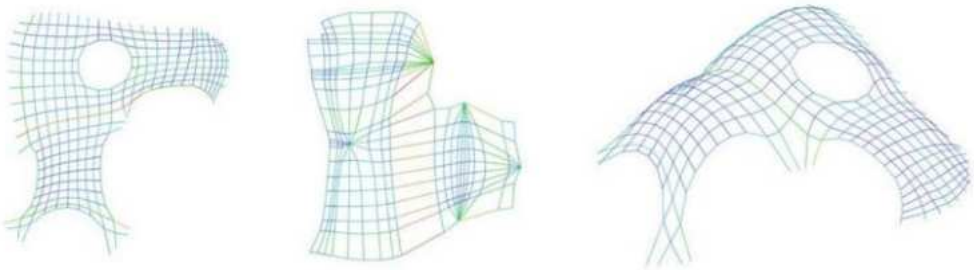

Figure 8. Form Finding with RhinoVault [14].

In the project, although the brick and mortar walling phase was executed manually, the process was facilitated by digitally designed scaffolding and reinforcement systems. The complex form was generated using RhinoVault and a waffle system fabricated with CNC machines (Figure 9). Despite the use of digital technologies, the traditional thin ceramic vault system was manually assembled on site, demonstrating a harmonious integration of craftsmanship and computational design.

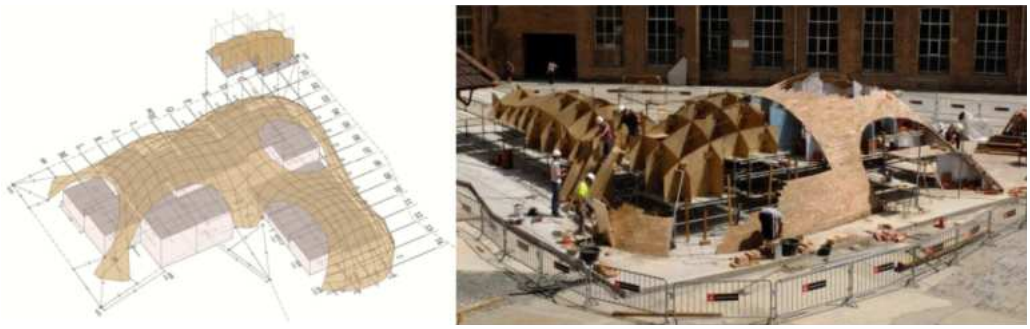

Figure 9. Formwork scheme and axonometry [14].

Ceramic Constellation Pavilion; designed by Lange & Holohan in 2017, utilizes the potential offered by today's computing and production tools to develop a system that relies on its own structural material capacity. Thanks to specially designed terracotta units, the pavilion has become an example that successfully demonstrates the potential of terracotta.
The building features a self-supporting structural system comprised of specialized brick units using robotically controlled 3D printing technologies. Thanks to the interlocking structure, the proposed system eliminates the need for an additional organizational structure. In designing the pavilion, the brick material was produced using traditional brick production techniques, and instead of conventional molding, the unit was created using new systems.

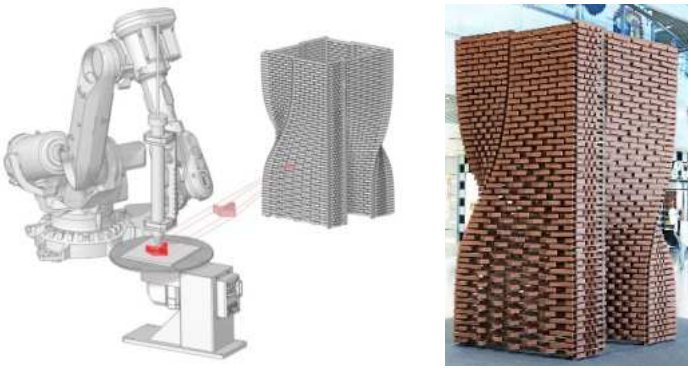

Figure 10. Manufacturing process [15].

Building on the pavilion's integration of contemporary computing and production tools, a parametric design approach was employed in its creation. An algorithm was developed to configure each brick unit, whose geometry gradually varies while considering its relationship with neighboring units, enabling a digitally optimized assembly process [15]. The pavilion further refined these brick units (Figure 10) using 3D printing, demonstrating how digital technologies can be effectively combined with traditional terracotta materials to produce complex, self-supporting structures.

Figure 11. Units of Project [15].

Vertical Village; The Vertical Village project, implemented as a prototype in 2011, represents a utopian concept and is the first example of an assembly (flight assembly) production technique utilizing a drone-based mechanism. The structure features a hollow form composed of 60 distinct, vertically overlapping layers. Digital tools were utilized to optimize the form, allowing the project to be realized using complex polystyrene bricks. Its intricate geometry and production process are shaped by advanced digital technologies, demonstrating how robotic fabrication can pave the way for large-scale architectural structures. Unlike traditional construction, the project adopts a fully robotic assembly approach, eliminating manual intervention.

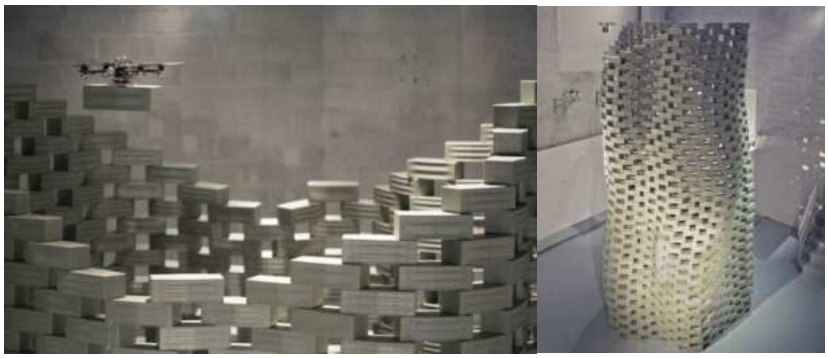

Figure 12. Vertical Village Project

In the Vertical Village project, the structure's envelope was generated using a customized algorithm that incorporates gravity and tolerance calculations. Flight-Unified Architecture represents the first architectural installation assembled entirely by flying robots without human intervention. The system comprises over 1,500 modules deployed by multiple quadcopters, which operate collaboratively according to mathematical algorithms that translate digital design data into the coordinated behavior of the flying machines [16].

4 CONCLUSION

Terracotta has been used in unique forms across cultures throughout history, reflecting the spirit of the regions in which it was produced. One of its most significant advantages as a building material is that architects can work with life-size details of the more ornate aspects of their designs before firing. This allows the material to directly convey the designer's vision, as it can be examined, refined, or modified prior to finalization, reflecting the architect's personality more effectively than almost any other material. Its unrivaled properties have always made terracotta a versatile and valuable building material. Today, these same properties make terracotta increasingly relevant in contemporary architecture. This study traced the evolution of terracotta in architectural applications, showing that, as in traditional contexts, it remains a highly effective material due to its structural, economic, and aesthetic advantages.

The growing interest in terracotta in recent years not only aids in the preservation of architectural heritage but also supports the shift toward sustainable building practices. Its high performance and customizable structure offer unique possibilities for architects and construction professionals. With its natural texture, wide range of colors, and long-lasting durability, terracotta continues to be an indispensable material in both historical and modern architecture. These qualities demonstrate that terracotta is not merely a cultural symbol of tradition, but a fundamental material for shaping the image of contemporary architecture.

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Chair "Education and Research in Sustainable Bioclimatic Urban Planning and Architecture"
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UNESCO CHAIRE ISCEAH International Scientific Committee on Earthen Architectural Heritage
Earthen Architectural Heritage
13th International Conference
25-27 September 2025; Rabat/MOROCCO

Traditional Construction Techniques in Vernacular Architecture

Earthen architecture traces back thousands of years worldwide making it one of the oldest construction traditions known to humanity. This method of construction relies on locally available natural materials like soil, clay, straw, and water to create buildings that are both durable and culturally meaningful. From America's adobe homes to Asia's earth rammed fortresses and Europe's cob cottages, soil based architecture shows the relationship between humans and their environment. As global focus shifts towards more sustainable solutions and climate resilience, these culturally adapted building techniques are emerging as valuable approaches to creating practical solutions in modern architecture.

This thorough review focuses on traditional earthen construction techniques, including their methods, cultural significance, sustainability, difficulties and emergent role contemporary building practices. It takes into account why earthen architecture has still managed to keep its remains to this day and why it is still relevant. It focuses on how it can inspire and improve next-generation building techniques.

Wang, Aurelia. "This Surrealist Cob House Is Straight Out of Lord of the Rings." Architectural Digest, 6 May, 2024, https://www.architecturaldigest.com/story/this-surrealist-cob-house-is-straight-out-of-lord-of-the-rings

One of the most influential reasons for the resurfacing interest in soil-based architecture is its advantage in sustainability. As opposed to modern constructions where concrete, steel and fired bricks are the main building materials, earth-based materials need less energy to produce.

Moreover, earthen constructions have more energy efficiency in use. Their thick and dense walls keep the temperature balanced by absorbing heat during the day and releasing it during the night. This natural system reduces the need for mechanical heating and cooling, saves energy and increases indoor comfort.

The usage of local materials supports local economies and promotes self-sufficiency by reducing dependence on imported or industrially produced resources. In various places that are currently improving this option being economically friendly plays a major role in combating housing shortages and poverty.

Furthermore, earthen materials are biodegradable and recyclable. Different from concrete and plastic, earthen walls can be returned to the ground without any ecological damage. This contributes to a circular approach to building materials.

Culturally earthen architecture is a way of storing identity and heritage. It contains the stories of the community, their skills and their aesthetics. It connects the past and present. Materials and methods materialize the space based on the building, that makes the buildings a part of the landscape.

Despite its advantages, earthen architecture faces some issues in today's world. One of them is its sensitivity to water. Especially walls made out of unprotected mud or adobe are extremely vulnerable against heavy rain, flood and damage caused by rising groundwater. Without proper protective measures such as lime plaster, raised foundations or proper roof eaves, these buildings can deteriorate rapidly.

Some modern construction trends are also causing trouble. Many communities and governments are seeing concrete and steel as a symbol of improvement and modernity causing traditional buildings leading to their marginalization or destruction.

Additionally, the transfer of structural information is weakened. As the new generation migrates or embraces modern construction techniques the skill and wisdom on earthen architecture is more at risk of being lost. This decrease not only affects physical buildings but also threatens the cultural continuity it represents.

Accessed 6 Sept. 2025.

As a response to these struggles, numerous initiatives aim to revitalize, adapt and preserve the earthen architectural heritage. Researchers, architects, conservationists and communities are all working together to develop techniques that address the limitations of earthworks while preserving their sustainability and cultural richness.

Protective coatings such as lime or natural plasters are increasingly used in order to protect earthen walls from moisture without compromising breathability and in order to prevent the water damage foundations can be raised on stone or concrete foundations. Furthermore, integrating modern tools and scientific research has improved the understanding of material properties and structural performance.

Some worldwide programs such as UNESCO and CRAterre are extremely important in passing on the cultural knowledge and skills to the new generation engineers and architects. These programs promote awareness in the environmental and cultural importance of earthen architecture and provide practical experience in the field of maintenance.

There is also a growing movement among architects to mix traditional techniques with today's methods while also still respecting architectural heritage but also including modern functional and aesthetic demands. These projects show that earthen architecture can be innovative and current. It shows that earthen architecture can offer solutions for affordable housing, climate adaptation and sustainable urban development.

Another main issue in earthen buildings is that its not durable duirng earthquakes due to adobe being heavy, brittle and weak against pulling. As a solution to this problem some researchers have found alternative solutions; mud based grout which is a mixture of sand and cement mainly used for filling in joints and cracks between tiles, or in historical monuments, cracks. Another alternative solution is reinforcement with nylon rope mesh which is using a net made out of nylon ropes to keep the building strong or to prevent it from possible cracking or breaking.

Earthen construction techniques contain a variety of techniques which use unbaked earth as a primary building material. These techniques have evolved based on local climate, current resources and cultural preferences leading to different approaches for different environments.

Adobe is one of the most common and historically one of the most significant methods in architecture. Adobe is a sun-dried brick with a mixture of clay-rich soil, sand, water and organic fibers, usually straw. After the sun-drying process we have a brick with the perfect ability of heat instulation. Adobe was most common in North Africa, Middle East and Southwest USA, usually places that were semi-arid areas. Wide walls made out of adobe would absorb heat during the day and during nighttime they would slowly release the heat creating comfortable indoor temperatures without being in need of mechanical heating and cooling systems.

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Rammed earth construction technique uses a process where damp soil is put inside wooden molds and pressed until they are solid and dense enough to be made into walls. Usually stabilizers, lime and cement, that are mixed with soil layers are systematically compressed creating a resistant wall. The compressed soil is known for its strength, resistance and its original appearance that allows us to see the layers of soil. This method is commonly used in areas with the suitable soil for this technique and due to its thermal mass it stabilizes temperature fluctuations increasing the energy efficiency.

Cob construction is more reliant on manual labor and more flexible. Clay soil, sand, water and straw are kneaded to create a soft and malleable mass. This mass is later put together and shaped by craftsmen. Differently from adobe, in cob, there are no molds or bricks in the process, this helps create corrugated walls and decorative details and gives the opportunity to create organic and sculptural forms. Cob is also differentiated from adobe because it is noticeably lighter making it a preference in architecture by some parts of the UK and a large area in West Africa for centuries. It is also used for its ability to stabilize indoor humidity creating a healthier living environment.

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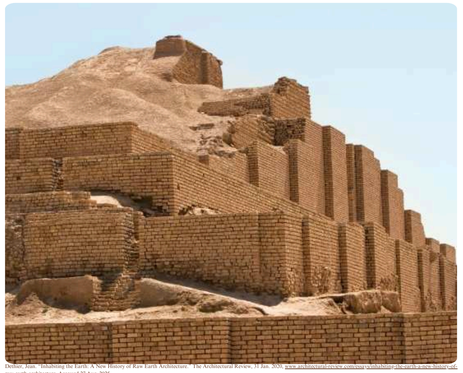
The wattle and daub method uses a wooden framework (wattle) woven from branches or reeds with a daub, a render made from earth, clay and straw. This is a very old technique still being used in many traditional structures in Asia, Africa and Europe. Walls made with this method are breathable, lightweight and easy to repair, making them a common preference in places with high humidity. Moreover the fact that the building process depends on local materials helps structures made with this method both economic and eco-friendly.

Each of these methods emerged as a response to the local context; they reflect the growing knowledge, the climate and the cultural needs that have evolved there for centuries. The fact that they are still used now shows us the permanent value they hold.

The study of earthen architecture and its preservation not only helps keep old buildings alive but it also is a way for learning sustainable solutions for today's problems mainly caused by global warming. While climate change intensifies and global construction demands increase, the need for low-impact, durable, and locally adapted buildings become even more critical.

Earthen architecture is an example of resilience built on materials, environment and culture knowledge that has been building for generations. It encourages people to build in harmony with nature, rather than against it; these techniques have made it possible for human settlements to develop in diverse and often harsh climates.

By valuing and investing in earthen architecture, the community will be able to maintain environmental sustainability, cultural identity, equality in social life and economy. This approach could inspire a future where new buildings are grounded in tradition but forward looking, contributing to the creation of healthier and more sustainable communities.



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Earthen architecture is one of the oldest construction traditions known to humanity, developed thousands of years ago and carried across continents. Using simple, locally available materials such as soil, clay, straw, and water, people built homes and communities that were both durable and deeply tied to their culture. From adobe houses in the Americas to rammed earth fortresses in Asia and cob cottages in Europe, these structures show how humans have long lived in harmony with their environment. Today, in an age marked by rapid urbanization and environmental challenges, the lessons of earthen construction remain especially relevant. This review looks at traditional methods, their cultural and ecological significance, the challenges they face, and their emerging role in modern building practices. Issues such as water vulnerability, modernization pressures, and knowledge loss present difficulties, yet conservation efforts and adaptation continue to keep these traditions alive. Earthen architecture is more than a building technique; it is a way of connecting past knowledge with present needs and future possibilities. By learning from these traditions, modern societies can create buildings that are sustainable, resilient, and culturally meaningful. Sometimes, the oldest ideas hold the greatest promise for the future.

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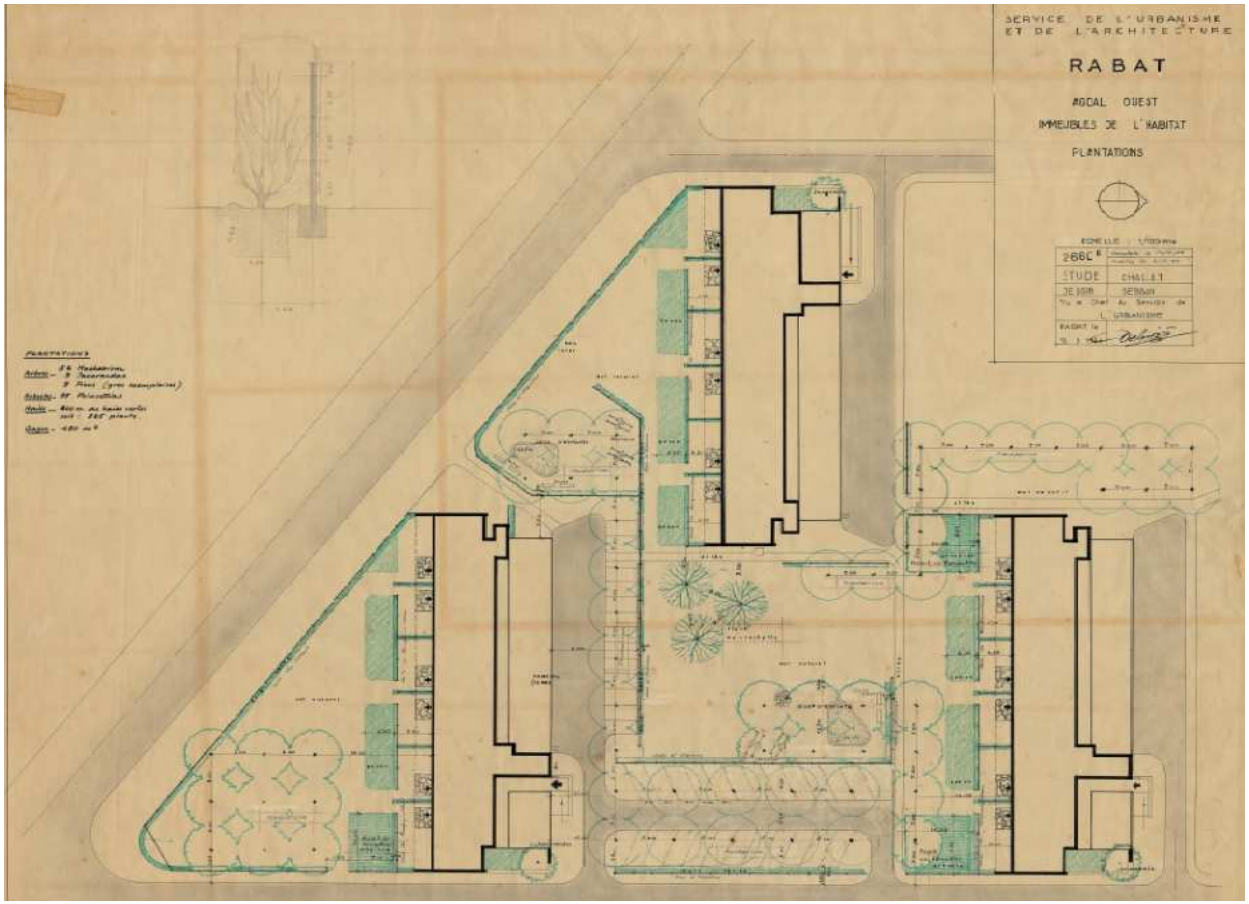
Resilience of vernacular intermediality devices in colonial housing in Morocco



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Landscaping and development of building surroundings, Agdal, Rabat.

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This communication analyzes spatial intermediality devices in Morocco, revealing the persistent influence of traditional models on collective housing. Intermediate spaces (landings, staircases, courtyards) articulating private and public spheres have been adapted by users within collective housing from the Protectorate period. Although designed according to modernist standards, these spaces were gradually reappropriated by inhabitants who reintroduced traditional uses, transforming circulation areas into collective zones.

Based on vernacular and colonial housing projects, the study highlights "informal" appropriations revealing cultural continuity and subtle resistance to colonial standardization. Inhabitants perpetuate spatial codes from traditional dwelling systems, creating duality between designed and lived space.

This contribution reconsiders informality not as design flaw, but as dwelling strategy rooted in spatial memory, enabling adaptation through daily reinvention of the produced space.

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Material–Structure–Design Interactions in Rammed Earth Housing: A Study on Wall Design, Components, and Detail Solutions

Between 2014 and 2024, eight projects were analyzed in terms of foundation, slab, wall, column/beam, and roof materials, based on interior and exterior views, to examine how rammed earth structural elements were integrated into the design.

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This study explores the interplay between material properties, structural systems, and architectural design decisions in contemporary rammed earth housing projects. Focusing on wall design, construction components, and detail solutions, the research investigates how earthen materials influence architectural and structural strategies in an integrated manner. Emphasizing the interdependence of material and structure, the study highlights the performative and aesthetic potential of rammed earth in sustainable housing design. The methodology involves a comparative analysis of selected projects documented in architectural journals and professional websites. Through the examination of wall typologies, material compositions, reinforcement methods, and junction details, the study categorizes different design and construction approaches shaped by local material availability and contextual needs.As part of the analysis, eight main structural materials types were identified across the selected cases: rammed earth, reinforced concrete, wood, stone, metal, steel, brick, gloss and other systems. These structural variations are examined in relation to wall thickness, material mix, and detailing techniques to understand how different load-bearing strategies influence the use of rammed earth. These results underline the necessity of a holistic design approach that integrates material logic with construction and spatial thinking. Rammed earth housing, therefore, emerges as a field where architectural expression and structural efficiency are closely tied to material and context.

KERPİC'25

13th International Conference

"EARTHEN ARCHITECTURAL HERITAGE"

25-27 September 2025, Rabat / MOROCCO

Kerpic 2025 is pleased to announce the call for the 13th International Conference on "Earthen Architectural Heritage". The conference will be held on September 25-27, 2025, organized by Kerpic Akademi, Kerpic Network, and the Ecole Nationale d'Architecture in Rabat, Morocco.

The aim of the conference is to bring together findings and knowledge related to the theme of "Earthen Architectural Heritage".

The conference will focus on the use of soil as a building material, and graduate students, academics, and professionals shared their findings and experiences at the event. The conference provided an opportunity to understand the strategies, advantages, and advancements made in soil-based materials in contemporary construction technology.

ISBN: 978-9920-9058-3-1

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