Editors C. Mileto, F. Vegas, A. Hueto-Escobar, S. Manzano-Fernández

EARTHEN HERITAGE

CONSERVATION, ADAPTIVE REUSE AND SUSTAINABLE DESIGN

edUPV
Universitat Politècnica de València

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Preface

C. Mileto, F. Vegas, A. Hueto-Escobar, S. Manzano-Fernández
Research Centre for Architecture, Heritage and Management for Sustainable Development (PEGASO), Universitat Politècnica de València, Valencia, Spain

The "HERITAGE2025 International Conference on Earthen and Vernacular Heritage: Conservation, Adaptive Reuse and Urban Regeneration" has been organized within the framework of three research projects. The first of these, the research project "**Earth4Future -** Sustainable Reuse of Earthen Architecture and its Lessons for Contemporary Architecture", is funded by the Spanish Ministry for Science and Innovation (PID2022-139154OB-I00) and directed by the Universitat Politècnica de València. The second research project, "**Re-Habitat**– Restoration and sustainable rehabilitation of traditional dwellings in historic contexts", is funded by the Department of Innovation, Universities, Science and Digital Society of the Generalitat Valenciana (CIAICO/2022/035) and directed by the Universitat Politècnica de Valencia. Finally, the research project "**ENACT 15mc** Envisioning Neighbourhoods and Co-Creating Thriving Communities in the 15-Minute City" is cofunded by the European Union (through Driving Urban Transitions Partnership, DUT, AEI, PCI2023-145946-2) and directed by the Norwegian University of Science and Technology, in collaboration with other associations, bodies, and universities including the Universitat Politècnica de València.

The project "**Earth4Future** Sustainable Reuse of Earthen Architecture and its Lessons for Contemporary Architecture", with a research team directed by the Universitat Politècnica de València, together with other universities both within and outside Spain, primarily aims to research the energy behaviour and viability of compatible interventions in earthen constructions within Spain. This seeks to identify solutions which increase energy efficiency and reduce emissions without jeopardising cultural, heritage, and social values. This project analyses issues such as respect for heritage values, real economic cost, environmental impact, and energy efficiency based on studies carried out on historic earthen constructions together with contemporary applications of earthen techniques in new constructions.

Furthermore, the project "**Re-Habitat**– Restoration and sustainable rehabilitation of traditional dwellings in historic contexts", with a research team led by the Universitat Politècnica de València and made up of researchers from universities both within and outside Spain, focuses on the analysis of historic buildings in urban and rural settings. By analysing similar parameters within the Comunidad Valenciana, it seeks to propose guidelines and intervention criteria that are compatible with heritage and are economically viable, environmentally sustainable, and energy efficient.

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Analysis on a larger scale features the project "**ENACT 15mc** Envisioning Neighbourhoods and Co-Creating Thriving Communities in the 15-Minute City" directed by the Norwegian University of Science and Technology and different collaborators. This project examines the potential of redesigning historic urban spaces and improving quality of life, active mobility, accessibility and social relations, in order to achieve the concept of "15-minute cities", through case studies such as Trondheim, Gdańsk, Valencia and Oxford.

The three projects are considered complementary, as they all seek to promote sustainable architecture and urbanism linked to heritage, energy efficiency, and community development, always aiming to strike a balance between tradition and innovation. This is a response to critical challenges such as climate change, population loss, the disappearance of traditional crafts, and the need for vibrant, inclusive, and resilient cities. This further highlights the pressing need to promote research, increasing awareness and action in multiple sectors, actively aiding the transition to more sustainable societies in terms of heritage and urbanism.

Given that these research projects display certain commonalities, particularly in relation to the challenges and perspectives for the future detailed above, and offer the potential for joint discussion, the main themes have been combined in the HERITAGE2025 International Conference. The themes established for the conference are: **1. Vernacular architecture** (study and cataloguing of vernacular architecture; study of traditional materials, techniques and construction crafts; mechanisms of sustainability of vernacular architecture; restoration and conservation of vernacular architecture; energy efficiency and sustainable design projects; management and maintenance); **2. Earthen architecture** (study and cataloguing of earthen architecture; study of traditional materials, techniques and construction crafts; mechanisms of sustainability in earthen architecture; restoration and conservation of earthen architecture; energy efficiency and sustainable design projects; management and maintenance), **3. Urban and rural historical sites** (studies of historic urban and rural areas; intervention and regeneration projects; management and maintenance, threats and opportunities in historic areas: tourism, infrastructure and identity; proximity economy and traditional commerce in historic contexts); **4. From tradition to contemporaneity** (contemporary projects inspired by tradition; traditional sustainability mechanisms applied to contemporary architecture; integration of contemporary projects in historical contexts; reinterpretation of traditional techniques for their application in contemporary architecture).

The Scientific Committee is made up of 89 renowned researchers and specialists in the themes analysed, hailing from 25 different countries from five continents. All the contributions to the conference – abstracts as well as final texts – have been subject to a strict peer review evaluation system by the members of the Scientific Committee. Of the 244 proposals submitted, a total of 150 papers written by 328 authors from 30 countries of five continents has been selected for final publication.

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The papers selected have been published in three volumes appearing in print and online format and titled *Vernacular Heritage: Documentation, Conservation and Adaptive Reuse*, *Earthen Heritage: Conservation, Adaptive Reuse and Sustainable Design*, and *Historic Settlements: Conservation, Regeneration and Management*.

The "HERITAGE2025 International Conference on Earthen and Vernacular Heritage: Conservation, Adaptive Reuse and Urban Regeneration" was held on 10-12 September 2025 at the Universitat Politècnica de València, Spain. The conference was carried out with the sponsorship of: WHITRAP – World Heritage Institute of Training and Research for the Asia and Pacific Region under the auspices of UNESCO; ISCARSAH – International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage, technical committee of ICOMOS; ICOMOS CIAV – International Council on Monuments and Sites: International Committee of Vernacular Architecture; ICOMOS ISCEAH – International Scientific Committee in Earthen Architectural Heritage; and PROTERRA – Ibero-American Network of Architecture and Earthen Construction. The organization, publication and development of the conference was made possible by funding from the Spanish Ministry for Science and Innovation for the research project "Earth4Future - Sustainable Reuse of Earthen Architecture and its Lessons for Contemporary Architecture" (PID2022-139154OB-I00) and the Department of Innovation, Universities, Science and Digital Society of the Generalitat Valenciana for the project "RE-HABITAT – Restoration and sustainable rehabilitation of traditional dwellings in historic contexts" (CIAICO/2022/035). The Higher Technical School of Architecture, PEGASO - Research Centre for Architecture, Heritage and Management for Sustainable Development, and the Department of Architectural Composition of the Universitat Politècnica de Valencia have also contributed to the development of this conference.

Finally, we wish to thank the authors who have contributed to the quality, range, diversity, and richness of the publication with their papers and studies. We are indebted to all the members of the advisory and scientific committees for their work throughout the entire review process for abstracts and papers. And above all, we would like to thank the organizing committee for their invaluable help in setting up the conference, the style and language reviewers for their corrections, and all collaborators for their inestimable work in the management and organization of each and every phase of the process.

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Table of Contents

Volume I

VERNACULAR HERITAGE. Documentation, conservation and adaptive reuse

Architectural Memory: Créole Houses as Living Monuments in Port Louis, Mauritius 1
K. Jeewa, M. Minguzzi

Between Oblivion and Regeneration. A Map of Abandoned Spontaneous Architecture in the Abruzzo Inner Areas (Italy) 9
G. Ciuca, A. Marra, I. Trizio, F. Savini

Characterisation of Vernacular Built Heritage in Corvo Island, Azores: Architecture, Construction and Alterations 17
C. P. Mouraz, J. M. Silva, T. M. Ferreira

Conflict and transformation: Historic perspectives of architectural heritage in Achuar communities—Ecuador 25
D. E. Morocho Jaramillo, C. Mileto, F. Sandoval-Gómez

Conservation of Rural Religious Heritage in the Western Mediterranean Region of Türkiye: Yukarı Kırlı Village 33
S. Akman Güler, D. Mazlum

Contribution to the Knowledge of Apennine Rural Architecture. Technical Culture in the Abandoned Historical Villages of the Upper Santerno Valley (Italy) 41
M. Coppola, A. Rosseti

Documenting and Studying the First Indigenous Peoples of South Africa's Villages and Dwellings in Baviaanskloof, Applying an Indigenous Methodology 49
M. Minguzzi

Exploring Rural Heritage in Central Sicily (Italy). Proposals for Cataloguing, Protection and Valorisation: the case study of Fondaco Cuba 57
A. Versaci, A. Cardaci, L. R. Fauzìa, M. Russo

José Luis Romany and the Vernacular Architecture of the Former Marquisate of Dénia (Spain) 65
A. Rubio Garrido, J. Calduch Cervera, A. B. Serrano Lanzarote

Millars Hydraulic Architecture (Almassora, Spain) 73
C. Burguete

Research on the Indigenous Architecture and Its Transformation of the Bahnar Rong Houses in Kon Tum City, Vietnam 81
C. Nguyen, T. Nguyen, H. Kobayashi

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Rural Architecture in Calabria (Italy): the Example of the Stabilimento degli Insiti 89
F. Tenuta, F. Bilotta

Rural Architecture in the Pinerolo Area (Piedmont, Italy): The Search for Evidence of Viticulture 97
A. Vergano, L. Panzani

Rural Settlements in the Territory of Alessandria (Italy): Types and Construction Techniques 105
R. Minnucci, F. Castiglione

The Architecture of Rural-urban Complexes through Typologies. The case of Maestrazgo (Teruel, Spain) 113
J.-L. Baró Zarzo, A. Almagro Vidal, F.-J. Gómez Patrocinio, R. Eppich

The Art of Milling in Calabria - Italy: History, Architecture, Construction Systems of Some Hydraulic Factories 121
B. Canonaco

The Calabrian Liquorice in the European Market of the Nineteenth Century: History, Production and Evolution Through the Knowledge of Some Architectures Along the Ionian Sea Coast 129
G. M. Ruffolo, F. Castiglione

The Census of Rural Architecture in Italy: a Replicable Model for the Cataloguing 137
F. G. Cavallero, V. Parisi, B. Scala

The Census of Rural Buildings in the Italian Region of Friuli-Venezia Giulia 145
E. Rulli, F. G. Cavallero, V. Macovaz

Traditional Moken Ethnic Houses in the Surin Islands, Phang Nga Province, Thailand 153
M. Attavanich, A. Fujieda, C. Iba, H. Kobayashi

Vernacular and Fertile. The Pantano Masseria di Puglia, Italy 161
F. Cotallo, M. Munafò

When the Shapes Unite: Cataloguing and Analysis of Vernacular Architecture in the Valleys of the Provinces of Bergamo and Brescia 169
B. Scala, C. Boniotti

Building Techniques and Environmental Stewardship of the First Indigenous Peoples of South Africa 177
L. Vosloo, M. Minguzzi

Damage Historical Prevention in Southern Italy's Built Heritage. A Focus on Holed Masonries Through Campania and Molise Regions 183
V. Russo

Insights from Past Technological and Intellectual Adaptations in Japanese Traditional Thatch Architecture 191
C. Jamin, H. Kobayashi, A. Fujieda, M. Suginaka

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Solaque: Examination of a Traditional Construction Technique for Water-repellent Continuous Rendering 199
A. G. Serrano-Gonzales, F. Vegas, A. Hueto-Escobar

The Construction Techniques of Vaulted-Stone Buildings in the Taihang Mountains Region of Hebei, China 207
L. Long, L. Gan, G. Semprebon

The *Jaboncillo* Gypsum Plaster in the Traditional Architecture of the Northwest Region of Murcia (Spain): History, Technique and Conservation 215
A. Nezreg Driche

Tradition and Didactics. Some Educational Experiences of Intergenerational Transmissions of Artisan Skills for Heritage Preservation 223
A. Squassina

Use and Conservation of Alabaster in Traditional Aragonese Architecture 231
J.-L. Baró Zarzo, V. La Spina, A. Pascual Rubio

Vernacular Architecture in Disappearing: Unveiling Japan's Mason Work Huts in Shiga Prefecture 239
C. Ochiai, J. Wang

Architectural Heritage and Photovoltaic Solar Panels: Regulatory Framework and Action Criteria in Navarra (Spain) 247
J. L. Franchez Apecechea

Co-thinking the Language of Vernacular Heritage through a Transdisciplinary Approach: Mapping, Regenerating and Creating 255
R. Lorusso, A. Mazza, A. Guida

From Vernacular Wisdom to Contemporary Design: Bridging Traditional Patterns with Modern Sustainability 263
V. Maini

Passive Thermal Performance of Glazed Balconies from Northern Portugal Vernacular Architecture and Contribution to a Regenerative Built Environment 271
J. Fernandes, M. Castro, S. M. Silva, R. Mateus

Qualities and Values of Rural Vernacular Architecture: by Way of a Decalogue 279
G. Rivero-Lamela

The Alfano Ironworks in the Cilento National Park (Italy): An example of Vernacular Architecture 287
G. Vinciguerra

The Montalván Hacienda: Traditional Construction and Thermal Strategies in Cañete, Peru (18th-19th centuries) 295
T. Montoya, A. Scaletti, M. Wieser

A Holistic Approach to Vernacular Heritage Conservation 303
H. Mahdy

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Assessment of the Material Fabric Through Non-Invasive Tools, Characterization Process, and Formulating Compatible Repair Material: A Case of Kalidas Jethabhai House, Dharmaj, Gujarat, India 311
S. Ram

Comparison of Conservation and Repair Methods for Stone Arch Bridges in Spain and Japan 319
N. Miyamoto, S. Hamada, F. Vegas, C. Mileto

Extrados Vaults in the Chartreuse of San Giacomo in Capri, Italy: History, Knowledge and Conservation of a Vernacular Architecture in the Mediterranean Landscape 327
S. Iaccarino

Preserving Heritage, Inspiring Revival: Restoring Traditional Japanese Thatch Culture through Transformative Professional and Associative Initiatives 335
C. Jamin, H. Kobayashi

Rethinking Local Heritage Through Networked Perspectives: Mylos Project on Imbros (Gökçeada), Turkey 343
A. Dinççağ Kahveci

The Farmhouses of the Cuma Archaeological Park in Pozzuoli (Naples, Italy): Between Conservation and New Enhancement Strategies 351
F. Naldi, L. De Riso

The Rehabilitation of the Morisco-era House at Calle San Buenaventura 7, Albaicín (Granada): An Over Fifty-Year-Long Project 359
A. Orihuela Uzal

The Transformation of Tradition: Restoring original Estonian Vernacular Architecture in a Situation where Traditional Materials are no Longer Available 367
E. Lutsepp

The Vernacular Architecture of the Island of Ibiza (Balearic Islands, Spain): a Brief Overview of the Current State of Research 375
M. H. Hermanns

Traces of Vernacular Architecture in the Royal Palace of Portici (Naples, Italy) between Knowledge and Restoration 383
L. E. Buono

Vernacular Rural Architecture with Extradosed Vaults. Case Studies from the Inland Areas of Southern Italy 391
M. G. Basilicata

Materials and Components for the Sustainable Retrofitting and Climatic Optimization of Etnean Wineries in Sicily, Italy 399
G. Giuffrida, L. Dipasquale, R. M. Pulselli, R. Caponetto

Multidimensional Evaluation of the Rehabilitation of Traditional Dwellings: Application to a Protected Dwelling in the Cabanyal-Canyamelar Neighbourhood in Valencia (Spain) 407
F. Vegas, C. Mileto, A. Hueto-Escobar, V. Cristini, S. Manzano-Fernández

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Passive Heating Strategies and Thermal Characteristics of Vernacular Buildings in Northeastern Portugal: A Case Study of Vernacular Building in the Montesinho Natural Park 415
S. Khei, R. Mateus, J. Ortega, R. Briones-Llorente, J. Fernandes

WEDoVer Strategy for Documenting and Enhancing Vernacular Heritage: a Case Study of the Excavated Wine Cellars in Utiel (Spain) 423
Y. Hernández-Navarro, P. de Dato de Gennaro

Bourbon Industrial Architecture and Territory: The Recovery of the Vanvitellian Mills in Valle di Maddaloni (Italy) 431
A. Staiano, M. Paradiso

Re-envisioning Rural Heritage as a Resource for Regeneration: The Case of Abandoned Farmhouses in Northern Italy 439
A. Psoma

The Risks to Vernacular Architecture Associated with Depopulation in the Valencian Community, Spain 447
E. Tortajada Montalvá, F. Vegas, D. E. Morocho Jaramillo

Beyond the Surface: Neo-Vernacular Architecture in Sweden and Denmark's Contemporary Landscape 455
B. T. Eybye, M. Dabaieh

Integrating Traditional Mechanisms in the Escalà HDU at the Solar Decathlon Europe 21/22 (Valencia, Spain / Wuppertal, Germany) 463
E. Tortajada Montalvá, M. Burgos Martinez

Sustaining Traditions, Preserving Forests: Adaptation of Vernacular Woodworking in Rural Japan 471
J. Wang, C. Ochiai

The Knowledge Production of Ecovillages and the Issues with Contemporary Regenerative Architecture 479
L. M. B. Jensen, C. Dayer, B. T. Eybye

Author Index 487

Volume II

EARTHEN HERITAGE. Conservation, adaptive reuse and sustainable design

The Three Great Pioneers of the Art of Building with Raw Earth: from 1789 to the Present Day 489
J. Dethier

Earthen Architecture and Landscape: The U-shaped Temples of Pre-Hispanic Lima 497
E. Saez, J. Canziani

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Earthen Architecture in Costa Rica: Building Typologies in the Historic Centers of Cartago and Santo Domingo de Heredia 505
I. Hernández-Salazar

Inventory and Cataloguing of Traditional Houses in the Province of Veraguas, Panama 513
C. Aponte

The Footprint of Earthen Architecture: Digital, Open-access Library of Earthen Building Cultures 521
A. R. Olivera, A. González, E. E. Villaseñor

The Role of the Terra Conferences in Promoting and Conserving Vernacular Earthen Architecture 529
A. Sprega, C. Cancino, B. Marcus, E. Macchioni

Dynamics of Transformation in Earthen Architecture: The Case of the Region of Northwest Murcia, Spain 537
F. Sandoval-Gómez, V. La Spina, S. Manzano-Fernández

Tips and Tricks to Study Mudbricks. Experiences from the Protohistoric Site of Casas del Turuñuelo, Spain 545
L. M. Carranza, J. Canivell, B. Cutillas-Victoria, M. Fortea, P. Guerra, M. A. León, M. Lorenzón, A. Medialdea, E. Revert, J. C. Salcedo, E. Rodríguez González, S. Celestino

Comparative Study of Yikeyin Adobe Houses of the Han Ethnic Group in Central Yunnan, China and Rammed Earth Houses in Songyang, Zhejiang, China 553
J. L. Xu, W. H. Jiang

Earthen Architecture in the Castle of Segart, Valencia (Spain) 561
L. Mantecón, M. Pitarch, P. Herrero, F. Navarro, A. Morro, S. Estruch, F. Piñó, E. García, S. Juanes, J. Alfonso

Exploring Earth-Building Techniques with Local Knowledge Holders in Siaya County, Kenya 569
S. Hage, A. Obama, S. Hollerman

Hakka Architecture in China: Analysis of Rammed Earth Buildings 577
F. Ye, C. Mileto, F. Vegas

Knowing Earthen Architecture in Albania: Investigating some Case Studies in Tirana and Kavaje 585
S. Rescic, L. Luvidi, M. Mattone, F. Fratini, L. Çapeli, J. Meniku, A. Voksh

Preliminary Study on Traditional Chinese Cob Buildings and Their Construction Techniques: a Case Study of Yaozhuang Township 593
T. Y. Xie

Ancient Solutions for Earthen Architecture in Humid Tropical Environment 601
A. J. E. Daneels

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Approximation to the Environmental Impact of the House of Gongora, Cehegín (Murcia, Spain): an LCA Perspective 609
A. Quintana-Gallardo, F. Sandoval-Gómez, V. Celina-Sáez, E. Zamora-Marina, J. G. Secondo-Maglia, F. A. Mendiguchia, I. Guillén Guillamón

Landscape, Memory, and Sustainability: A study of Troglodytic Architecture in the Canary Islands (Spain) 617
L. Martínez Díaz

Rammed Earth as an Alternative to Conventional Construction Methods in Valencia: a Comparative Life Cycle Assessment Perspective 625
A. Quintana-Gallardo, A. Sirera-Cocera, E. Zamora-Marina, V. Sáez, F. A. Mendiguchia, I. Guillén Guillamón

Seismic Risk Analysis of the Rammed Earth Residential Buildings in Niebla (Huelva, Spain) 633
A. Guardiola-Víllora, L. Basset-Salom

Assessing the Performance of Earthen Sites Exposed to the Environment: The Wupatki Pueblo Case in Arizona, USA 641
L. Gambilongo, R. A. Silva, P. B. Lourenço

Balancing Sustainable Conservation and Risk in Earthen Archaeological Structures: Insights from a Case Study 649
S. Manzano-Fernández, V. Cristini, D. E. Morocho Jaramillo

Between Respect and Innovation. Innovative Recovery and Extention of a Historic Rammed Earth Farmhouse in Novi Ligure, Italy 657
G. Bollini

Compatibility between Sustainability and Conservation in Earthen Architecture: Initial Analysis of Restoration Interventions and Contemporary Applications in Spain 665
C. Mileto, F. Vegas, A. Hueto-Escobar, L. García-Soriano, S. Manzano-Fernández

Conservation Strategies of Earthen Architecture at the Acropolis of Kaminaljuyu, Guatemala 673
L. Guerrero, B. Arroyo

Diverse Approaches from a Participatory Perspective: The Experience of Nuestra Señora de la Purísima Church in Tabladitas (Jujuy, Argentina, Argentina) 681
J. Tomasi, J. Barada, N. Veliz, N. Losa

Energy Retrofitting Solutions for Traditional Half-Timbered Walls with earth infill in Spain: Challenges and Technical Recommendations 689
A. Hueto-Escobar, F. Vegas, E. Tortajada Montalvá

Experimental Investigation of the Mechanical Behaviour of an Earth Material from an Afghan Architectural Heritage 697
A. Lico, R. Grazzini, A. Boostani, G. Misseri, S. Rescic, L. Rovero

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Lessons Learnt from Adaptive Reuse of Earthen Heritage in Desert Oases in Hot Arid Climates 705
M. Khalil, O. Pons Valladares, M. Bosch González

Memories: Perspective of Intervention for the Safeguarding of Vernacular Earth Architecture 713
A. Weston

Organic Stabilizers of Plant Origin in Archaeological Structures: Influence of Cactus Mucilage in the Making of Sacrificial Mortars 721
O. Medina Lorente, B. Carrascosa Moliner, L. Osete Cortina

Preservation of Earthen Architecture in Spanish Archaeological Sites: Proposals for a Sustainable Action Diagram 729
S. Manzano-Fernández, V. Cristini, E. Tortajada Montalvá

Raw Earth Construction and Restoration Technique: Experimental Protocol and Interventions in the Historic Village of Al Jazeera Al Hamra (United Arab Emirates) 737
R. Liberotti, V. Amer, V. Gusella

Research and Comparative Analysis of Earth Mortars for Conservation and Restoration of Archaeological Structures. The Case of the Sant Jaume Site (Alcanar, Catalunya, Spain) 745
M. Roca Cabedo, B. Carrascosa Moliner, L. Osete Cortina

Restoration and Conservation of the Earthen Architectural Complex in Tazumal Archaeological Park, El Salvador, Central America 753
S. Shibata

Studies of Material Intervention to Conserve the Living Archaeological Site of Shuijingjie Distillery Site in Chengdu, China 761
Y. Wu, YH. Wu, C. Jiang, X. Chen, S. Dai

Conservation and Sustainability of an Earth Architectural Heritage located in the Historic Center of Lima (Peru): House Museum, Challenges and Opportunities 769
M. Diaz-Santivañez

Compressed Stabilized Earth Blocks for Improving the Durability of an Ancient Technique 777
M. L. Germanà, A. D'Amore

Difficulties and Opportunities for the Conservation of the Convent of San Bernardino in Cuenca de Campos, Valladolid. The Task of the 'Rehabitar Tierra de Campos' Foundation 785
J. L. Sainz Guerra, J. M. Sastre, J. Olcese Ortega, J. Garcés Rallo, A. Sainz Esteban, M. A. Garcés Desmaison

Status and Protection Strategies for Low-Grade Vernacular Architectural Cultural Relics in Rural Chungking, China 793
Y. Shu

UNESCO Management Plans and Community Collaboration: A Comparative Analysis from Lyon, Djenné and Yazd 801
C. Scudellaro, T. Joffroy, M. Mattone, B. Rakotomamonjy

BY-NC-SA 2025, Editorial Universitat Politècnica de València

The Illusion of Heritage: Critiquing Pseudo-Earthen Vernacular Architecture in Qatar 809
M. Dabaieh, M. Sakr

Bioclimatic Enhancement of a Low-cost Earthen Dwelling in Niger Through Comfort Optimisation and Local Skills-based Technologies 817
R. Pennacchio, S. Fantucci, F. De Filippi

Earthen Construction, a Question of Permanence 825
J. M. Gentilleau, R. Guerrero, A. Nicolas, S. Popot

Traditional Architecture and Urbanism of Veraguas, Panama, in a Globalized Reality 833
C. Aponte

Author Index 841

Volume III
HISTORIC SETTLEMENTS. Conservation, regeneration and management

From Documentation to Strategic Planning: GIS-Based Survey and Assessment of AlUla's Vernacular Wall Paintings 843
S. Whittaker, A. Rava, E. Woolley, L. Alqadi, M. Giangraso

From the Inca Ushnu to the Holy Cross Church: Materialities in the Sacred Landscape of Sahuara, Arica and Parinacota, Chile 851
M. Pereira, B. Yuste

Stereotomy and Composition in Maya Architecture: The Medial Moulding at the Palace of the Governor at Uxmal (Yucatán, México) 859
A. L. Rosado Torres, L. Gilabert-Sansalvador, G. Muñoz Cosme

Restoration Project of Vernacular Architecture. A Case Study: Consolidation-Underpinning Works and Post-Control of Deformations in the Church Juslibol (Zaragoza, Spain) 867
A. Gracia, F. J. Torrijo, A. García

The Venice and its Lagoon UNESCO site (Italy): Cultural Heritage and Climate Change 875
F. Trovò, G. Bruschi

A 'String Figure' Perspective on Heritage Sites - Examining a Village, a Fishing Harbour and a Former Railway Area in Denmark 883
M. Kirkegaard

Aesthetic Qualities and Fragments of History in the Tiburtine Landscape (Italy). Places of the 'Sacred' and Ancient Itineraries 891
V. Montanari

Analysis and Strategies for the Conservation and Enhancement of Abandoned Villages in Southern Italy: The Case of Castrum Vayrani 899
E. Coppola

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Analysis of Rural Settlement in the Czech Republic: A Case Study of Dolní Kounice 907
Z. Syrová Anýžová, J. Syrový

Circular Villages and Field Systems on a Large Estate of Teplá Abbey in the Czech Republic - Land Arrangement, Settlement Pattern, Surveying and Metrological Analysis 915
M. Cernansky

Decision Support Strategies for Urban Resilience: Mediterranean Historical Centres as Living Laboratories for Climate Adaptation 923
F. Armocida, F. Giglio, A. Sarlo

Building Archaeology in Support of UNESCO Rural Heritage Projects: The Case of Fortified Church of Viscri (Romania) 931
I. Burnichioiu, M. L. Moldovan

Identification and Conservation of Spatial Genes in Traditional Chinese Villages: A Case Study of Sandefan Village 939
X. Shi, B. Wu

Interpretations and Sensitive Representations for the Documentation of Matera Vernacular Heritage 947
E. De Santis, E. Chiavoni

Mapping the Urban and Rural Character of Historic Sites in Spain through a Digital Database 955
A. Castellón Valderrama

Physical and Social Vulnerability to Heat Waves in Rural Communities with Vernacular Architecture: Villages in the Montesinho Natural Park (Portugal) as a Case Study 961
S. Graus, T. M. Ferreira, G. Vasconcelos, J. Ortega

Re-naturalizing Minor Centers with Strong Historical Connotations: Strategies and Technologies 969
A. Mamì, E. Nicolini

Study and Evaluation of the Seismic Features of a Rural Roman Temple: The Case of the Temple of Ain Harcha, Lebanon 977
A. Alonso Durá, H. Bitar

The Roman Villas in the Territorial Context of Ancient Pompeii: Conservation of Vernacular Characters and New Forms of Accessibility to the Archaeological Heritage 985
R. Picone

The San Antonio Neighbourhood of Valencia and the Church that Gives it its Name 993
P. Blanco

Traces and Memories of a Rural Reuse of Roman Amphitheatres: Archaeological Restoration and Landscape 1001
L. Cappelli

Traditional Landscape Geography of China's Ou Region: A Perspective from Water and Soil Transformation 1009
X. H. Cao

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Transformation of an Area with Industrial Buildings in the Ottoman Empire in the 19th Century: İstanbul, Zeytinburnu 1017
T. Darendeli, C. Binan

A New Paradigm toward Resilient Morphogenetic Open Processes 1025
P. Bracchi, A. Boix, D. Giordanelli, F. J. Torrijo

After the Earthquake: The 'Interrupted' Landscapes 1033
S. D'Avino

Forum Novum at Mile X of Via Traiana (Italy) 1041
L. Salierno, G. Panarese, R. Bozzella

Hands-on Approach in Dry Stone Architecture and Landscape Heritage Safeguard: The Case of Kato Meropi (Greece) 1049
V. Demertzidou Kiouzepi

Holy Spaces, Contemporary Art: Reuse and Conservation in Naples' Churches (Italy) 1057
L. Romano, E. Vitagliano

Masonry Walls Restoration and Urban Regeneration in the Clock Tower of Monóvar (Alicante, Spain) 1065
V. Fernández-Mora, E. Moya Soriano, C. Boigues

Revealed Spaces. The Hypogeal Churches of Naples Between Improved Knowledge and New Forms of Expanded Fruition 1073
V. Cera, S. Pollone

Solar Cadastre for Heritage Sites: A Geoinformation Tool for Balancing Energy Potential and Conservation Needs 1081
M. Debevec, T. Bevk, G. Stegnar, D. Gantar

The Historic City of Doha in Qatar; Tourism as a Catalyst for a Sustainable Urban Regeneration 1089
D. Boussaa

The Walls of Philippe Auguste in Paris across the Centuries: General Strategy of Conservation and the Case of Jardins Saint-Paul 1097
C. Mazzoni, F. Magliacani, A. Pane, E. Polverino, C. Ruggiero, D. Treccozzi

Guidelines to Support the Sustainable Conservation of Cultural Heritage Buildings in Slovenia 1105
M. Tomšič, N. Goršič, S. Mujkić, M. Šijanec Zavrl, N. Jejčič, D. Gantar

Implementation of an Innovative Model of the Comprehensive Energy Renovation Project of a Cultural Heritage Building in Ljubljana, Slovenia 1113
N. Jejčič, M. Tomšič, M. Šijanec Zavrl

Rural Settlements as Cultural Heritage: Guidelines for Renovating and Building Houses in the Municipality of Cerknica, Slovenia 1121
D. Gantar, N. Goršič

BY-NC-SA 2025, Editorial Universitat Politècnica de València

Between the Protection of the Urban Landscape and Cultural Tourism: Risks and Opportunities for the Painted Architecture of the Historic Center of Malaga (Spain) 1129
L. Royo Naranjo

Cultural Agrarian Landscapes: the case of the Valencian Citrus Fields as a GIAHS candidate (Spain) 1137
O. Lozano Muñoz, A. Besó Ros, L. Gilabert-Sansalvador, M. J. Viñals

From Village to Sky: Analysis of the Historical Evolution and Heritage of Benidorm (Alicante, Spain) 1145
M. Piqueres Martínez, A. Hueto-Escobar, V. Cantero

Marginality versus Resilience. Opportunities of Inner Areas' Territorial Heritage: The Case of Valle del Giovenco-Valle Roveto 1153
C. Salve, A. Tosone, D. Di Ludovico

Transformation of Historic Areas of Spa Towns under Urbanization Pressure: The Case Study of Bukovička Spa (Aranđelovac, Serbia) 1161
S. Milovanović

Approximation to the Concept of 15mC in the Historic Centre of Valencia (Spain): Demographics, Economy, Housing and Emblematic Establishments 1169
J. Orozco-Messana, C. Mileto, F. Vegas, V. Cantero

Vernacular Terraces for Sustainable Urban Ecosystems in Two Cities in the Andes 1177
S. Santa-Cruz, M. Vilela, A. Dueñas, C. Zeballos-Velarde, L. Rodriguez, L. Moya, G. Fernández de Córdova, I. Ortiz, G. Romero

The Archaeological Site of Abella Castle (Avella, Campania, Italy): History, Conservation and Accessibility 1185
A. Pane, G. Spizuoco, A. Mazzei, A. Polcari

Author Index 1193

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The Three Great Pioneers of the Art of Building with Raw Earth: from 1789 to the Present Day

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Abstract

In recent decades, the revival of raw earth architecture has gained remarkable momentum as a sustainable and culturally rich alternative to industrialized building methods. This essay traces the pioneering contributions of three key figures who revolutionized the field from 1789 to today: François Cointeraux in Enlightenment-era France, Hassan Fathy in postcolonial Egypt, and the CRATerre group in contemporary France. Each responded to urgent social and environmental contexts by modernizing vernacular techniques and promoting raw earth as a viable material for ecological, affordable, and human semi-artesanal-centered construction. Their innovations—ranging from "Nouveau Pisé" to Nubian vaults and encyclopedic technical research—have inspired a global movement among architects, educators, and communities. Together, their legacy highlights how raw earth construction must help decarbonize the building industry, mitigate climate change, and renew architectural meaning through a synthesis of technology, culture, and ethics.

Keywords: *architectural heritage; raw earth; building techniques; vernacular innovation*

1. Introduction

Over the past four decades, starting in 1985, newly built raw-earth architectures have amazingly progressed in both quantity and quality, improving their efficiency and appeal. This remarkable evolution spans a wide world-wide typology of individual and collective dwellings, as well as an extensive range of buildings fulfilling many different functions, particularly within urban settings.

These include educational facilities (from primary schools to university campuses), healthcare institutions (from small clinics to ambitious hospitals), cultural centers (from libraries to museums), tourist accommodations (from hotels to holiday villages), religious buildings (from churches to mosques), commercial and tertiary sector infrastructures, and more. This vigorous proliferation has been particularly notable in France, Europe, and across all continents. Such a phenomenon necessitates careful exploration of the main origins of this dynamic resurgence: a quest for the vital sources that have inspired numerous architects, engineers, craftsmen, and other innovators, who have embraced a civic eco-responsibility by enhancing the virtues and qualities of "the art of building with raw earth".

The objective of my lecture is therefore to summarize the innovations in this domain attributed to the three most significant "Pioneers of Modernity": those who initiated the most revolutionary and influential ideas and projects

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from 1789 to the present day. Each of them paved the way for hundreds of other contemporary "*avant-garde*" creators, whose innovative intelligence encompasses architecture, technology, social responsibility, and environmental sustainability. This quadruple ambition corresponds to a critical requirement of the 21st century: to contribute to the colossal challenge of decarbonizing our construction methods and materials, a vital obligation to mitigate the escalating threats of climate change.

Before evoking the narratives and tributes to these three pioneers, it is essential to recall that the Universal Saga of Earthen Builders began several millennia ago[1]. It was during the Neolithic Revolution that human groups transitioned from prehistoric nomadism to a sedentary lifestyle, which involved the invention of agriculture and architecture. In the heart of the "Fertile Crescent" of Mesopotamia (today's Iraq and Syria), the first agricultural villages - and subsequently the first cities in history - were constructed using raw earth. This ancient urban creativity acquired such magnitude and impact that, in my view, it constitutes the most essential and enduring "Epic of Human History".

It was within these inspiring territories that earthen construction first demonstrated its capacity to meet the housing needs of all social classes, from the most disadvantaged to the most privileged. Moreover, it served to erect monumental city walls, spectacular temples & palaces as well as huge ziggurats. Archaeological findings reveal that the world's first "skyscraper" – the famous Tower of Babel– was built of raw earth and reached an astonishing height of 85 meters at the heart of Babylon. From these audacious and pioneering origins, this ancestral know-how slowly diversified into countless historic expressions, both scholarly and vernacular, across Europe, Asia, the Americas, and Africa.

2. Francois Cointeraux: Europe's first Great Pioneer, active since 1789

François Cointeraux (Baridon et al., 2016), a self-taught artisan and mason from a modest background in France, was the first builder in human history to simultaneously develop a theoretical and modernized practical system for building with raw earth. In doing so, he intuitively fulfilled a demand articulated by Vitruvius —the most renowned architect of ancient Rome— who asserted that the art of building must equally be the result of practice and theory. Cointeraux's innovations emerged within the spirit of the 18th century Enlightenment, the French Revolution of 1789, and the era's social, cultural, political, and technical transformations heralding a Great Renewal.

His ambition was to democratize access to modern, rational housing in villages and towns for all social classes, from the working class to the bourgeoisie. He promoted also the construction of public, artisanal, and even industrial buildings in cities: especially in Lyon with his huge (unbuilt) cotton manufacture designed in 1790. To achieve all those innovations, François Cointeraux (1740–1830) amalgamated inspirations from the rural vernacular traditions of the Lyon and Grenoble regions: particularly the technique of rammed earth locally called "*pisé*" or *"pisé de terre"*. This ancient method (possibly inherited from Morocco via Spain) involved compressing earth within wooden formworks to build thick, monolithic load-bearing walls, between 40 and 60 cm wide (Fig. 1).

[1] For further information see: Dethier, J. (1981–1986). *Des architectures de terre: L'avenir d'une tradition millénaire* (Exhibition catalogue published by Centre Pompidou, translated into 9 languages). Dethier, J. (2019). *Habiter la terre: traditions, modernités et avenir écologique de l'art de bâtir en terre crue.* Flammarion. Translated 2020 in Spanish by Blume, in English by Thames & Hudson + Princeton Architectural Press.

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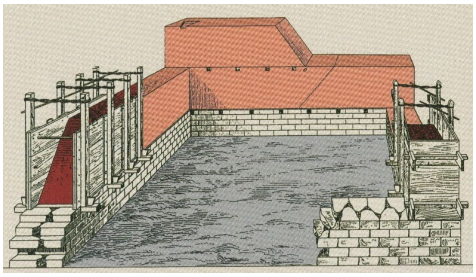

Fig. 1 – *New-Pisé initiated by Cointeraux* (Dethier).

Cointeraux rationalized this traditional know-how, branding it as *"Nouveau Pisé"* (New Rammed Earth). In order to promote this modernized technique —which would later prove to have real international potential and impact— he published, starting in 1789, over 40 militant, technical, and educational booklets. Given their huge success, they were translated —sometimes by very renowned architects in England and Germany— into eight languages and adopted for practice in numerous European countries and even overseas.

Throughout the 19th century, and even up to the 1910s, this new technique led to a multitude of pilot projects not only in France but also in England, Germany, Switzerland, Italy, Spain, Scandinavia, Russia, Australia, and in North America. In the United States, Cointeraux's methods even attracted the attention of future President Thomas Jefferson, an architect himself, just as in France, they impressed Emperor Napoleon I, who in 1807 commissioned him to design an entire "new town to be built with *Nouveau Pisé*" (unfortunately unacheived).

Boldly, Cointeraux self-proclaimed himself an architect as well as "professor of architecture", founding various "New Pisé Schools" in Lyon, Grenoble and even Paris, also inspiring similar institutions in Germany and Russia. In these schools, he pioneered a revolutionary pedagogy that promoted a "self-building practice" based on his constructive principles, defining it in one of his seminal publication: "The art of building, oneself and solidly, multi-storey houses using only raw earth, at the lowest possible cost" (Cointeraux, 1790) (Fig. 2).

The influence of Cointeraux's ideas and practices grew considerably when they were incorporated since 1812 into a seminal treatise: Jean-Baptiste Rondelet's prestigious "Theoretical and Practical Treatise of the Art of Building" (Rondelet, 1812). This encyclopedia quickly became a fundamental reference throughout Europe and was reprinted sixteen times during the 19th century. Its ambition was to finally establish "a science of construction guaranteeing the strength, durability, and economy of architecture".

After a long period of neglect during the 20th century, Cointeraux's pioneering work was finally rediscovered and revalorized during the 1980s, particularly through the scholarly efforts of professor Hubert Guillaud**,** co-founder of the group CRATerre (Guillaud, 1997). Today, François Cointeraux is internationally fully recognized as a true "*avant-garde*" figure ahead of his time.

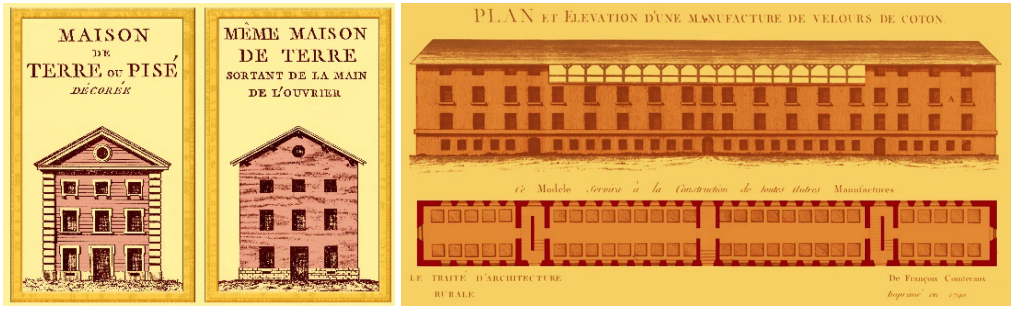

Fig. 2 – *House for rich or modest owners + cotton-manufacture by Cointeaux* (Dethier).

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3. Hassan Fathy: the first Great African Pioneer, active since 1946

Born in 1900 into a bourgeois family established in Cairo, Hassan Fathy graduated as an architect in 1926 from the local Polytechnic School, whose curriculum at the time was heavily influenced by European standards and even the Bauhaus movement. Initially, his early works were constructed in reinforced concrete. However, a double political and social context, beginning in the 1930s, radically transformed his ethical and creative orientations (Guillaud, 1997). Becoming deeply aware of the extreme poverty faced by the most disadvantaged people in Egypt, Fathy grew sympathetic to ideological struggles against the dominance and imitation of Western models.

He embraced the ideals promoted by leaders like Gandhi in India, who advocated for boycotting industrial products imported from Europe and for valorizing local natural resources and artisanal creativity to foster self-sufficient housing production. Within this spirit of protest and resistance (El Wakil, 2013), Fathy abandoned the use of cement and steel, passionately rediscovering the ancestral rural know-how of vernacular Nubian masons (Fig. 3).

These artisans mastered the construction of their villages using sun-dried adobe bricks and were the only ones in the world to have preserved an ingenious, millennia-old practice: the construction of "Nubian Vaults" amazingly erected without the need of wooden formworks for support.

Fathy rationalized this ancestral technology and used it to build his first major works: the villages of *New Gourna* (1946) and *New Baris* (1963), along with their remarkable schools, mosques, and agricultural cooperatives (Fig. 4). These two pioneering projects exemplify Fathy's talent for drawing upon the "*Genius Loci"* or Spirit of the Place, but his endeavors faced persistent hostility from Egyptian authorities, who rejected his references to traditional rural models, despite his skillful modernization of them.

Tragically, his ambitious pedagogical project to establish an *"Institute of Appropriate Technology"* dedicated to raw earth construction never materialized. Faced with institutional obstacles, Fathy turned to writing, publishing 2 major books that contributed greatly to his international reputation (Fathy, 1970, 1986).

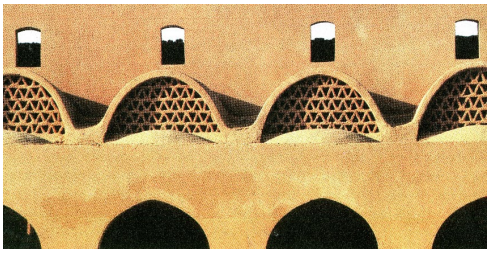

Fig. 3 – *Agricultural cooperative by Fathy, New-Baris village* (Bastin-Evrard).

In "Architecture for the Poor" (originally published in Arabic in Cairo, then translated into French in 1970 and later into English in the United States), he championed raw earth as the ideal material for self-sufficient, community-led construction projects for modest populations. He affirmed: "A man cannot build a house alone, but ten men can together build ten houses. So, we must submit technology and science to the economy of the poor" (Fathy, 1970).

Although this "manifesto-book" initially had limited impact in the so-called "Third World" — except in Egypt through his friend and disciple Ramsès Wissa Wassef and later in Morocco with Elie Mouyal— it paradoxically gained lasting influence mainly in Europe, but also partly in USA.

During the 1960s–1980s, young architects, engineers, and artisans from France, Belgium, Switzerland, Italy, Germany, Britain, Canada, and the United States (through the *Peace Corps* established by President Kennedy) sought to transpose Fathy's ideas into newly independent "Emerging Nations" as part of bilateral technical, cultural, and humanitarian cooperation missions.

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Fig. 4 – *New-Gourna village by Fathy* (Aga-Khan-Award).

Later in life, Fathy finally received due recognition. At age 80, he was honored by the Aga Khan Award for Architecture, acknowledging him as a top pioneering figure in the Muslim world. And the International Union of Architects awarded him with its highest reward: the Gold Medal. Upon his death in 1989, the French main newspaper "Le Monde" wrote: "By rejecting Western concepts deemed unsuitable for developing countries, Fathy created an inventive body of work rooted in his country's vernacular traditions".

4. CRATerre: the first contemporary Grand Pionnier, active since 1979

In 1979, two young French architects, Patrice Doat and Hubert Guillaud, together with Belgian engineer Hugo Houben, founded CRATerre —International Center for Earth Construction— at the Grenoble National School of Architecture, later integrated into the University of Grenoble (Fig. 5). Their militant, nonprofit association grew within a complex context shaped by four major forces.

- The student revolts of May 1968, which challenged academic teachings in architecture as outdated and disconnected from social needs.
- The global energy crises of the 1970s.
- The emergence of a progressive "North-South dialogue", emphasizing solidarity between Europe and newly independent countries suffering from acute housing crises.
- As well as the rise of environmental awareness and ecological responsibility.

CRATerre developed pioneering strategies that were —and remain— unmatched in scope and ambition. During the 1970s, Patrice Doat and his colleagues discovered —much like Cointeraux two centuries earlier— the vernacular legacy of rural and urban rammed earth architecture in the regions of Grenoble and Lyon. Admiring the rational intelligence and minimalist elegance of this traditional knowledge —at that time nearly forgotten or disdained— they committed themselves to inventorying and updating ancestral wisdom, both in France, Europe and later world-wide.

These patient investigations culminated in 1987 with the publication of their monumental encyclopedia: the *"Traité de construction en terre"* which remains the world's most comprehensive and pedagogical reference on all traditional and modern raw earth building techniques (Houben & Guillaud, 1987). This *"Opus Magnum"* became an essential tool for earthen builders worldwide and was praised by Renzo Piano, one of the most creative and renowned architects of our time. In 2009, Piano wrote:

> "Patrice Doat and his team returned to the essential, without being seduced by the vanities and traps of contemporary architectural practice. Today, in the era of architectural ecology, it is CRATerre that shows us the way forward with the new and best ways to build with raw earth. They are ahead of their time" (Piano, 2009; Fontaine et al., 2009).

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Fig. 5 – *4 among 64 social housing units in the "Domaine-de-la-terre" inaugurated 1985, Villefontaine, France* (Dethier).

The comprehensive strategies and actions of CRATerre have, for over 45 years, been carried out by a diverse, multicultural team of about 60 people and enlarged with two new teams located (between Grenoble and Lyon) at Villefontaine:

- The "*Grands Ateliers de l'Innovation Architecturale*" (GAIA), established in 2001 (Bardagot, 2022).
- The "*Atelier des Matières à Construire"* (AMaCo), founded in 2012 (Amàco, 2013).

Together, these three complementary teams have spearheaded extraordinary interdisciplinary efforts worldwide across more than sixty countries.

5. Summary of CRATerre's seven main fields of pilot activities

5.1. Scientific research

- Advanced studies optimizing raw earth construction techniques and establishing databases.
- Fieldwork in diverse environments to test and adapt techniques.
- Collaboration with AMaCo to better understand the physical and chemical behavior of various soils, culminating in a major trans-disciplinary book: "*Bâtir en terre: du grain de sable à l'architecture*" (Fontaine & Anger, 2009).

5.2. Education and training

- Creation of the world's first higher education program specializing in raw earth construction, launched in Grenoble in 1980.

Followed by the creation of the UNESCO Chair in Earthen Architectures, Constructive Cultures and Sustainable Development.

- Founding in 2001 (in Villefontaine) of the "*Grands Ateliers*": an exceptional site for experimental, hands-on architecture education focused on the best practices and uses of natural building materials, including raw earth (Fig. 6). The avant-garde training developed here is based on Parice Doat's philosophy developed in his inspiring and influent strategic manifesto: "For an Indispensable Cultural and Pedagogical Revolution" (Doat, 2019).

5.3. Social actions

- Improving living conditions in various communities and countries, especially through sustainable housing projects fully adapted to local cultures and resources.
- Emergency shelter interventions, including the large one developed after the Haiti earthquake.
- Ethnographic & technological studies of vernacular housing traditions in many countries.

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Fig. 6 – *Earth construction students workshop by CRATerre at "Grands-Ateliers"* (CRATerre).

5.4. Social housing

Two highly innovative and successful projects have been achieved:

- In South- East Africa on the Mayotte Island (a French territory) with the development, since the 1980s, of 20 artisans cooperatives producing earthen blocks from local soil, leading to the construction of 30,000 highly economical homes (Fig. 7): the largest social housing program developed so far in the world (Lietar & Tessier, 2021).

Fig. 7 – *Social housing in Mayotte designed according to CRATerre's strategy (*CRATerre*).*

- In France at Villefontaine (30 km. south of Lyon), the "*Domaine de la Terre" was* inaugurated in 1985 as the world's first contemporary urban district of social housing built with four raw earth modernized techniques: including "*pisé*" bearing walls without any additional cement. This pilot-program was initiated by the Centre Pompidou Museum — requesting also the scientific contribution of CRATerre— to develop an obvious full size social & technological demonstration of the validity of the ideas developed in its militant exhibition produced in 1981 to promote the ecological future of raw earth architecture.[2] (French Ministry of Equipment, Housing and Urban Development., 1986).

5.5. Cultural initiatives

- Extensive publishing strategy, including many scientific, cultural and educational works.
- Organization (in Villefontaine *"Grands Ateliers"*) of the annual "International Raw Earth Architecture Festival".
- Creation (in Villefontaine also) of the world's largest documentation center focused on all the facets of earthen construction[3], with over 25,000 publications, thesis, mission reports, expertises, articles, etc.

5.6. Knowledge transfers

- Permanent development of many local, national or international symposiums and workshops.
- Co-organization every 3 to 5 years of a "World Conference on Earthen Architectures" (the last one in Lyon)

5.7. Ecology and the environment

- Promoting raw earth as an essential natural material for sustainable construction, including in urban context to develop realistic alternatives to the excessive use of cement and concrete.

[2] On the occasion of the 40th anniversary of the inauguration of the *Domaine de la Terre*, the publication of a commemorative monograph (highlighting its history, innovations and influences) is planned for 2026 or 2027 in partnership with CRATerre.

[3] The Documentation Center of CRATerre —accessible to researchers— is located in Villefontaine at the Maison Levrat. Its management is ensured by Audrey Carbonelle: a.carbonnelle@craterre.org

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6. Conclusions

The successive contributions of Cointeraux, Fathy, and CRATerre have each progressively elevated raw earth from an undervalued material to a recognized, versatile, and progressive construction resource. Their cumulative achievements clearly demonstrate that raw earth can serve, now and in the future, a wide range of applications: from comfortable residences to affordable social housing as well for many other kinds of buildings. And it offers highly valuable ecological and technological, economic, social and cultural advantages. Each pioneer, by integrating vernacular intelligence with modern rationalization, initiated a vital renewal that resonates with the profound transformations of their respective eras: Cointeraux within the context of the 1789 French Revolution, Fathy with the hopes related to decolonization, and CRATerre with the ecological awakening of the past 50 years. Today, faced with the existential challenge of climate change, it is essential to massively decarbonize the construction sector. To do so, raw earth must become one of the leading alternatives to reduce the far too massive and aggressive universal use of cement and steel. Those industrial products are indeed combining one of the largest world consumption of fossil energy and emission of greenhouse gases. Thanks to the visionary legacies of our three pioneers, raw earth must become one of the pillars of a new, more intelligent, sustainable, and humanist common practice to design responsibly our built environment. Through its sobriety, beauty and sensuality, its warm colors and harmony with nature, raw earth also invites us to invent a "New Art of Living": a daily cultural and democratic revolution in profound symbiosis with the most common, abundant and local resource of our planet Earth. As final statements, here are two quotations from Edgar Morin, a leading contemporary French philosopher and sociologist (Morin, 2004): "The great movements of transformation always begin marginally, deviantly, modestly, even invisibly" and "Any attempt to improve our future must reconcile rational and practical brain power with emotional and affective cleverness drawn from the living sources of our cultures".

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Earthen Architecture and Landscape: The U-shaped Temples of Pre-Hispanic Lima

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Abstract

Contemporary Lima is located between the Andes and the Pacific, in a desert area comprising three valleys. Because of extensive urban sprawl, the existing city, home to over ten million people, has effaced the traces of the indigenous territory and its ancient architecture, intensely connected to the landscape. Vestiges include a series of temples of colossal dimensions, built more than 4,500 years ago, that are testimony of an innovative landscape architecture, even by contemporary terms. From the territorial standpoint, this architecture is evidence of the civilizing process that involved the transformation of desert space into agricultural land. Such initial public architecture comprises ritual spaces and specialized support activities that reflect complex forms of social organization and signify the birth of new forms of power. It is a primigenial architecture linked to the territory that appears in the landscape made up by indissolubly, mutually supportive construction units. The large platforms containing ceremonial spaces rise as a huge U-shaped landscape structure spanning spaces of up to 40 hectares, open to the landscape. Our research aims to recover the territorial memory of this landscape architecture, and with it, the diachronic link between architecture and territory, broken by intense colonization and urbanization. With the support of archaeological work, architectural analysis, historical graphic documentation and modern photogrammetric techniques, we draw maps and adopt reconstructive approaches, covering every step, from the drawing of the territory to architectural modeling. These maps lay the foundation for an essential planning and design tool, allowing us to intervene in the city from a different perspective, to recover the memory and take a sensitive look at the past, to understand contemporary space without breaking continuity with the underlying indigenous territory, and to draw lessons from this unique cultural landscape, permeated by the Andean worldview that is still latent in today's overflowing metropolis.

Keywords: *Andean architecture; ceremonial earthen architecture; Andean urban planning; territorial transformations; cultural landscapes; Pre-Hispanic Peru*

1. Introduction

Upon submitting this work to the congress, we identified two theme available for selection: Study of earthen architecture and Studies of historic urban and rural areas. The decision to categorize the article under earthen architecture prompted an engaging discourse, frequently conducted in Lima, concerning architecture, urbanism, and landscape studies, as well as inside

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our research collective. This discourse, however scholarly, gains importance when we address the reality of pre-Hispanic architecture, where the distinctions between architecture, urbanism, and landscape become indistinct.

The chance to pose these inquiries constitutes a vital lesson or attribute of the vast complexes we examine, aiming to map them, comprehend them thoroughly, and utilize them as a foundation for the preservation of this earthen-built heritage.

This heritage manifests in the modern urban landscape as a profound testament to almost 4,500 years of history and 500 years of significant disruption, reflecting a sensitivity to comprehend the terrain and integrate architecture into a unified reality.

This paper is based on the research project *Cartographies of Lima* (Canziani & Sáez, 2020), which has already produced previous publications and presentations (Canziani & Sáez, 2021).

2. Cultural landscapes of the tropical desert

The region that comprises contemporary Peru consists of significant geographic and environmental units: the Andean mountains range centrally located, the Amazon rainforest to the east, and the coastal desert to the west (Pulgar, 2014). The challenges of inhabiting and cultivating these regions, stemming from constraints in water availability, soil quality, and climatic conditions, have resulted over millennia in the emergence of civilizations that rendered the land habitable through advanced cultural, environmental, and technological strategies, culminating in the creation of a series of remarkably beautiful cultural landscapes.

In the case of the coastal desert, which is the focus of this research, the combination of its tropical latitude, the cold Humboldt current, and the thermal inversion phenomenon create the unique conditions of this tropical desert. A territory that is warm, humid, and without rainfall, with seasonal fog phenomena that produce a particular landscape, which Andean societies have inhabited through various forms of building what we would today call buildings, urban spaces, and cultural landscapes, whose boundaries intermingle and blur, with a mystical and plastic load intrinsic to indigenous societies and their unique way of intervening in the territory (Fig. 1).

Fig. 1 – *Cultural landscape of the Chincha valley, showing main canals, ditches, and cultivated fields built on the desert* (José Canziani, 2000).

This desert is marked by a sequence of transverse valleys, with a Pacific slope, whose alluvial deltas generate suitable spaces for agriculture, achieved through the deployment of large artificial irrigation systems. The anthropic construction of the territory was accompanied, from its earliest beginnings, by the development of urban centers. and the erection of monumental architecture. Various architectural traditions and forms of earthen architecture have been recorded in distinct regions of the Peruvian coast, dating back to the Formative Period (1500 – 500 BCE), associated with the development and gradual extension of agricultural valleys (Canziani, 2012; Canziani, 2021; Lumbreras, 1981; Williams, 1981).

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3. Contemporary Lima, archaeological territory and research

Modern Metropolitan Lima is situated on the alluvial plains formed by the Chillón, Rímac, and Lurín rivers. The city, currently home to more than 10 million inhabitants, has grown through massive urbanization of the territory since the first half of the 20th century.

Such massive urban growth has largely destroyed and affected the enormous pre-Hispanic heritage of earthen architecture and urbanism. Nevertheless, many notable testimonies still remain within the urban fabric. These appear blurred and scattered as *huacas*—the pre-Hispanic sacred places—or archaeological remains, protected as objects and delineated by an archaeological perimeter (Canziani, 2013; Canziani, 2014; Ravines, 1985; Tello, 1999).

These *huacas*, preserved as monuments, lose the essence of their *raison d'être* as is their relationships with the territory and the landscape, with which they formed a single unit. It becomes impossible to perceive this architecture as part of the landscape, distorting part of the history of the territory. In fact, when represented on maps, they appear as points, also a consequence of traditional forms of representation.

From this standpoint, our project aims to build maps and reconstructions, all along from territorial drawing to architectural modeling, to lay down the bases of an essential planning and design tool permitting them to intervene in the city from a perspective that will be sensitive to the memory of the place and can teach lessons drawn from this cultural landscape.

To this end, we use architectural analysis, historical graphic and photographic documentation, the study of archaeological works, drone and ultralight plane flying, photogrammetric and architectural modeling techniques, in a long-term project underway since 2016.

4. Earthen architecture and territory

Historically, the language of these earthen creations, present in the valleys of Lima for over 6,000 years, demonstrates a continuity among what is contemporarily referred to as architecture, urbanization, and landscape, perceived as a cohesive entity.

This urbanistic style features an urban pattern mostly shaped by mural architecture, incorporating linear elements that organize and define the landscape. Similarly, the platform, a crucial component of this architecture, generates both expansive landscape structures and smaller features, with the tiered horizontal plane, varying in elevation, serving as one of the essential principles of its architectural lexicon.

Moreover, the importance of form, geometry, and orthogonal order is another perceived fundamental element to this architectural logic, which could create large-scale territorial structures with astounding formal accuracy.

In this sense, U-shaped temples are one of the most interesting pre-Hispanic architectures in the Lima valley. These are colossal structures that, since the initial times of the Formative Period (1500 – 500 BCE), essentially displayed these compositional elements of earthen architecture (Agurto, 1984; Burger, 1993; Canziani, 2008; Williams, 1980).

5. The U-shaped temples and the valleys

The Rímac valley began to be progressively populated as its extensive alluvial plain allowed the gradual expansion of agriculture through the management of irrigation canals, with significant both technological and scalar development. Surplus agricultural production served as the foundation for a flourishing social development, giving rise to one of the most important civilizations on a global scale. From its very beginnings, this process finds its most transcendent expression in monumental public

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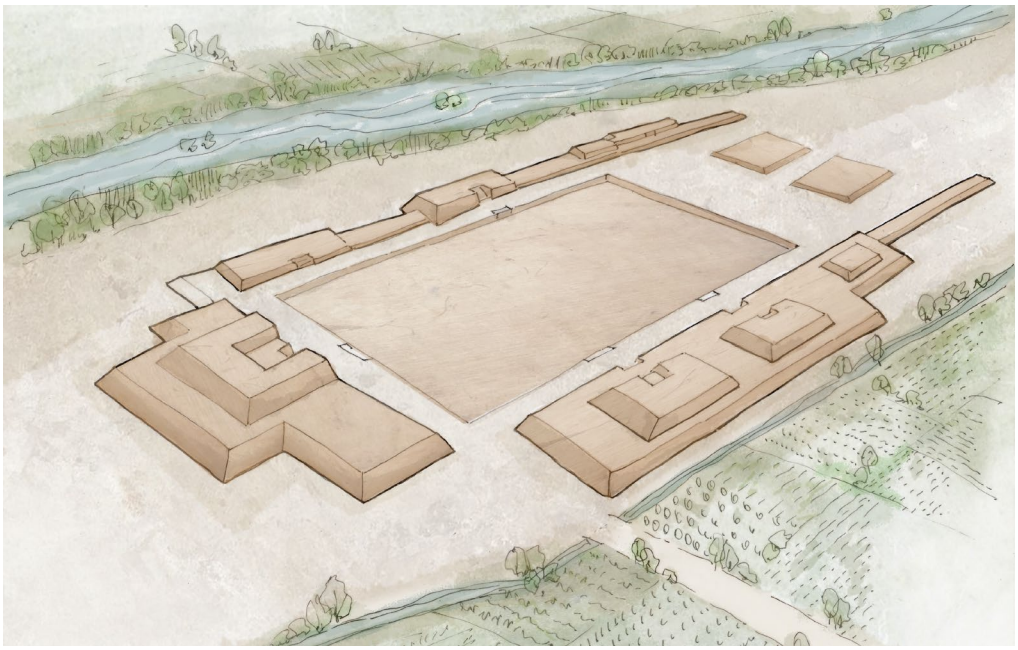

Fig. 2 – *Reconstruction of the Chocas complex in the Chillón valley landscape* (Canziani & Sáez, 2020).

architecture, principally manifest in emerging urban centers with administrative, ceremonial, and representative purposes. These buildings, which are both urban spaces and landscape structures, featured from their early stages a set of constitutive elements, namely a preference to build large plazas, defined by two parallel arms that open to the landscape, and at the center, a pyramidal structure platform rising towards the sky (Fig. 2).

Interestingly enough, their logic and congruence are identical at all scales. Firstly, the territorial scale implantation of these temples is usually the same: they are located at the boundary between the agricultural area and the desert, creating a mediating structure between the two; the U-shaped plan oriented towards the east or northeast. The U-shaped Plaza interacts with the *apus*, or sacred mountains, highlighting another constant in pre-Hispanic architecture: positioning themselves under the protection of a mountain while simultaneously contemplating it from the distance of the plaza.

An early precedent of the U-shaped temples is the El Paraíso complex, dating back to the Late Preceramic Period (3000 – 1500 BCE). These complex features two ceremonial buildings that open onto a gigantic plaza measuring 500 meters long by 170 meters wide, framed by low platform lateral arms (Fig. 3).

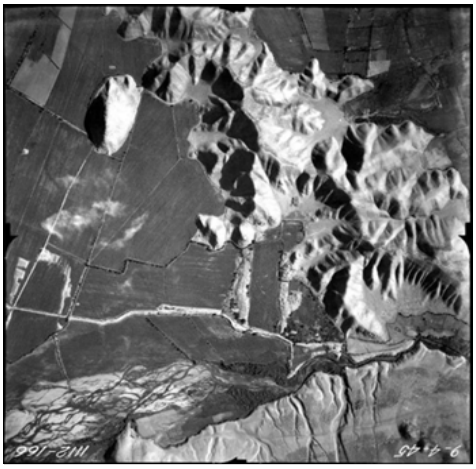

Fig. 3 – *Aerial photograph of El Paraíso* (National Aerial Photography Service, 1945).

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An old aerial photograph from 1945 helped in a hypothetical reconstruction of the relationship between this early monumental architecture and the arrangement of the ceremonial center, considering the possible territorial transformations associated with irrigation and the beginning of agricultural production in this sector of the Chillón Valley. Additionally, based on contemporary panoramic photographs, we have reconstructed the integration of the compound into the landscape and its strategic location between the lower valley and the coastal area (Fig. 4).

Fig. 4 – *El Paraíso. Hypothetical reconstruction of ceremonial complexes integrated into the landscape* (Canziani & Sáez, 2020).

Huaca La Florida is one of the oldest and most significant compounds, La Florida clearly shows the typical components of a U-shaped complex, along with its morphological characteristics. Indeed, the old aerial photograph from 1944 (Fig. 5), clearly shows the large central platform crowned in the center by a pyramidal volume housing the ceremonial atrium.

Along the axis, which is the same symmetry axis of the entire complex, we see the staircase descending towards a fenced forecourt and, from there, to the main plaza measuring 500 meters long by 350 meters wide, bordered by long lateral platforms.

Fig. 5 – *Aerial photograph of La Florida* (National Aerial Photography Service, 1944).

In addition to reconstructing the architectural composition of the complex, special attention was given to analyzing its unique location associated with the early canals that made possible farming on the right bank of the Rímac River, as well as the orientation of the complex towards San Gerónimo Hill, which rises 750 meters above sea level (Fig. 6). This notable mountain might have been regarded as the tutelary deity of this sector of the valley, especially given the intense phenomenon of "*lomas*" or fog vegetation on its slopes (Fig. 7).

Fig. 6 – *Panoramic view of the urban expansion of Lima over the pampas of Amancaes and the slopes of Cerro San Gerónimo* (Merino-Reyna, 2014).

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Fig. 7 – *Reconstruction of Huaca La Florida in a temporary greenery landscape resulting from the "lomas" phenomenon* (Canziani & Sáez, 2020).

Lima's urban sprawl has not only destroyed these sensitive ecosystems and the memory of the popular festivities that were held there, but it has also erased the lateral arms of the temple and occupied the ceremonial plaza with buildings and sports facilities, obliterating the historical memory that had sedimented in this place since pre-Hispanic times.

Huaca Garagay is the largest U-shaped ceremonial complex of all Lima valleys (Fig. 8). In addition to sharing the characteristic features described above, Garagay stands out because the archaeological excavations conducted in the atrium of the pyramid have documented a set of polychrome friezes and reliefs painted on the figures and clay-coated walls (Ravines & Isbell, 1975).

Fig. 8 – *Panoramic view of Garagay surrounded by the urban expansion of Lima* (Merino-Reyna, 2014).

Mina Perdida is the largest complex from the Formative period in the Lurín Valley. The 1945 aerial photograph shows the colossal dimension of its U-shaped plan, containing an extensive plaza that, although already occupied by crop fields, still shows its "sunken" layout as it is framed by low platforms. This old aerial photograph shows the association with Parka, a smaller complex that, as has been verified elsewhere, established a certain functional duality, for reasons that remain to be explained.

Cardal, also located on the left bank of the Lurín Valley, is one of the best-preserved and most elegant complexes for its composition (Figs. 9 & 10), clearly defining a sunken plaza and the presence of circular ceremonial wells, both on the side arms' platforms and as annexes to the ceremonial plaza (Burger, 1993; Burger & Salazar, 1992).

Fig. 9 – *Panoramic view of the monument affected by agricultural use of the ceremonial plaza* (Merino-Reyna, 2014).

6. Conclusions

Knowledge and the cultivation of sensitivity are key elements for the conservation of heritage and its territorial memory.

We must maintain and rehabilitate not only the invaluable cultural artifacts exhibited in our museum displays and magnificent buildings but also the territory and the landscape. The temples exemplify a nuanced understanding of the territory, instructing us on its conservation.

As architects, our production method contrasts with the deconstruction employed in archaeology; the convergence of both disciplines enables us to comprehend these locations more effectively.

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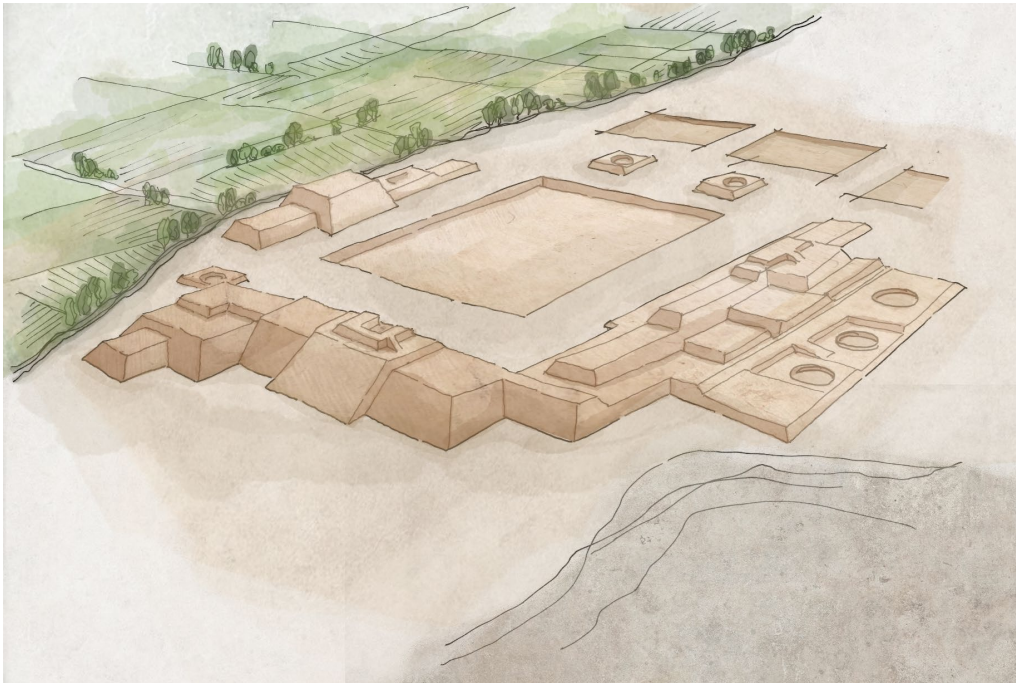

Fig. 10 – *Reconstruction of Cardal's architecture and landscape* (Canziani & Sáez, 2020).

Drawing provided the foundation of our intervention which respects the relationships between elements and understands them not only as objects but as places, and not only as form or matter but also from their geographical, environmental, cultural, and mystical aspects.

The links between architecture and landscape remain intact because it is the persistent relationship of these colossal temples with permanent elements, such as mountains, valleys, and the sea, that have allowed them to endure over time.

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Earthen Architecture in Costa Rica: Building Typologies in the Historic Centers of Cartago and Santo Domingo de Heredia

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Abstract

Earthen architecture in Costa Rica experienced two significant stages of development. The first corresponds to the pre-Columbian period, during which local inhabitants constructed their dwellings using logs, thatch, plant fibers, and mud as infill material. The second began with the Spanish conquest, which introduced adobe construction — a technique previously unknown in the region. Cities such as Cartago, which served as the national capital until 1835, were primarily built using adobe. Over time, the influence of this construction technique spread throughout Costa Rica. Urban centers like Santo Domingo de Heredia still retain numerous adobe buildings integral to their historic urban landscape. Due to the region's geographical and climatic conditions, Costa Rican domestic architecture from the 17th century onward generally followed two principal typologies: urban and rural. Both share similar characteristics, such as thick masonry walls, small openings for doors and windows, steeply sloped roofs, and wide eaves in response to climatic factors. Despite these similarities, cities evolved in terms of density and land use, resulting in a broader and more complex range of building typologies today. This study forms part of the research project "Seismic Earth: Physical and Mechanical Analysis and Characterization of Adobe and Bahareque Construction Systems in the Historic Centers of Cartago and Santo Domingo de Heredia as a Basis for Seismic Adaptation". The project seeks to deepen understanding of the adobe and bahareque construction systems, including their pathologies and specific features. Preliminary findings reveal the distinctive characteristics of various building typologies in the two case study areas and their relationship with the urban development of these historic centers.

Keywords: *adobe; bahareque; historic urban landscape; seismic earth; construction systems*

1. Introduction

Located in Central America, Costa Rica was under Spanish colonial rule from approximately 1519 until independence in 1821. Unlike some neighboring countries, Costa Rican architecture did not stand out for its scale or degree of sophistication. Although there is evidence of significant pre-Columbian architectural complexes, such as the Guayabo National Monument and the stone sphere settlements in the Diquís area, most buildings were vernacular in nature and constructed with perishable materials. As a result, only a few structural elements—such as stone foundations, roads, or aqueducts—have survived to the present day.

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The limited presence of pre-Hispanic architecture and even of structures from later periods can be attributed to the convergence of several factors. During the pre-Columbian era, Costa Rica was a meeting point for cultures such as the Maya and the Chibcha, whose influence is evident in local crafts, cuisine, and customs. However, the region was primarily a zone of transit and exchange rather than a permanent settlement for these cultures.

During the colonial conquest, proximity to administrative centers established by the Spanish was crucial for developing new settlements. In this context, Costa Rica's geographic conditions and the dispersion of its indigenous populations kept it relatively isolated from key colonial cities in Guatemala, Nicaragua, and Panama. This isolation contributed to a scarcity of skilled labor familiar with the construction techniques introduced from other parts of the world.

Another key factor that affected the country's architectural heritage preservation was the region's persistent seismic activity. Historical records document significant earthquakes as early as the 17th century, which repeatedly necessitated the rebuilding of homes, municipal buildings, churches, and other structures (González, 1994).

The pre-Columbian period was characterized by vernacular construction using local raw materials. "Elliptical and rectangular huts were common in the North Pacific, while circular ones dominated in the Central Valley; in contrast, the Caribbean and South Pacific regions typically featured palenques" (Molina & Parmer, 2017, p. 15). These buildings employed wood for the primary structure and palm leaves for the cladding. The steep roof pitch often extended to the ground, functioning as walls. A clay pot was suspended from the highest point of the roof to collect rainwater and prevent flooding inside the dwelling. The walls were made waterproof using a mixture of earth and water. In drier regions such as the Greater Nicoya area, roofs were less steep, and the gaps in wooden or cane walls were filled with earth. This technique closely resembles bahareque, a method found in other parts of the region.

The colonial period brought a notable rise in using earth as a building material in Costa Rica. With the founding of Garci Muñoz by Juan de Cavallón in 1561 and Cartago by Juan Vázquez de Coronado in 1563 (Mata, 1999), the adobe construction technique was introduced to the country. This system became characteristic of the new colonial settlements, which contrasted with indigenous ones not only in materials but also in urban layout. Settlements followed the grid pattern mandated by the Royal Ordinances of Philip II in 1573 (Woodbridge, 2007).

Adobe construction became popular in the country's former capital and spread to other cities such as San José and Heredia, including towns like Escazú, Pacacua, Barva, and Santo Domingo. These towns replicated the colonial grid layout, with the church and main square as central elements around which buildings were organized. Despite the expansion of adobe construction across various regions, only a few urban centers retain a significant number of earthen buildings within their historic fabric. The loss of this architectural heritage can be attributed to frequent earthquakes, flooding, and increasing pressures from land value. The research project "Seismic Earth: Physical and Mechanical Analysis and Characterization of Adobe and Bahareque Construction Systems in the Historic Centers of Cartago and Santo Domingo de Heredia as a Starting Point for Seismic Adaptation," conducted by the Costa Rica Institute of Technology, aims to inventory these buildings to enhance the understanding of their construction techniques and highlight their cultural value.

This paper presents some initial findings from identifying these structures based on the research activities carried out during the project's first year.

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2. Materials and methods

In 2024, both study areas were delineated to determine the zones for identifying earthen buildings. This task was carried out through the consultation of historical maps at the National Archive and a bibliographic review conducted at the Center for Cultural Heritage Conservation (CICPC) or the Heritage Directorate. In the case of Cartago, the delineation proposed by Fallas-Pastor (n.d.) and Mata-Gamboa (1999) was considered, along with its correspondence with the map by Figueroa-Oreamuno (1801–1821). This information was further contrasted with the notes of Tristán-Fernández (1910). For Santo Domingo, the delineation by Ruiz-Briceño (n.d.), the map by Riggioni and González (1920), and the study by Zamora and Vives (2005) served as key references. The comparison of historical cartography and bibliographic sources led to the determination of the historic center boundaries in both cities.

Subsequently, a documentary review was conducted to understand better the characteristics of Costa Rica's earthen constructions and their associated building typologies. Key references included the works of Gutiérrez-Rojas (2018), Fonseca & Garnier (1998), and Woodbridge-París (2003).

Building on this foundation, a preliminary inventory of adobe and bahareque constructions was developed through archival research involving architectural thesis projects, historical records, and registries of protected buildings. This stage relied on prior studies such as the work by Guevara and Navarro (2014) in the historic center of Santo Domingo, the study by Morera-Cortés (2015) in the city of Cartago, and the inventory compiled by Sancho-Víquez (1985).

A standardized survey form was designed to guide field data collection from this preliminary inventory. The form was created in Excel format and implemented in print and digitally through the Plumsail application. Field visits were conducted to validate existing records and to identify additional undocumented buildings. In the case of Cartago, three site visits were conducted, while six sessions were required for Santo Domingo.

Finally, the research team analyzed the collected data to define the building typologies in each historic center and compare their current configuration with those described in the consulted literature.

3. Results

3.1. Delimitation of Historic Centers

3.1.1. The Historic Center of Cartago

Cartago served as the capital of Costa Rica from 1563 until 1823, when the seat of government was relocated to San José. The city was laid out following a grid pattern (*damero),* with the Plaza Mayor at its center, organizing the parcels allocated to various buildings: the Santiago Apóstol parish to the east, the Cabildo (municipal council) to the north, as well as other governmental institutions and the residences of local authorities in the surrounding blocks. Around 1635, the discovery of the image of the Virgin of Los Ángeles in the area known as Puebla de los Pardos led to the construction of a chapel on the site. It altered the city's morphology by expanding its historic center eastward (Mata, 1999). According to historical records, by 1719, the city had approximately 70 adobe and tile-roofed houses (Zamora & González, 2009), and by the early 19th century, the urban core comprised 40 city blocks.

According to the map by Figueroa-Oreamuno (1801–1821), prior to the 1910 earthquake, the city perimeter was clearly defined: to the north along 14th Street behind the military barracks up to Cinco Esquinas in the San Nicolás neighborhood, to the west along the eastern edge of the general cemetery; to the south, bounded by the municipal slaughterhouse; and to the east,

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extending to Calle de La Soledad. In total, 189 blocks were recorded, with dimensions ranging between 77 and 130 meters and sidewalks approximately 1.10 meters wide (Mata, 1999).

Cartago's history has been shaped by a series of natural disasters that progressively transformed its urban image and influenced the evolution of construction systems. Earthquakes in 1715, 1722, and 1841, along with the 1891 flood, caused significant loss of life and damage to the built fabric of the historic center. However, the most devastating event occurred in 1910 with the Santa Mónica earthquake, which remains the worst disaster in the city's history. According to the provincial governor of Cartago, José María Peralta, the event resulted in 233 deaths and the destruction of approximately 85% of the city's buildings (González-Víquez, 1994).

Despite repeated natural disasters, Cartago was rebuilt, maintaining its original urban layout while introducing new reconstruction regulations. These included a ban on adobe construction, a reevaluation of bahareque as a building method, and an incorporation of stylistic influences favoring timber construction, such as Victorian architecture.

3.1.2. The Historic Center of Santo Domingo de Heredia

Before the colonial period, the indigenous Toyopán group inhabited the area. Following the Spanish conquest, the territory came under colonial control, and in 1829 the first chapel dedicated to Saint Dominic of Guzmán was constructed. This religious dedication gave the settlement its current name. The building, originally made of adobe and clay tile, was later demolished to make way for the construction of the Church of El Rosario in 1838 (Zamora & Vives, 2005). Located facing the plaza and oriented east-west, the church and the cabildo (town council) constituted the urban core of the settlement. The layout of the historic center was formalized by the decree of then-president Braulio Carrillo, who mandated the grid plan (damero) for all new urban centers. By 1840, Santo Domingo had 296 houses, according to records from the military administration under Carrillo (Ruiz-Briceño, n.d.).

During the 19th century, the town consolidated as a key settlement due to the cultivation and processing of tobacco, followed by coffee. The rise of the coffee economy led to the appearance of hacienda-style houses built in adobe and bahareque, typically located on large plots of land.

These dwellings evolved. Mid-18th-century constructions, built during the tobacco boom, were situated outside the urban centers. By the early 19th century, houses increased in scale, integrated within the blocks of the historic center, and reflected the transition from colonial peasantry to small-scale coffee producers (Ruiz-Briceño, n.d.). Eventually, corner houses appeared on the city grid, usually owned by large-scale coffee growers.

According to the map by Riggioni & González (1920), the historic center of Santo Domingo was bounded to the north by Calle de Tures, to the east by Calle Iglesia Nueva—located behind the basilica and running along its perimeter up to Calle la Real or Quintana—to the south between Calle Ronda. What is now 12th Avenue, and to the west by Calle 8. 71 blocks were documented, with dimensions ranging from 87 to 105 meters, except for the lots adjacent to the basilica, which measured between 50.5 and 58 meters. This urban layout remains largely intact today, along with many earthen constructions dating from the late 19th century.

3.2. Early building typologies

3.2.1. Urban housing

The building was constructed from the corner of the block, directly on the property line, following an "L"-shaped configuration on the site. The main entrance was oriented toward the most

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important street, while the secondary entrance served complementary functions such as carrying firewood or allowing access to animals. The house's layout created an interior yard or patio, enclosed on two sides by the two wings of the building (Gutiérrez, 2018). It was connected to the interior by a lateral corridor. Though lacking walls, this space was sheltered by the roof, which rested on a structure of wooden beams and columns.

The various rooms were interconnected and linked to the corridor, with their use determined by each owner according to their needs. However, the house generally featured a room or vestibule adjacent to the main entrance, bedrooms, and, in some cases, a dining room connected to the kitchen area (Gutiérrez, 2018). The oven and the bathroom were separated from the dwelling but connected by a tangential path, isolated from the main structure for safety and hygiene purposes. At the end of the property, the troja area was located, where firewood, grains, and washing spaces were stored, and occasionally, it also served as a shelter for domestic animals.

The roof was generally gabled with a four-pitched configuration that followed the plan's layout, featuring wide eaves and steep slopes. On some occasions, the eaves of the more exposed facades had decorative details. "To extend the eaves without risking structural integrity, corbels were embedded in the wall, which, in some cases, were made of perforated wood for aesthetic purposes" (Gutiérrez, 2018, p. 38).

3.2.2. Rural housing

The house was perpendicular to the street, with one of the narrower facades facing the public space. This characteristic allowed for the creation of a front yard, providing greater privacy and contributing to the adaptation to climatic variables: vegetation was used to mitigate sunlight, and cross-ventilation was achieved through the surrounding corridor.

The rectangular-shaped house extended inward on the plot, with the first room functioning as the living area, followed by the bedrooms. The dining room was omitted, as this function was integrated into the kitchen space, typically located at the rear of the house (Gutiérrez, 2018).

Separated from the house, there was a small area for the oven, a washing space, and a small volume housing the sanitary service farther from the main structure. There was no dedicated bathroom area, as the inhabitants used nearby streams for bathing.

The roof was typically gabled with a two-pitched design, featuring a change in slope over the corridor area, where the roof extension helped protect the space.

To complement the housing functions, a troja was located apart from the house in a square-plan structure made of wood and clay tile.

Rural housing was more common in areas with larger plots, whereas urban housing, although larger in dimensions, had less available land due to the restrictions of the city block grid.

In both types of construction, the walls ranged from sixty centimeters to one meter in thickness, with foundations consisting of compacted trenches for rural homes and stone-filled trenches for urban homes. Both types featured small openings for windows, shutters, and wooden doors.

A notable characteristic of earthen dwellings is the purity of the volumes, typically of a uniform scale, usually one-story, and with minimal ornamentation.

3.3. Evolution of building typologies

The inventory work carried out in the historic centers of Cartago and Santo Domingo de Heredia, as well as the comparison with the urban and rural housing typologies studied in the bibliographic references, identified the following variants.

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3.3.1. Corner unit

This type is located at one of the corners of the block. Its floor plan is rectangular, without an "L" shape. It features a gable roof, with one slope facing the front and the other facing the rear (Fig.1).

3.3.2. Corner unit with courtyard

Located at one block's corners, this unit extends on both sides of the property in an "L" shape. The roof follows the floor plan's form. It includes an open space or courtyard on both sides of the building, sometimes open to the street or enclosed by a low wall. An internal corridor may connect to the courtyard (Fig. 1).

3.3.3. Attached corner unit

Like the previous types, this unit is located at a corner of the block but maintains a continuous relationship with the adjacent building. This condition may result from urban expansion in the years following the original construction (Fig.1).

Fig. 1 – *a) Corner Unit, b) Corner Unit with Courtyard, c) Attached Corner* Unit (Chavarría-Villagra, 2025).

3.3.4. Attached unit

Located centrally within the block, this type has a rectangular floor plan and shares lateral boundaries with neighboring properties. It generally has a gable roof, one slope facing the front and the other facing the rear (Fig. 2).

3.3.5. Semi-attached unit

This unit is positioned centrally within the block, sharing one lateral boundary with the adjacent property. On the opposite side, it typically has an open space, such as a courtyard or uncovered passage, bordered by a small wall. The roof is hipped, with slopes toward the front, back, and courtyard or passage (Fig. 2).

3.3.6. Detached unit

Situated centrally within the block, this unit retains setbacks on both sides. It is typically used as a patio or lateral passage enclosed by a small wall. It can have a gable or hipped roof, with slopes facing the front and rear (Fig. 3).

3.3.7. Semi-detached unit

This unit is centrally located within the block. It has a rectangular floor plan and shares a lateral boundary with an adjacent property. On the opposite side, there is a setback for the patio. The most notable feature is the roof shape, usually with three slopes (Fig. 2).

Fig. 2 – *a)* Attached Unit*, b)* Semi-attached Unit, *c) Semi-detached Unit* (Chavarría-Villagra, 2025).

3.3.8. Paired units

A group of housing units sharing a boundary. The roof structure is continuous, typically with two slopes—one facing the front and the other facing the rear. In some cases, these units may be located at the corners of the block. This configuration reflects the evolution of the inhabitants' needs over time (Fig. 3).

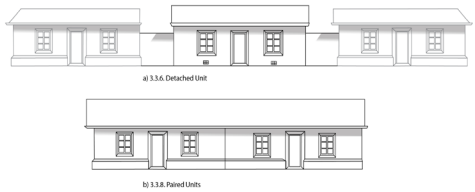

Fig. 3 – *a) Detached Unit, b) Paired Units* (Chavarría-Villagra, 2025).

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3.3.9. Rural unit

This type is distinguished from the others by its perpendicular alignment to the street or road. It features a garden and courtyard on at least two sides of the building, enclosed by a small wall. These units are situated on larger plots of land and generally have a lateral corridor, usually only one segment long.

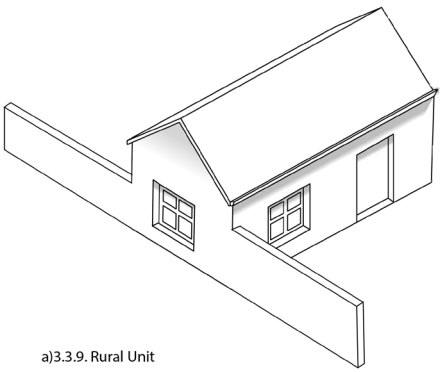

Fig. 4 – *a) Rural Unit* (Chavarría-Villagra, 2025).

In the historic center of Cartago, 24 earthen buildings were recorded. Of these, 21 correspond to the bahareque construction system, and 2 are adobe buildings and 1 in mixed construction system. Regarding typologies, the distribution is as represented in Table 1.

The historic center of Santo Domingo de Heredia records a total of 102 earth buildings. In the area, there are 92 adobe constructions, 5 bahareque constructions and 5 in mixed construction system. The distribution by construction typology is represented in Table 2.

4. Discussion

Earthen buildings in Costa Rica correspond to specific geographic locations, either within or outside the city centers. However, their constructive evolution is related to the original urban grid layout and the social and economic background of their inhabitants at the time of construction, particularly during the 19th century.

Table 1 – *Distribution in historic center of Cartago.*

Typology	Amount	%
3.3.1	1	4.16
3.3.2	2	8.33
3.3.3	5	20.83
3.3.4	6	25
3.3.5	3	12.5
3.3.6	0	0
3.3.7	2	8.33
3.3.8	1	4.16
3.3.9	4	16.66

Table 2 – *Distribution in historic center of Santo Domingo de Heredia.*

Typology	Amount	%
3.3.1	5	4.90
3.3.2	16	15.68
3.3.3	23	22.54
3.3.4	20	19.60
3.3.5	12	11.76
3.3.6	4	3.92
3.3.7	1	0.98
3.3.8	21	20.58
3.3.9	0	0

Variations in the urban and rural housing typologies were identified in both historic centers. These differences reflect adaptations to the owners' needs, the cities' spatial growth, and the increasing population density.

Regarding the construction materials, in Santo Domingo, only 1.98% of the recorded buildings correspond to bahareque constructions. In contrast, in Cartago, the opposite trend is evident, with 93.1% of the earthen buildings made of bahareque. This stark contrast in building systems can be attributed to the historical prohibition on adobe construction in the former capital.

As previously mentioned, following the 1910 Santa Mónica earthquake, adobe was legally restricted, which promoted the use of alternative systems such as bahareque and timber framing.

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Cartago's predominant typology corresponds to attached buildings, while in Santo Domingo, most registered buildings follow the attached corner typology. In both cases, the growing urban density may have contributed to this configuration, as some property owners subdivided their lots and sold portions of land, encouraging the construction of new adjacent dwellings.

Notably, in Santo Domingo, most buildings are located on corner lots, and no rural typologies were identified in the sample. In contrast, 13.79% of the recorded buildings in Cartago are rural. This discrepancy deserves further investigation. Although Cartago—being the former capital and one of Costa Rica's earliest colonial cities—would be expected to present a more urban character, Santo Domingo underwent significant development in the mid-19th century due to the rise of tobacco and coffee production. This may have led to a stronger trend toward reproducing urban housing models.

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Inventory and Cataloguing of Traditional Houses in the Province of Veraguas, Panama

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Abstract

The Republic of Panama possesses a valuable architectural heritage that has evolved over time, shaping a unique identity in each region. In Veraguas, one of the provinces with the richest history and cultural significance, vernacular architecture has been a fundamental pillar in defining lifestyles and community organization. However, in recent decades, globalization has driven the replacement of traditional materials and construction techniques with industrial methods and standardized foreign designs, accelerating the disappearance of traditional typologies. This research aimed to identify, analyse, and document traditional housing in the province of Veraguas during the years 2021 and 2022, with the objective of contributing to the preservation of Panama's architectural heritage through a detailed record of its characteristics and current state. To achieve this, rural communities where these dwellings were still present were identified, followed by in situ visits to analyse and document their construction methods, state of conservation, materials, legal status, and spatial organization. Interviews were conducted with homeowners and local builders, enabling the collection of information on construction techniques, historical context, and the evolution of these dwellings over time. This approach integrated direct observation with local knowledge, allowing for a comparative analysis of architectural patterns and their relationship with the socio-cultural environment. As a result, the inventory documented a total of 30 dwellings located in five districts of the province of Veraguas. Understanding the key characteristics of these typologies, the social factors that influenced their construction, and the way they responded to their immediate environment provides valuable insights for assessing their advantages over contemporary housing models, opening new possibilities for the improvement of architectural practices.

Keywords: *tradition; sustainability; cultural heritage; construction; rural population*

1. Introduction

Over time, technological advancements and globalization have transformed social, economic, and cultural dynamics. While these changes have facilitated access to technology and information, they have also contributed to the erosion of local traditions. The Republic of Panama has developed a rich and diverse architectural heritage that spans the entire national territory. This architecture varies across regions, adapting to the specific characteristics of the locations in which it was built.

One example is the province of Veraguas, which, with more than 500 years of history, has become one of the most culturally significant regions in the country.

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This cultural identity has been expressed in various forms, including art, music, and architecture. However, today this heritage is increasingly threatened by globalization and is now largely confined to rural areas, where it persists in a weakened form. In the architectural realm, this phenomenon has led to the displacement of traditional typologies — originally adapted to their environment— by new, foreign models that lack such contextual responsiveness.

The objective of this research was precisely to document the physical and social characteristics that define these architectural and urban models, in order to provide a comprehensive understanding of their evolution and current relevance. Through this process, the study aims to promote the integration of traditional architectural elements into contemporary projects, encouraging the recovery and adaptation of key aspects of local architecture.

Moreover, the findings seek to be a resource for researchers, architects, and professionals in the field, fostering greater awareness of the region's architectural heritage and encouraging its conservation, revitalization, and application in the design of new constructions that respect both the traditions and the cultural context of the area.

2. General study information

2.1. Problem statement

Traditional architecture in the province of Veraguas reached its peak between 1860 and 1945, a period during which most of these typologies were built. However, their decline began shortly thereafter, largely due to the increasing proliferation of housing models introduced by the United States during the construction of the Panama Canal—typologies that had already started to gain ground following the Canal's completion in 1914. The 1981 thesis "El Hábitat Rural de Panamá" provides early statistical evidence of this phenomenon, documenting the replacement of traditional housing typologies:

> "The housing designs provided by the State to rural communities, in addition to disregarding local materials and resources, present the problem of being based on patterns adopted from urban areas. These designs do not align with economic realities of rural communities, but are instead determined by the preferences of the users. This creates dependency among rural dwellers and diminishes their appreciation for the materials offered by their own environment" (Arias & Martínez, 1981, p. 357).

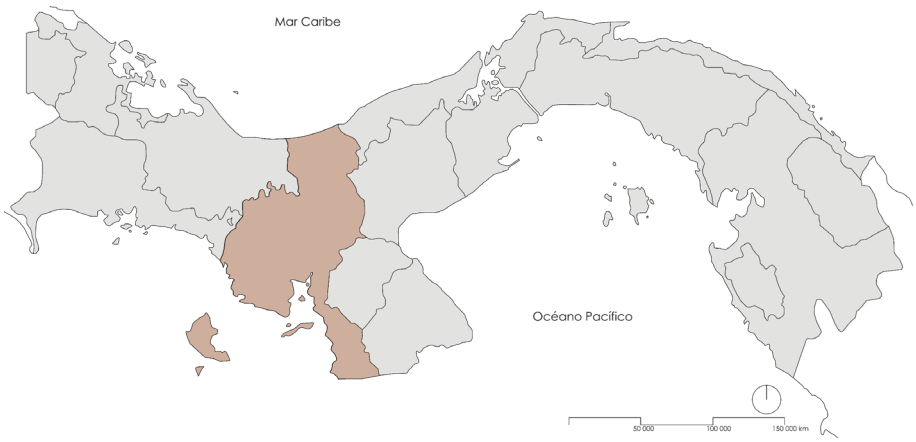

Fig. 1 – *Location of Veraguas Province in the Republic of Panama (Carlos Aponte, 2022).*

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This issue is also addressed in the Report on the Characterization of Rural Spaces developed by ECLAC, which supports the claim that traditional housing typologies—built with locally sourced materials—were gradually replaced by today's standardized construction models, which feature concrete block walls, reinforced concrete structures, and corrugated zinc roofs. These new structures, designed primarily for urban and highly globalized contexts, have been extended into rural areas of the country, contributing to the erosion of local culture and identity. Vernacular typologies, by contrast, are characterized by easy access to materials, minimal need for specialized labor, and their role in fostering community cohesion, as construction was traditionally a collective, social activity. These qualities translate into significant reductions in housing construction costs.

2.2. Relevant information

In the Veraguas region, rural settlements exhibit a defined structure and organization, shaped by physical conditions, economic factors, and traditions passed down through generations. For the purposes of this study, the representative dwellings of Veraguas will be those identified in the Report on the Characterization of Rural Spaces, published in 2015 by the Economic Commission for Latin America and the Caribbean (ECLAC); namely, the following:

- ***Quicnha*:** is a traditional technique for building walls, consisting of a wooden framework filled with plastic earth (mud) mixed with plant fibers. Given the presence of different materials, it is classified as a mixed construction system (Jorquera, 2015, p. 10). The *quincha* house can be considered the most widespread throughout the region, as evidence of its development can be found in all districts.
- **Adobe Brick:** emerged after *quincha* homes. However, according to local testimonies, they did not replace *quincha* construction but rather offered an additional option at the time. The bricks were made from a mixture of mud and straw (sometimes sand in coastal or river areas). These bricks were molded and dried in the sun for several days or weeks. In some communities, artisanal kilns were built to fire the bricks, a process that increased their durability and resistance to moisture. While less common than sundrying, this method was particularly useful in regions with higher rainfall or where greater structural longevity was desired.
- **Vegetal Housing:** as its name suggests, is constructed entirely from materials sourced from the endemic vegetation of the region. The first type, which could be considered the most widespread, was the "penca" house, characterized by a roof made of dry palm leaves and walls made from bamboo or wood. The second type developed in more specific areas, such as the Santa Fe region, where "caña blanca" houses are found, easily recognizable by their yellowish cane walls

2.3. Scope information

The study was conducted in five districts of the province of Veraguas (Calobre, Cañazas, La Mesa, Santa Fe, and Santiago), as well as in the Ñürün region of the Ngäbe Buglé Comarca, with the aim of collecting verifiable data to build a robust inventory. A total of 30 structures that met the research criteria were analysed and included in the catalog.

These structures were selected based on their state of conservation, physical characteristics, and application of traditional construction techniques and typologies. From them, valuable information was gathered regarding the history of the dwellings, year of construction, information about the builders, ownership, alterations to traditional systems, organizational layout, and basic dimensions of the structures. This information ultimately served as the backbone of the research.

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2.4. Collection tools

The data collected in the inventory were initially organized in form-type tables, with an individual sheet assigned to each documented dwelling. These tables contained detailed information about architectural characteristics, construction materials, state of conservation, and other relevant aspects (Tables 1–5).

Subsequently, the data were transferred to the QGIS software, where a digital table linked to a georeferenced map was created.

This structure allowed for the correlation of the location of each dwelling with the inventory information, facilitating the interpretation of architectural distribution patterns in the study area.

Table 1 – *Calobre Distric* (Aponte, 2022).

Number	District	Subdistrict	Current Use	Previous Use	Date	Status	Typology
V-C-0001	Calobre	La Raya	Storage	Dwelling	1932	Fair	Quincha
V-C-0002	Calobre	La Raya	Dwelling	Dwelling	1947	Good	Quincha
V-C-0003	Calobre	La Raya	None	Dwelling	1940	Poor	Quincha
V-C-0004	Calobre	La Raya	Storage	Dwelling	1972	Good	Quincha
V-C-0005	Calobre	La Raya	Storage	Dwelling	1970	Poor	Quincha
V-C-0006	Calobre	La Raya	Storage	Dwelling	1892	Good	Quincha

Table 2 – *Cañazas District* (Aponte, 2022).

Number	District	Subdistrict	Current Use	Previous Use	Date	Status	Typology
VCZ0001	Cañazas	San Marcelo	None	Dwelling	1987	Poor	Quincha
VCZ0002	Cañazas	San Marcelo	Kitchen	Kitchen	1970	Good	Quincha
VCZ0003	Cañazas	San Marcelo	Dwelling	Dwelling	2002	Poor	Wood
VCZ0004	Cañazas	San Marcelo	Dwelling	Dwelling	1980	Fair	Adobe Bricks
VCZ0005	Cañazas	San Marcelo	Kitchen	Dwelling	2012	Good	Quincha
VCZ0006	Cañazas	San Marcelo	Dwelling	Kitchen	1955	Excellent	Adobe Bricks
VCZ0007	Cañazas	San Marcelo	Dwelling	Dwelling	1963	Excellent	Adobe Bricks

Table 3 – *La Mesa District* (Aponte, 2022).

Number	District	Subdistrict	Current Use	Previous Use	Date	Status	Typology
V-LM-0001	La Mesa	Bisvalle	Dwelling	Dwelling	1944	Good	Quincha
V-LM-0002	La Mesa	Bisvalle	Dwelling	Dwelling	2018	Good	Vegetal
V-LM-0003	La Mesa	La Mesa	Storage	Dwelling	1939	Fair	Quincha
V-LM-0004	La Mesa	La Mesa	Dwelling	Dwelling	1967	Fair	Adobe Bricks
V-LM-0005	La Mesa	La Mesa	Dwelling	Dwelling	1971	Good	Quincha
V-LM-0006	La Mesa	La Mesa	Storage	Dwelling	1970	Poor	Plastered Quincha
V-LM-0007	La Mesa	La Mesa	Dwelling	Dwelling	1942	Good	Adobe Bricks
V-LM-0008	La Mesa	La Mesa	Rental	Dwelling	1987	Fair	Plastered Quincha
V-LM-0009	La Mesa	La Mesa	Dwelling	Dwelling	1992	Good	Plastered Quincha
V-LM-0010	La Mesa	La Mesa	Dwelling	Dwelling	1987	Excellent	Quincha
V-LM-0011	La Mesa	San Bartolo	Storage	Dwelling	1982	Excellent	Quincha

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Table 4 – *Santa Fe District* (Aponte, 2022).

Number	District	Subdistrict	Current Use	Previous Use	Date	Status	Typology
V-SF-0001	Santa Fe	Santa Fe	Vacation	Dwelling	1992	Excellent	White Cane and Wood
V-SF-0002	Santa Fe	Santa Fe	Dwelling	Dwelling	1970	Poor	White Cane and Wood
V-SF-0003	Santa Fe	Santa Fe	Dwelling	Dwelling	1990	Excellent	White Cane and Wood
V-SF-0004	Santa Fe	Santa Fe	Hostel	Dwelling	1982	Excellent	White Cane and Wood

Table 5 – *Santiago District* (Aponte, 2022).

Number	District	Subdistrict	Current Use	Previous Use	Date	Status	Typology
V-S-0001	Santiago	Santiago	Dwelling	Dwelling	1907	Poor	Quincha and Blocks

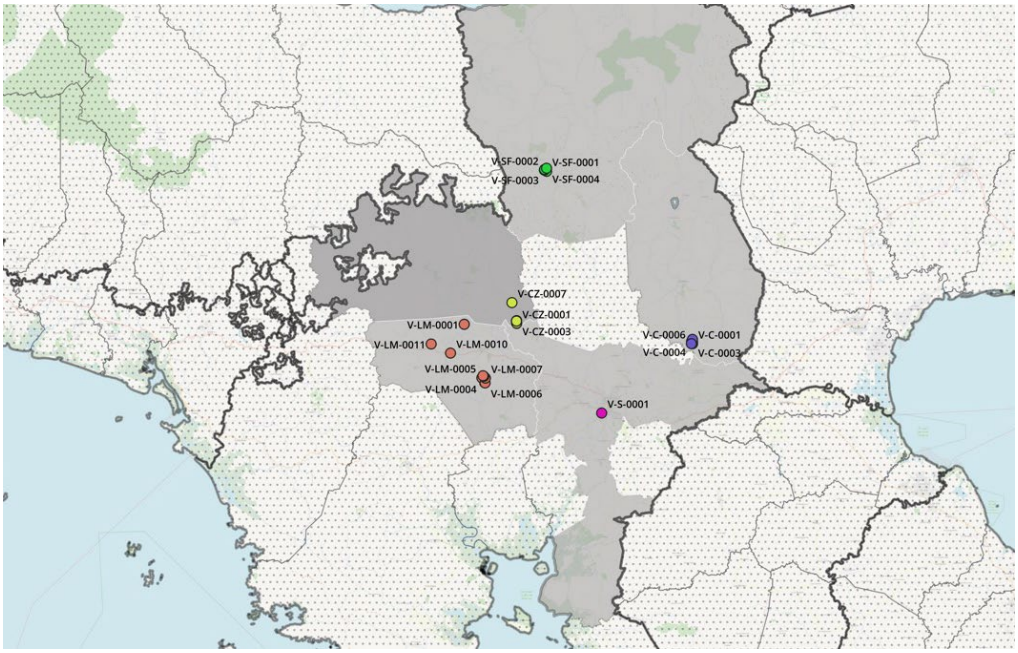

Fig. 2 – *General Location of the Inventoried Dwellings* (Aponte, 2022).

3. Inventory results

3.1. Calobre district

As part of the study conducted in the Calobre district, located in the northeastern part of the Veraguas province, a technical visit was carried out to the "La Raya" Subdistrict on March 12, 2022. During this inspection, 6 buildings were identified that met the criteria.

The following sheet summarizes some of the data collected (Table 1).

- All are built using *quincha*, are over 50 years old, and were originally residential buildings. Now, due to lack of maintenance, they are used as storage.
- Only one remains a dwelling thanks to constant maintenance. The others are used sporadically.

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- Some structures are well preserved, showcasing original techniques. The front columns are wooden trunks spaced 3.40 meters apart with a height of 2.60 meters.

Fig. 3 – *Map Enlargement 1: "La Raya" Subdistrict* (Aponte, 2022).

Fig. 4 – *Dwellings V-C-0006 and V-C-0005* (Aponte, 2022).

3.2. Cañaza district

The Cañaza district is located in the northwestern region of the Veraguas province. During the fieldwork, a visit was made to the “San Marcelo” Subdistrict, where 7 buildings were identified that met the necessary technical and heritage criteria to be included in the inventory. These structures displayed relevant construction characteristics, making them subjects of study and documentation within the context of the built heritage of the area.

Fig. 5 – *Map Enlargement 3: "San Marcelo" Subdistrict* (Aponte, 2022).

Fig. 6 – *Dwelling V-CZ-0004 and V-CZ-0005* (Aponte, 2022).

The following sheet summarizes some of the data collected (Table 2).

- Adobe brick construction is the most common in the area. The buildings range from 10 to 52 years old.
- Most of the structures remain in use and are in very good condition.
- Traces of the earth ovens used in the past to make bricks are still preserved in the ravines.
- The adobe bricks have a standard size of 0.30 x 0.10 meters and are made with earth, horse manure, and straw.
- Dwellings have small porches that cover half the width of the building and do not protrude from it.
- The average height of the buildings is approximately 2.50 meters.

3.3. La Mesa district

The La Mesa district, located in the center of the Veraguas province, included the Subdistrict of “La Mesa Cabecera”, “San Bartolo”, and “Bisvalle” in the study. In these areas, a total of 11 buildings were identified that met the necessary criteria to be included in the inventory, providing relevant data for the research.

The following sheet summarizes some of the data collected (Table 3).

- Adobe construction is the most common in the area, with buildings ranging from 10 to 52 years old.

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- Most of the buildings are still in use and in good condition, demonstrating the durability of these structures.
- Traces of earth ovens used to make bricks are preserved, along with knowledge of this construction technique.
- Some dwellings, plastered with cement, have remained standing for over 35 years.
- Height of the dwellings: 2.74 meters.
- Average portal width: 2.30 meters, with a length equivalent to half the size of the dwelling.

Fig. 7 – *Map Enlargement 4: "La Mesa" Subdistrict* (Aponte, 2022).

Fig. 8– *Map Enlargement 3: "Bisvalle" Subdistrict* (Aponte, 2022).

Fig. 9 – *Dwelling V-LM-0009 and V-LM-0008* (Aponte, 2022).

3.4. Santa Fe district

In the Santa Fe district, located to the north of the Veraguas province, 4 buildings were identified that met the necessary criteria to be included in the inventory, providing relevant data for the inventory.

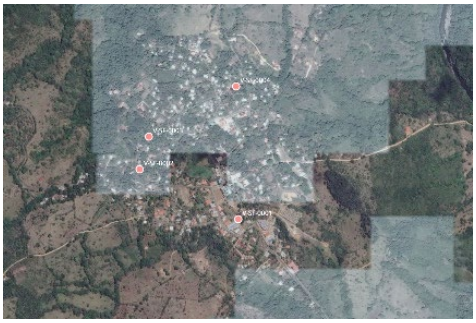

Fig. 10 – Map Enlargement 5: "Santa Fe" Subdistrict (Aponte, 2022).

Fig. 11 – Dwelling V-SF-0001 and V-SF-0002 (Aponte, 2022).

The following sheet summarizes some of the data collected (Table 4).

- The buildings are primarily constructed with white cane and wood, with over 37 years of age.
- They remain in good condition, especially those that have been varnished. It is common to replace the white cane every 20 years, which explains the presence of recent renovations.
- Their height is 2.40 meters, with two story dwellings and sloped roofs reaching 8.00 meters.
- Portal width ranges from 2.00 to 1.90 meters.

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3.5. Santiago district

The Santiago district, located in the center of Veraguas, included the study of the "Santiago Cabecera" Subdistrict. In this area, only one building was identified that survived and met the necessary criteria for inclusion in the inventory.

Fig. 12 – *Map Enlargement 6: "Santiago" Subdistrict* (Aponte, 2022).

Fig. 13 – *Dwelling V-S-0001* (Aponte, 2022).

The following sheet summarizes some of the data collected (Table 5).

- The dwelling partially preserved its original roof and facade, although most of it was replaced with conventional construction (concrete blocks and metal beams).
- Some original tiles from the roof were still in place.
- Width: 1.20 meters, with a length equal to that of the dwelling.
- The dwelling was in poor condition, with a risk of collapse. Although a recovery plan was made, it was not executed, and the house was demolished at the beginning of 2023.

4. Conclusions

The data collected in this inventory were fundamental for the research, serving as the foundation for the arguments presented and the design proposal. Additionally, this information will be used in the VIP-01-03-04-2017-05 project, "Urbanism and Traditional Architecture of Panama," which aims to highlight and disseminate the values of traditional Panamanian architecture through an updated study.

The inventory documented 30 dwellings: 1 in the Ngäbe-Buglé comarca and 29 in Veraguas. Of these, 17 were of *quincha* construction, 6 of vegetal type (white cane and palm), and 6 of adobe bricks. This work contributes to the preservation and promotion of traditional architectural heritage.

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The Footprint of Earthen Architecture: Digital, Open-access Library of Earthen Building Cultures

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Topic: T2.1. Study and cataloguing of earthen architecture

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Abstract

This study embarks on a journey to document earthen architecture by constructing a digital library that intertwines the tale of earth-based building systems with human history. Through examples of ancient and contemporary earthen architecture from around the world, this library seeks to catalogue and preserve the cultural and ecological value of these materials and methods, echoing thousands of years of sustainable building practices and cultural resilience. Each project included is profiled with the following characteristics: name of the structure, author(s), year(s) constructed, location, construction system, and architectural typology. This data is then contextualized with additional layers of information like edaphology, rainwater precipitation, wind speed, and maximum temperature. We chart a living, breathing narrative of earth. This process is supported by research from a variety of sources, including academic publications, books, online resources, and social media platforms. The data is then compiled into an Excel database and added into a Geographical Information Systems software (QGIS) to eventually be poured into an open-access website. This platform will, in addition to being a repository for catalogued projects, provide a space for architects around the globe to contribute and add to the data, thus encouraging global collaboration on the ongoing project of the digital preservation of cultural heritage. The digital library is presented as a visual and academic research tool, mapping the historical trace of soil as a building material, from its earliest practices to its various contemporary usages. This reinforces the forever present relevance of earthen architecture and how it stands against modern challenges, offering a sustainable design model that is aware of its context and is adaptive towards the future.

Keywords: *building cultures; digital library; preservation; earthen architecture; QGIS*

1. Introduction

This project is part of the activities carried out at ITESO, the Jesuit University of Guadalajara, Mexico, within the framework of the UNESCO Chair on Earthen Architecture, Constructive Cultures, and Sustainable Development. Its purpose is to contribute to the initiative of facilitating the exchange and transfer of knowledge and the know-how in earthen construction (UNESCO, n.d.).

Aligned with UNESCO's efforts, which established the World Heritage Earthen Architecture Programme (WHEAP) in 2007 with

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the aim of conserving and managing earthen construction sites, a world heritage inventory of earthen architecture was published in 2012 revealing that 150 World Heritage sites have been classified as earthen architecture (Gandreau & Delboy, 2012). Thus, it seems relevant to seek their digital preservation by innovating a system consisting of an online repertoire of earthen architecture aided by GIS.

Earthen architecture is a tangible expression of the intrinsic relationship between humanity and its environment (Figueiredo et al., 2011). From the earliest civilizations to contemporary societies, earth has served as an essential building material, adapting to diverse climatic conditions and cultural contexts. As such, additional to the cataloguing of the world heritage earthen architecture sites, we are including in the digital library examples of other ancient earth-based building remains that still exist. Even if one of the buildings that was found doesn't exist anymore, we are proposing they still form part of this project as a piece of history that we are aiming to digitally preserve. This way, our library can become a digital testimony of past and present earthen cultural landscapes.

We are promoting the digital preservation of earthen architecture by documenting it through a global chronology that intertwines geolocation with climatic and environmental factors. By showcasing examples of ancient and contemporary buildings from around the world, this work seeks to classify and preserve the cultural and ecological value of these materials and techniques, reflecting centuries of sustainable use and relevance both in their original context and today.

This is an invitation to observe the past within the present and envision the future of a sustainable and adaptive habitat unique to each society and culture. The research culminated with a digital library made using GIS tools and published online into an open-access website.

2. Objective

The goal is to recover, systematize, and disseminate knowledge on earthen architecture through the creation of a globally accessible and collaborative digital library. By documenting and classifying architectural projects constructed using earthen techniques throughout history, a framework contextualizing their location, evolution, impact, and relevance is established.

This effort aims to demonstrate how numerous construction solutions developed by ancient civilizations (refined over centuries or even millennia) remain relevant today. The resulting database will serve as a tool for architects, educators, researchers, and builders, promoting a responsible design model that integrates traditional knowledge with technological innovations to foster more sustainable development.

The preservation and dissemination of this knowledge will facilitate its incorporation into contemporary architecture, contributing to a future built upon principles of sustainability, efficiency, and cultural resilience.

3. Methodology

The research relies on various sources of information available, at first, within the immediate context of ITESO University in Mexico, including academic publications, books, online resources, and social media platforms. The data was collected and manipulated in Spanish over six distinct phases:

3.1. Compilation of an individual technical data sheet per project

The first step consisted of identifying within the bibliography architectural projects or construction examples built with earth. The information obtained from the bibliography was filtered, classified, and ordered into technical data sheets containing relevant data from each project (Fig.1). The resulting data sheets were captured in a Word document.

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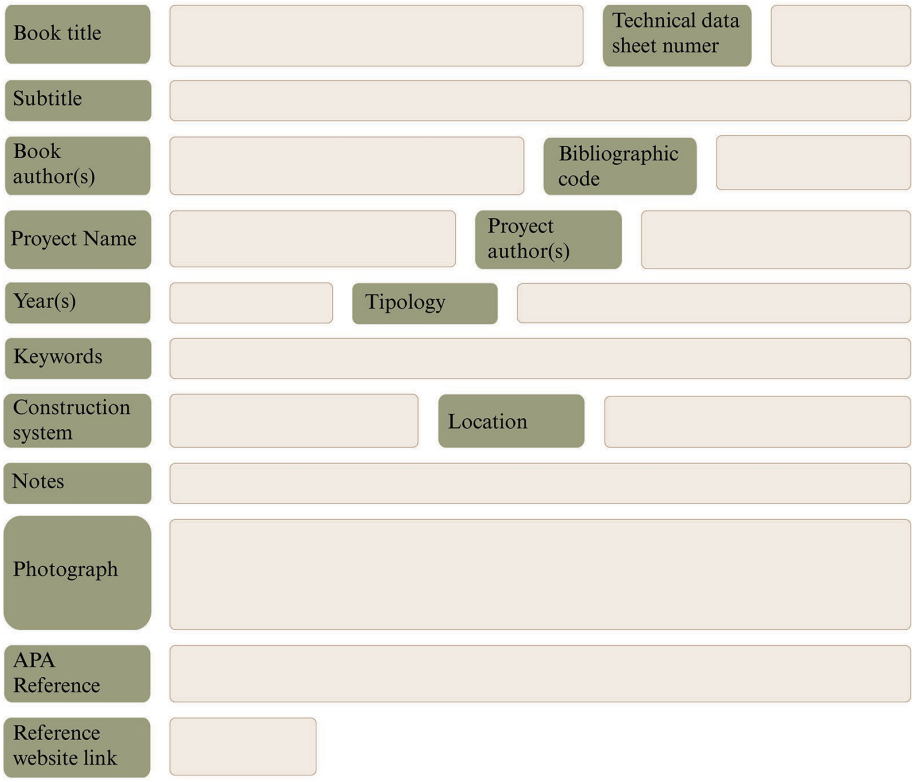

Fig. 1 – *Technical Data Sheet per project* (Authors, 2025).

The data collected included the fields visible in Figure 1. It's worth noting that for the field of "year" the active building period of a structure was used, not the structure's lifetime. Additionally, for "typology", five possible categories were used to catalogue each project: residential, public space, urban amenities, religious, and ceremonious/worship spaces. If a specific example requires so, multiple concepts are used at a time, as is the case for Paquimé (Table 1).

3.2. Initial Excel database

During the second phase the information from the technical data sheets was entered into an initial Excel database (Table 1). It became necessary to have a filtered lecture of the compiled information from all the projects spanning from 10,000 BCE to 2025. At this point, the database consisted of around 350 projects. By project, we are referring to an individual example of earthen architecture. At times, an entire city was mentioned as a single project since we're talking about an encompassed archetype or earthen-construction tradition. For example, the city of Teotihuacán (Correia, 2016) is its own general example. If within those cities mentioned above an individual structure differed from its context by importance, building type, construction technique, or similar, it was input as a separate project. For example, the pyramids of El Sol and La Luna from the city of Teotihuacán were added as their own individual project due to their relevance and change in construction techniques/materials compared to the rest of the city.

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Table 1 – *Initial Database* (Authors, 2024)

TDS #	**15**
Book title	Arquitectura de tierra en América Latina
Subtitle	Patrimonio Mundial en México
Bibliographic code	720.980 ARQ
Book author	Correia, M. (2016)
Keywords	Patrimonio Mundial, Mesoamérica
Project name	Paquimé
Project author (s)	Cultura Paquimé de Casas Grandes
Year(s)	1200 - 1450 d.C.
Location	Chihuahua, México
Construction system	Tierra moldeada, densificada y alisada
Typology	Habitacional, Ceremonia/ Culto, Equipamiento, Servicios
Notes	Único sitio dentro de la Lista de Patrimonio Mundial de México realizado completamente con tierra.
Photo	NA
APA Reference	Correia, M. (2016). Arquitectura de tierra en América Latina. Lisboa, Portugal: Red Iberoamericana Proterra, Argumentum.
Reference website link	NA

3.3. Filtering and synthesis

For this stage the information from the initial database was filtered and synthesized to create the database needed for importing into QGIS (Fig. 2). The number assigned to each technical data sheet became each project's ID number and a shift from using book photographs to custom illustrations was needed. Other fields of information that were added were references to external links and the identification of coordinates per project, including their longitude and latitude.

3.4. QGIS database

For this step the resulting database from the last phase was linked to QGIS so that each earthen architecture project could become a point containing XY coordinates derived from the longitude and latitude values given in the database. Each point contains the information included in the QGIS Excel database for said project as well as its illustration in the form of a reference link. In parallel, open-access digital maps were added as layers containing historical data of 1) maximum temperature, 2) edaphology, 3) wind speed, and 4) rainwater precipitation around the world (Fig.3). With these layers of information, we seek to understand and explain the chosen construction system, materials and form for each project throughout history as a codependent entity, and the direct result of, its bioclimatic natural context.

3.5. Digital library

For the fifth stage the digital library was posted as a QGIS file to ITESO University's server (an open-access website). This file contains the geolocated earthen architecture projects with their data, illustration and the previously mentioned overlayers of bioclimatic information integrating historical data per location (Fig. 4).

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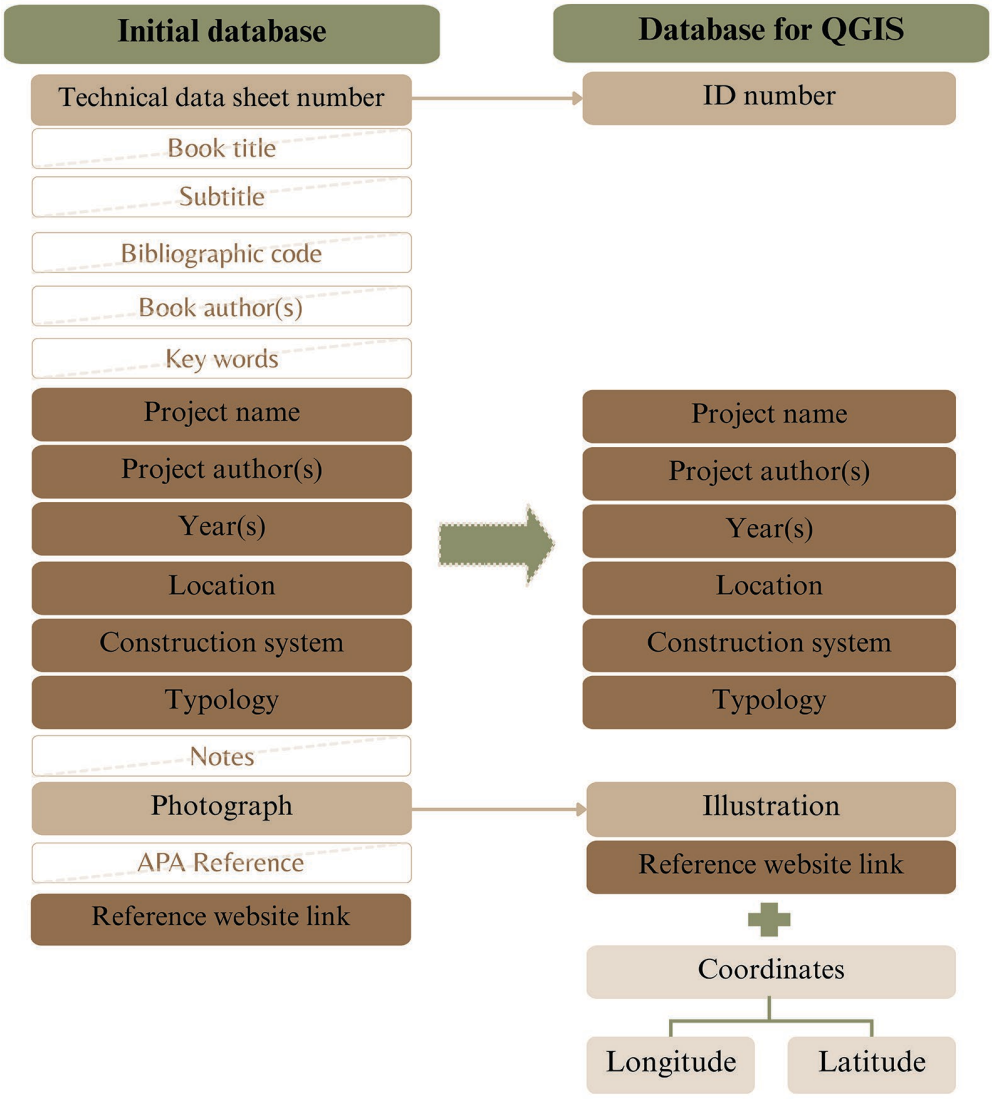

Fig. 2 – *Database transition for QGIS* (Authors, 2025).

3.6. Outsourcing of information.

The next step for the digital library is to transform it into a more graphic and visually attractive tool. We aim to develop an interactive narrative map using QGIS and post it on the internet as its own website. This way, we would be documenting, recovering, systematizing, and communicating earthen architectural knowledge in a more approachable way. It would be a free, adaptable tool useful in geographically narrating these processes using a technical and pedagogical approach. After these six phases, the internal processing of information is completed and now the opportunity arises to continue enriching the project in the form of external collaborations.

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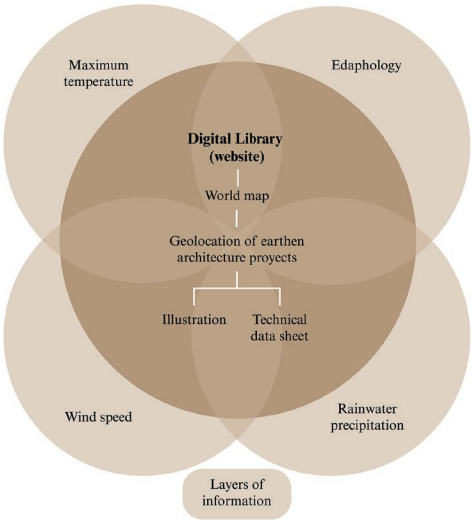

Fig. 3 – *Digital library* (Self-made creation, 2025).

4. Findings

The digital library of earthen cultural landscapes not only allows project localization accompanied by additional variables (mentioned in the methodology), but it also demonstrates how architectural works respond to their environment.

It reveals the existence of an adaptive habitat where earthen architecture embodies the tangible balance between traditional knowledge and the specific conditions of each region (Dethier, 2019).

A bidirectional link with the timeline is established, thus enabling analyses between historical context and bioclimatic conditions.

This georeferenced framework reveals that earthen construction methods not only emerge as technical solutions but also as expressions of environmental circumstances acting jointly with cultural elements.

Across all five continents, these architectural expressions appear at different periods as human responses to their surroundings (CRAterre, n.d.), adapting to the limitations and possibilities of their time, soil conditions, and region. Despite climatic variations, earthen architecture is present in most countries worldwide.

The Footprint of Earthen Architecture was initially conceived as a database that was then transformed into an interactive, narrative map and posted to an open-access platform through QGIS onto ITESO's server.

Our digital library is not merely a data repository but a living testament to the relationship between humanity and the earth tool for rediscovering, preserving, and projecting knowledge towards a future where sustainable construction is a conscious practice rooted in history.

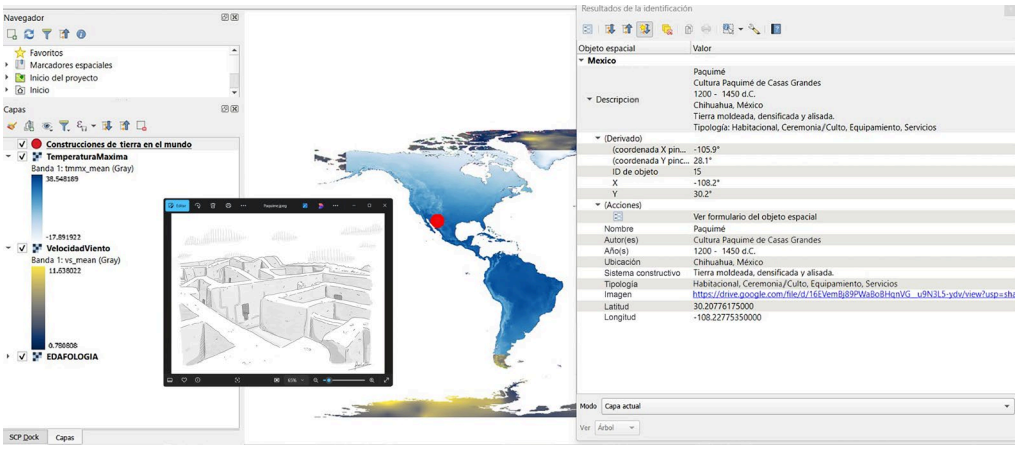

Fig. 4 – *Integration of information in QGIS* (Authors, 2025).

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5. Conclusions

This project transcends mere documentation to become a comprehensive resource for research, education, and dissemination. Earthen architecture, far from being a relic of the past, is a testament to adaptation and sustainability, whose principles remain relevant in contemporary construction. We are providing access to extensive knowledge serving as a constructive reference aligned with history and the environment.

Beyond its value as a historical archive and academic resource, this study lays the foundation for future projects as a manual on earthen construction. It compiles principles and techniques according to specific climatic and socio-cultural conditions, essential for the application of earthen building practices. This way, the project becomes a historical record book narrating the evolution of earthen architecture over the centuries all the way into modern times.

The Footprint of Earthen Architecture encourages the recovery, documentation, and cataloguing of earthen architecture and earth-based building systems through their digital preservation. This information is relevant to both past and future generations since we are ensuring that, through ancestral knowledge and techniques, future architects can define earth as not only a building material, but also a living legacy of resilience, identity, and harmony with the environment. Subsequent research articles could delve into the significance, challenges, and potential of earthen architecture today.

6. Future outlook

The project is anticipated to be a medium-to-long-term endeavor. Currently, we foresee two key aspects requiring future consideration:

1. We intend for the digital library to have a friendlier, more approachable format for the public. As such, we are proposing the creation of a website. We would use QGIS as the base platform and the qgis2web plugin to export an interactive version of the map that could be accessed from any browser without the need for additional software. It is a free, adaptable, and very useful tool for narrating these processes territorially from both a technical and pedagogical perspective.
2. At this time, we have around 800 examples in our database. We are seeking to expand and add new projects through collaborators from around the world. Each contributor would retain authorship of the information they upload (authorship must be verified) and filters for data verification and revision would be added. Collective contributions would enrich the project and ensure appropriate cataloguing of earthen architecture's history.

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The Role of the Terra Conferences in Promoting and Conserving Vernacular Earthen Architecture

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Abstract

Vernacular earthen heritage is deeply embedded in the landscapes and cultural traditions of the communities that build and inhabit these structures. Made from locally sourced materials and constructed using local techniques, these buildings embody sustainability, adaptability, and cultural identity. While formal recognition within international frameworks gained prominence with the ICOMOS Charter on the Built Vernacular Heritage in the early 2000s, discussions on vernacular earthen heritage in urban and agricultural settlement have been present throughout the Terra conferences since their inception in 1972. These events have played a key role in shaping discussions around vernacular earthen heritage, advocating for its conservation, and emphasizing the importance of integrating traditional knowledge with modern preservation strategies. As part of its broader objective to assess trends and gaps in earthen heritage conservation and inform future strategic directions, the Getty Conservation Institute (GCI), through its Earthen Architecture Initiative (EAI), conducted a comprehensive review of 636 papers presented at Terra conferences. This study examined the evolution of research and practice in the field, with vernacular earthen heritage representing just one of many key themes. Building on this extensive review, this paper specifically analyses how vernacular earthen heritage has been represented in Terra conference discourse over time. Through a systematic examination of relevant papers, it identifies conservation challenges, maps the geographic regions where this heritage has been most studied, and assesses evolving strategies for its protection. Additionally, it highlights how the Terra conferences have contributed to raising awareness about vernacular heritage, fostering community participation in conservation efforts, and supporting the revitalization of historic earthen rural and urban centers.

Keywords: *vernacular heritage; Terra conferences; earthen heritage conservation; systematic analysis*

1. Introduction

Vernacular heritage, rooted in cultural, environmental, and historical traditions, expresses the identity of communities worldwide. Among its forms, earthen heritage holds a central place, as earth is a widely available and locally sourced material that showcases community ingenuity (Houben & Guillaud, 1994) while representing some of the most vulnerable and overlooked heritage assets. These forms have often been marginalized within mainstream heritage conservation discourse.

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Carlos et al. (2022) examined the limited recognition of vernacular earthen heritage within international frameworks, noting that conservation efforts traditionally prioritized monumental or archaeologically significant structures. Influential early works, such as Bernard Rudofsky's *Architecture Without Architects* (1964), and scholars like Paul Oliver, brought greater visibility to the cultural and environmental significance of traditional construction practices, including earthen techniques (Vellinga, 2014). However, heritage conservation efforts often overlooked vernacular forms that did not align with conventional criteria for Outstanding Universal Value (Correia et al., 2014). This selective focus led to a conceptual gap, where many historically and culturally significant vernacular structures received less attention compared to more prominent architectural landmarks.

Efforts to address this disparity have been directed by documents such as the Charter on the Built Vernacular Heritage (1999), which underscores the importance of vernacular buildings as living expressions of cultural diversity and community identity (ICOMOS, 1999). The Charter advocates for the involvement of local communities in the conservation process, recognizing that the significance of vernacular heritage lies in its continuous use and adaptation. It also emphasizes that vernacular architecture should not be viewed in isolation but as part of an integrated cultural landscape, reflecting the dynamic interplay between people, their environment, and their built forms.

This Charter was one of the products of the work of the International Scientific Committee on Vernacular Architecture (CIAV) established under ICOMOS in 1979 (Machat, 2001). CIAV plays a crucial role in advancing the study, documentation, and protection of vernacular heritage globally.

The VerSus project and its continuation VerSus+ / Heritage for PEOPLE further advanced the recognition of vernacular architecture by identifying sustainable design strategies rooted in traditional practices (Mileto et al., 2020). Expanding on the principles established by VerSus, VerSus+ emphasizes the transmission of vernacular knowledge to broader society, demonstrating how historical construction methods, and earthen techniques, can inform contemporary sustainable architecture.

Despite these advancements, vernacular architecture, especially made with earthen materials, remains vulnerable to threats such as urbanization, economic pressures, and environmental changes. The integration of vernacular architecture into mainstream heritage discourse continues to evolve, driven by a growing acknowledgment of its role in sustaining cultural identities and promoting sustainable development practices (Vegas et al. 2022).

The purpose of this paper is to explore the role of the Terra Conference proceedings in promoting vernacular earthen heritage. By examining the published proceedings of these conferences, this paper aims to establish how they have influenced recognition, conservation strategies, and academic discourse surrounding vernacular heritage.

2. The evolution of the Terra conferences

The Terra conference series has played a pivotal role in advancing the study and conservation of earthen heritage, fostering a global exchange among researchers, practitioners, and policymakers (Cancino 2022). The first symposia, held in Yazd, Iran, in the 1970s, laid the foundation for future discussions, focusing on both material preservation and the cultural value of earthen architecture. Kassai (1972), in his study presented at the First Colloquium on Mudbrick Conservation, classified Iranian earthen monuments into two categories: isolated monuments and living monuments integrated into the urban fabric. While his classification

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emphasized the monumental value of these structures, it also introduced the concept that vernacular settlements play a crucial role in the longevity and functionality of earthen heritage. This perspective reinforced the need to maintain traditional knowledge and ensure the active use of historic structures.

As the Terra gathering gained momentum, they became increasingly interdisciplinary and geographically diverse. The 4th International Symposium in Peru (1983) further emphasized the intersection between vernacular and earthen heritage, by integrating discussions on traditional knowledge, adaptive reuse, and conservation strategies (Argumedo, 1980). By the 1990s and early 2000s, the conferences broadened their scope, officially introducing the term “Terra” in 1993, reflecting a more comprehensive understanding of earthen architecture and its cultural significance worldwide.

Over time, the Terra events continued to evolve, addressing urgent conservation challenges such as sustainability, climate resilience, and community engagement. The 2008 conference in Mali, the first to be held in Africa, focused on intangible practices and living heritage, recognizing the social and cultural dimensions of conservation. Similarly, Terra 2012 in Peru emphasized the growing threat of climate change to earthen structures, fostering discussions on disaster risk management and environmental adaptation strategies. The rebranding of Terra 2016 in Lyon as a "World Congress" reflected the increasing scale and influence of these gatherings, reinforcing their role as a leading platform for international earthen heritage discourse. The most recent conference, Terra 2022 in Santa Fe, New Mexico, brought renewed attention to community-based conservation, emphasizing the need to integrate local communities into preservation efforts. This event reinforced the idea that vernacular heritage must remain a living tradition, sustained through active participation, education, and knowledge-sharing between practitioners and local stakeholders.

3. Methodology

This study systematically examines the representation and evolving discourse on vernacular earthen architecture within the Terra events. While 636 papers have been published across 13 Terra proceedings, only 98 specifically address vernacular earthen architecture (approximately 15%). This subset was analysed to identify key trends in research and conservation efforts, focusing on four primary aspects: the geographic distribution of studies, the predominant construction techniques documented, the research methodologies applied, and the conservation interventions proposed. By evaluating these elements, the study aims to assess how vernacular earthen heritage has been approached over time and how conservation priorities have evolved.

The research framework was developed using a structured set of criteria for comparative analysis, drawing on the approach established by Matero and Cancino in their study of earlier Terra conferences (Matero et al, 2000). Their research examined shifts in archaeological and general conservation, revealing changes in focus, methodologies, and regional representation over time. Expanding on their methodology, this study applies selected criteria to evaluate past and current concerns in vernacular earthen architecture conservation, enabling a comparison of research directions and highlighting emerging trends.

The first stage of analysis categorized the 98 papers based on their geographic focus, identifying regions where vernacular earthen architecture has been most studied and highlighting research gaps. The second stage examined the construction techniques documented in each study, capturing a range of traditional building methods such as adobe, rammed earth, cob, wattle and daub, and various earth finishing techniques. Understanding these methods provided, insight into how conservation strategies have been adapted to different materials and

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regional contexts. The analysis then explored the primary causes of deterioration, which included environmental factors, natural hazards, urban expansion, abandonment, biological threats, and structural weaknesses. Additionally, the loss of local and traditional knowledge surrounding conservation practices and maintenance emerged as a key factor contributing to the decline of vernacular earthen structures. The final stage assessed the conservation interventions proposed in the studies, reviewing efforts related to documentation, structural stabilization, material treatments, educational initiatives, and policy development.

To ensure consistency and accuracy, the classification process aligned with the terminology and themes present in the original papers. The dataset was normalized to account for variations in the number of papers presented at different Terra conferences, enabling proportional representation and facilitating trend analysis. Since many papers addressed multiple criteria, they were classified into multiple relevant categories to retain maximum information.

4. Results and discussion

4.1. Vernacular heritage trend

Vernacular earthen heritage has been a recurring yet fluctuating theme within the Terra conferences. An analysis of the 13 proceedings reveals that the proportion of papers dedicated to vernacular heritage has varied between 0% and 30% across different editions (Fig. 1). In early events, vernacular topics were largely absent, but interest emerged during the Third International Symposium on Mud-Brick (Adobe) Preservation in Turkey with Jacques Vérité's (1980) study on the rehabilitation and adaptive reuse of North African vernacular earthen buildings, highlighting their cultural and functional relevance.

Significant attention to vernacular earthen architecture appeared at the Sixth International Conference of Earthen Architecture (Adobe 90), where 27% of papers addressed this topic. Articles from this event emphasized the historical and cultural dimensions of traditional earthen buildings and their connection to living practices and community engagement (Agnew & Taylor, 1990).

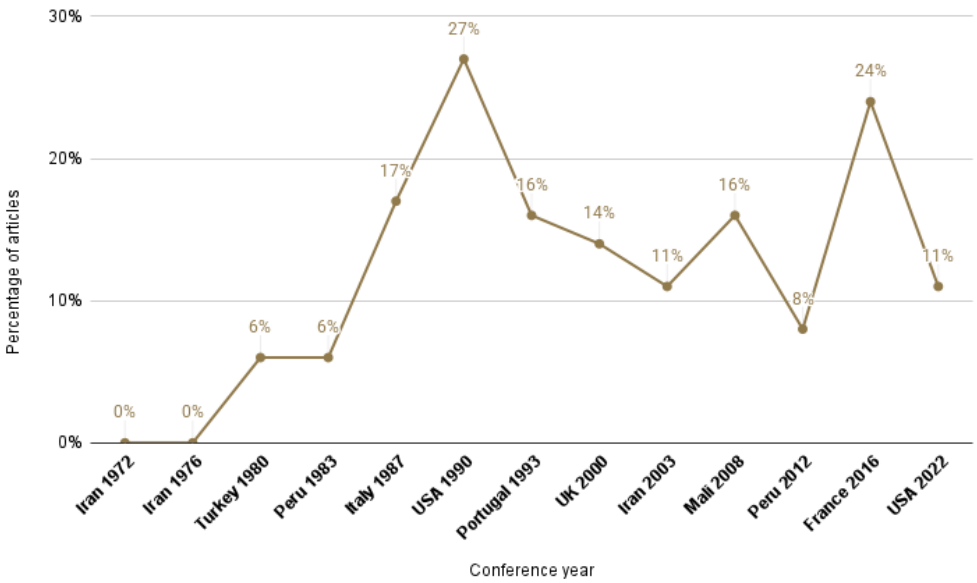

Fig. 1 – *Analysis of trends in published articles on vernacular heritage in terra proceedings.*

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The accompanying "Spectacular Vernacular" exhibition, held during the Terra event, further reinforced the recognition of vernacular traditions as dynamic cultural expressions.

This rise parallels critical developments such as the publication of CRATerre's *Traité de construction en terre* (1979) and the establishment of the GAIA training program (ICCROM, 1993), both of which were pivotal in promoting vernacular earthen traditions in conservation discourse. Following Adobe 90, vernacular-focused research declined, dropping to 11% by Terra 2003, as technical conservation and material science gained prominence. However, the Twelfth World Congress on Earthen Architecture (Lyon, 2012) saw a resurgence (24%), particularly emphasizing documentation, inventory, and traditional knowledge. Although Terra 2022 witnessed a decline to 11%, intangible heritage, cultural expressions, and traditional crafts—closely tied to vernacular practices—gained renewed attention.

4.2. Regional representation

The regional distribution of research on vernacular earthen architecture reveals a strong concentration in Europe, with 34 papers, with Italy, the United Kingdom, and Spain emerging as key contributors (Figs. 2 & 3). This reflects a well-established research tradition and institutional engagement in vernacular architecture conservation.

Africa follows with 24 papers, particularly focused on North and West African regions, where traditional earthen construction remains widespread. Asia (18 papers) shows concentrated research efforts in India and West Asian countries, while Central and South America (17 papers) demonstrate strong engagement, especially in Argentina, Brazil, and Peru. The presence in the region of organizations like PROTERRA (the Ibero-American Network of Earthen Architecture and Construction) and the SIACOT conference series has played a pivotal role in fostering academic discussions, promoting scientific projects, and advancing global knowledge dissemination on vernacular earthen heritage.

In contrast, North America has only 5 papers, indicating limited research activity in this field, while Oceania is entirely absent from the dataset. This highlights the influence of conference host locations in shaping research priorities, as well as the need for broader research collaborations, increased funding, and greater representation of underexplored regions to ensure a more comprehensive and globally inclusive understanding of vernacular earthen architecture.

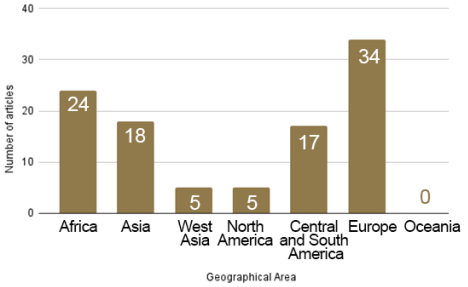

Fig. 2 – *Number of studies on vernacular heritage conducted across various geographical areas.*

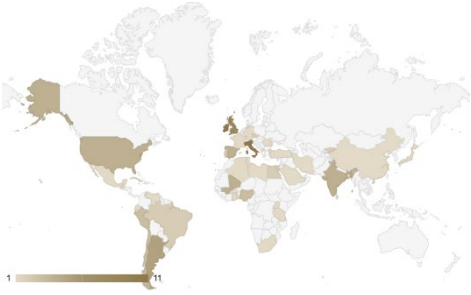

Fig. 3 – *Number of studies on vernacular heritage conducted across various countries.*

4.3. Type of construction

The distribution of construction techniques across the Terra proceedings highlights the evolving scope of vernacular earthen architecture studies. Adobe (earth-block) remains the most studied technique, accounting for 35.7%, as early conferences primarily

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focused on this form of construction (Fig. 4). However, as research progressed, a broader range of construction techniques gained recognition. Initially, discussions centered on mud brick and adobe conservation, but by the Rome 1987 meeting, the term "earthen architecture" was introduced to encompass a more diverse array of building traditions. Rammed earth (18.6%), wattle-and-daub (15.5%), and cob (12.4%) emerged as significant areas of study, reflecting regional variations in earthen architecture. Interest in earthen finishing techniques (11.6%) also grew, emphasizing the focus in the majority of conferences of surface treatments and conservation methods, while the remaining 3.9% encompasses less common or hybrid techniques.

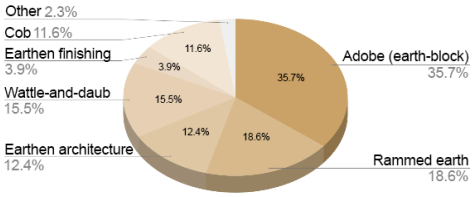

Fig. 4 – *Analysis of constructive techniques across all the Terra proceedings*.

4.4. Causes of decay

The analysis of all articles identifies environmental decay (17.5%) and natural hazards (17.5%) as the leading causes of deterioration affecting vernacular earthen structures (Fig. 5). These findings highlight the inherent vulnerability of such buildings to erosion, moisture infiltration, seismic activity, and extreme weather events, emphasizing the ongoing challenges in their preservation and resilience against climate-related threats. Disuse and abandonment (15.8%) also play a significant role, as neglected structures deteriorate rapidly without regular maintenance. Additionally, urban development (12.3%) threatens vernacular architecture through infrastructure expansion, modernization, and the replacement of traditional structures with contemporary materials.

Emerging challenges are also evident in the chart, particularly the loss of local knowledge (7.0%) and inadequate material interventions (3.5%), both of which highlight a decline in traditional construction skills, maintenance practices, and community awareness. The weakening of intergenerational knowledge transfer results in improper conservation approaches that may not align with the structural and cultural needs of earthen buildings. Climate change (12.3%) further exacerbates deterioration, with rising temperatures, extreme weather patterns, and shifting environmental conditions accelerating structural instability. Additional contributing factors include biological hazards (5.3%), such as pests and vegetation growth, material and structural defects (5.3%), and man-made hazards (3.5%), including vandalism and inappropriate modifications.

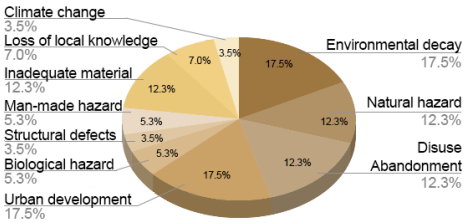

Fig. 5 – *Analysis of causes of decay across all the Terra proceedings*.

4.5. Conservation interventions

The distribution of conservation interventions and approaches applied to vernacular earthen architecture highlights documentation (33.8%) as the most prevalent strategy (Fig. 6). This underscores the importance of architectural recording for the understanding and conservation of vernacular structures.

This is followed by structural stabilization, consolidation, and monitoring (15%), which reflects the necessity of reinforcing vulnerable structures to ensure their long-term stability. Surface treatment (10%) and wall treatment (6.3%) highlight interventions focused on material protection, addressing erosion, water damage, and external deterioration.

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Education, capacity building, and training (6.3%) play a crucial role in strengthening local knowledge and technical expertise, while community involvement (7.5%) underscores the importance of participatory conservation approaches that integrate local stakeholders. Policy and regulation-based approaches, including building standards and guidelines (5%), demonstrate efforts to formalize conservation strategies. Conservation repairs and maintenance (5%), along with rehabilitation and adaptive reuse (5%), emphasize the significance of keeping earthen structures functional and integrated within their communities.

Overall, the distribution of interventions reflects a multidisciplinary approach, balancing scientific, structural, social, and policy-driven strategies to ensure the sustainable preservation of vernacular earthen heritage. The lower representation of new technology (2.5%) indicates that while scientific advancements are being explored, they have not yet become a dominant feature in vernacular conservation strategies.

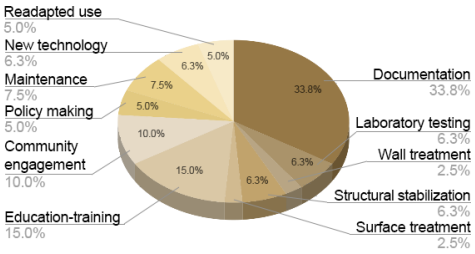

Fig. 6 – *Analysis of conservation interventions and approaches in terra conference proceedings.*

5. Conclusion

This study highlights the evolving role of the Terra conferences in advancing the discourse on vernacular earthen architecture. Since their inception, these conferences have facilitated knowledge exchange, addressed critical conservation challenges, and broadened recognition of vernacular heritage. While early symposia primarily emphasized monumental adobe structures, later events expanded their scope to incorporate diverse traditional earthen techniques and cultural contexts, reflecting a growing awareness of regional variations and sustainability. Although vernacular studies remain integral to Terra conferences, their prominence has fluctuated as thematic priorities shift toward broader issues such as disaster risk management, sustainability, and intangible heritage. This study underscores the need to reinforce vernacular architecture as a fundamental component of earthen heritage conservation, ensuring future research balances technical preservation with cultural, social, and environmental considerations.

Enhancing geographical inclusivity is essential for strengthening global engagement. Events like The Tenth International Conference on the Study and Conservation of Earthen Architectural Heritage in Mali (2008) and the AFRICA24 Conference organized by ICOMOS have played crucial roles in increasing awareness and expertise in underrepresented regions. Expanding such initiatives will encourage local scholars and practitioners to contribute to the global dialogue on earthen heritage.

Moving forward, fostering community participation, capacity building, and policy integration will be key to securing the future of vernacular architecture. By integrating traditional knowledge, promoting regional representation, and strengthening heritage policies, Terra conferences—along with other global initiatives—can continue to play a transformative role in sustainable conservation effort.

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Dynamics of Transformation in Earthen Architecture: The Case of the Region of Northwest Murcia, Spain

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Abstract
Earthen construction, widespread over time, continued until the arrival of new materials in the 20th century causing the practice was abandoned in many places. This work studies the case of the region of northwest Murcia, a place that has historically served as a transit point between the southern and eastern regions of the Iberian Peninsula. The research starts with a classification of earthen architecture into three main types: defensive, religious and residential. At this point, the methodology used is based on the parts of the facade in residential architecture, providing an overall analysis of the techniques and variants in relation to their state of conservation and the degree of modern intervention undergone. The aim is therefore to establish a diagnosis of the current situation of earthen architecture in the area based on its typological characteristics, the study of mechanisms that have favoured transformations, and the use of materials, since the disappearance as for the substantial alteration of the volume building. The global approach is the starting point for a later examination of the most representative cases.

Keywords: *rammed earth; transformation; earthen architecture; typology; Murcia*

1. Introduction

Since antiquity the region of northwest Murcia, in Spain, has been a point of passage between the south and east of the Iberian Peninsula following a secondary route of the Via Augusta (López-Mondéjar, 2013), defined in this text as the Valencia-Granada route. This area gained importance following the conquest of the territory by the Crown of Castille (1243) for its strategic position, bordering with the Nasrid Kingdom of Granada. The region is made up of five municipalities. Historically, the towns of Caravaca de la Cruz, Cehegín and Moratalla were the most important, which explains the higher profile of their built heritage. The two remaining municipalities, Calasparra and Bullas, were enclaves which remained primarily Muslim following the conquest, leading to numerous battles in the 13th century, preventing the population from settling until the 15th century in the case of Calasparra, and at least the 17th century in Bullas (Marín Ruiz de Assín, 2009).

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From the 14th until the mid 19th century this area was a land of military orders. All municipalities belonged to the Order of Santiago, except Calasparra, which was under the command of the Orden Hospitalaria de San Juan.

All this has led to a disparity which is echoed in the architecture of different municipalities currently organized within a single administrative unit. This provides an opportunity to contrast the evolution and transformation of this architecture.

Earthen construction, which has survived until the 20th century in this region, is not only limited to the Hispano-Muslim period. There is evidence of this in different documents such as construction work contracts or accounts of the Visits of the Order, as well as the many buildings that are still conserved.

To date, no overall analysis has been carried out on the vernacular construction of the region. Some authors have studied the region and cite masonry, somewhat scathingly, as a very widespread technique in non-monumental constructions. However, according to J.A. Martínez (2024, 81) in the 16th century, a time of great demographic and urban growth, most of the dwellings built in the administrative capital in that century featured rammed earth.

From this it can be deduced that the transformations of a significant part of the buildings which make up the historic nucleus were carried out on rammed earth constructions. Due to demographic growth, the introduction of new materials and changes in ways of life over the last century it is plausible that the actions with the greatest impact are the most recent ones.

Different socio-economic factors have meant that in recent decades the region has maintained a stable population. This contrasts with other areas in Spain, a country which is notorious for population loss. From 1960 to 1980 there was an

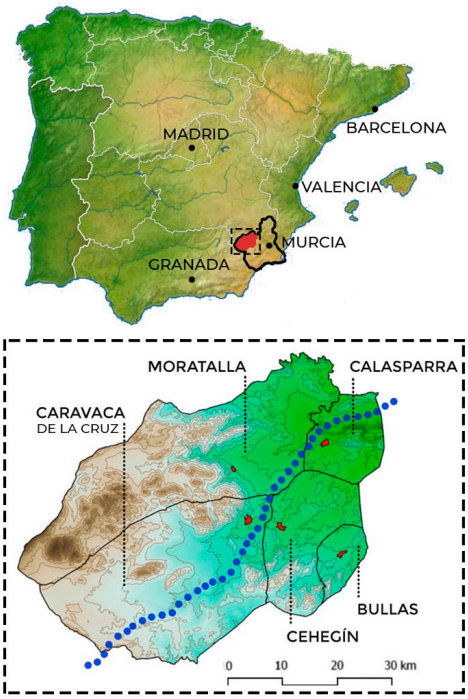

Fig. 1 – *Location in the region of northwest Murcia in Spain. The five municipalities and their surface are marked, with the top municipality marked in red. The main Valencia-Granada route appears in blue* (Sandoval Gómez, 2024).

exodus to the main industrial areas in Spain as well as to the region of Murcia. However, improved communications and infrastructures and the creation of a regional hospital in the 1980s contributed to the population settling. The capital, Caravaca de la Cruz, has been at the head of demographic growth, which has been less noticeable than in the other municipalities, except Moratalla, the only one which has been continuously losing population, according to the Spanish Statistical Office (INE), since the start of this exodus.

These demographic dynamics have promoted continued use in traditional architecture in some cases, transformations of different types in others, as well as examples of abandonment when the population moved to the new areas of the cities from the mid 20th century on.

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2. Objectives and methodology

This study aims to identify the scope of earthen construction in the vernacular architecture of the region of northwest Murcia and to carry out an overall analysis of the buildings where these transformations occurred. These transformations must be understood in different forms. They can be a constructive, morphological or typological evolution, a change in use or other changes due to socio-economic factors, and deterioration or abandonment of a building can be considered as a sort of transformation.

In order to identify the earthen architecture of the region of northwest Murcia a classification has been proposed into three typologies based on the original intended use: defensive, religious and residential. Fieldwork identified and analysed this earthen architecture, and bibliographical and archival research was carried out based on documentary sources. The total number of case studies was 48: 14 defensive, 9 religious, and 25 residential.

The criterion established is the visual detection of at least one wall of the building featuring an earthen constructive technique. This makes it possible to establish a number of cases in the area large enough to establish a sample for global study, although this does not constitute an exhaustive catalogue. Limitations are the result of inability to access the interior or the modern renders which conceal the constructive techniques.

The transformation of earthen architecture in this context is a complex issue, as not only does it entail the study of original constructive characteristics, but also a set of parameters which should be interlinked and have been defined by different case studies over time. The concept of transformation itself is transient and displays an evolution which is subject to multiple variables. However, conditioning factors in the research make it necessary to reconstruct and hypothesize much of the process.

Indeed, when resorting to bibliographical and documentary sources it is only possible to obtain a fixed photograph of certain moments. In addition, when considering a global analysis of the built context and not that of a standalone building, it is of great interest to identify behaviour or evolution patterns that are common to the whole. Furthermore, many earthen constructions have no associated documentation, given that it never existed or was lost at some point in time. In this regard it should be noted that, in the 1980s, during the rehabilitation work on the building for the Town Hall in Caravaca de la Cruz numerous documents considered “paperwork of no importance”, including notary protocols and construction work contracts, were lost.

Although documentary and bibliographical sources are a necessary support, the buildings should be seen as a primary source in order to ensure an overall understanding of the transformation phenomena. This interconnected method consists of several approaches previously used to study the historic centre of Valencia (Mileto & Vegas, 2018).

In view of this, the cases detected in fieldwork are classified by typology, establishing whether these are abandoned or conserved. Conserved cases include consolidation or maintenance interventions of different types. Finally, it is studied whether the building continues to have its original use or whether this has changed.

3. Results

In the northwest region, earthen architecture can be classified according to three typologies established:

- Defensive typology: consisting of the remains of walls and towers which surrounded cities. This category also includes castles or watch towers.
- Religious typology: this includes chapels, churches, and convents used for Catholic

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worship. These can be small single-nave buildings or more complex constructions with several articulated volumes.

- Residential typology: consisting of dwellings, highly variable in form, and ranging from a modest dwelling to ancestral houses.

This research has focused on cases in which earthen construction can be identified through direct observation. Thus, 14 case studies have been analysed in the category of defensive typology, 9 in the religious typology, and 25 in the residential typology. In terms of the total of possible cases, the degree of uncertainty is low in the defensive and religious typologies given the well-known limited number of constructions, although occasional excavations or discoveries could result in a slight increase of the number of cases. However, the degree of uncertainty is higher in the residential typology given the application of contemporary coatings. As a result, the sample analysed is also larger.

3.1. Constructive variants

Rammed earth is the principal technique in the area in terms of earthen architecture. To date, no adobe has been identified in load-bearing walls, only in interior and party walls. In all examples, the pieces appear in a shiner bond.

Simple rammed earth is very common in dwellings, where corners are often resolved with gypsum pillars or *brencas* and are executed following the guidelines of numerous treatises, with at least ten layers per formwork. In some modest buildings a poorer quality variant can be found: rammed earth with masonry, stabilized with very little gypsum. In the absence of laboratory tests confirming the proportion of bonding agent, the lack of consistency observed in the complex when adding an opening or carrying out an intervention on the wall, touch, and the ease with which aggregate breaks apart suggest that the amount of bonding agent is very low.

Although lime-crusted rammed earth appears in all three typologies, it predominates in the religious constructions. The chapel of San Sebastián de Caravaca, built with a single nave with diaphragm arches circa 1507, still conserves lime-crusted rammed earth on the front and back walls (Fig. 2), although side enclosures have since undergone several modifications. The nearby church of la Concepción, also with a single nave and diaphragm arches, preserves its side walls in rammed earth although several publications, including a very recent one (Melgares, 2024), state that these churches are built in masonry.

Fig. 2 – *Lime-crusted rammed earth in the chapel of San Sebastián de Caravaca* (Sandoval Gómez, 2024).

In some religious buildings, rammed earth was also combined with brick from the 17th, and especially, 18th centuries. The oldest example of this can be found in the convent of Madres Carmelitas de Caravaca as the building façade which gives onto the calle Mayor was built around 1625 (García et. Al, 2023). This façade has well conserved lime-crusted rammed earth walls with brick courses and pillars. However, subsequent expansions of this building and other convents in the region incorporated rammed earth with masonry combined with brick. Visually, these have different surfaces: while the former offers a smooth (lime crust) the latter incorporates stones at random in the mix, as in the case of the convent of San Francisco in Moratalla (Fig. 3).

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Fig. 3 – *Façade of the convent of San Francisco in Moratalla* (Sandoval Gómez, 2024).

3.2. Uses and state of conservation

In relation to the state of conservation (Fig. 4), a greater rate of abandonment can be observed in the defensive typology as, although most of the structures in villages have undergone interventions, there are structures scattered throughout the territory (small castles or watch towers) which have been abandoned and show no type of consolidation, which would be otherwise advisable given the advance in the progression of erosion. However, there is only one case of abandonment in religious typology, and it happens to be the oldest: the chapel of San Sebastián de Cehegín, built in the 15th century (Fig. 5).

In terms of use, defensive constructions have currently lost their function and there is a direct correlation between those which are abandoned and in disuse and those which have undergone consolidation or intervention, and are now used for tourism or culture. In the case of buildings which originally fulfilled a religious purpose, only two of those still existing have shifted their use from religious to cultural. It should be noted that in residential architecture a few examples can be found with no apparent use, but well conserved.

Furthermore, the change of use occurs in all cases due to the existence of a specific appealing element to the building: most of the time these are *casas principales*, that is, former ancestral homes of influential local families with a unique spatial, material or aesthetic richness. In some specific cases, this is apparently due to the building having been inhabited by some figure of cultural or spiritual relevance so that it has some intangible value. All these former dwellings are now used as museums or headquarters of some body of general interest.

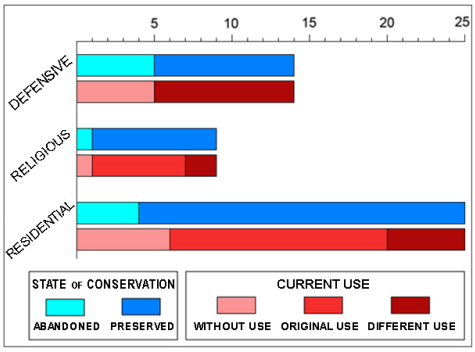

Fig. 4 – *State of conservation and current use by typology* (Sandoval Gómez, 2024).

Fig. 5 – *Remains of the chapel of San Sebastián, in Cehegín. The defensive Torre del Pozo can be seen in the background* (Sandoval Gómez, 2024).

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3.3. Unique cases

In addition to the information presented it is necessary to consider missing architecture. It is clear that this can be analysed in qualitative terms rather than in statistical terms. It is not possible to determine the number of dwellings built with earth that have disappeared, partly due to their anonymous nature, but there is a record of two buildings which were representative in the past. These are the castles of Bullas and Cehegín. There is no information on the former except what appears in written records, as it disappeared gradually in modern times.

However, the latter, the larger castle of Cehegín, remained in relatively good condition until 1957, when it was demolished in one of the greatest affronts to heritage in Spain. Its medieval defensive use had been replaced, transforming it into a winery, where a large part of the wine harvest of the city was stored until another dedicated building was constructed in the 17th century (Martínez & Peñalver, 1995).

> "The remains which are to be demolished […] lack any kind of architectural form, but are a shapeless collapsed mass with no aesthetic or ornamental value which might contribute to information on military architecture or be of any interest for research" (Author translation).

A photograph dating to 1950 (fig. 6) shows the main tower of the castle, a few years prior to demolition. This image clearly shows how this description did not reflect the real situation. This was the only tower with a pentagon-shaped base in the region.

In contrast to demolitions, interventions can be found that do not respect the building, transforming it into something it never was. This is the case of Torre Girón, built with rammed earth as a watch tower in the Middle Ages on the Valencia-Granada route. Up until 25 years ago, its 1.50-metre-thick walls were close to 9 metres high (Pozo, 1996). The recent intervention raised the height, adding four openings in the form of arches on freestanding columns completely alien to a military construction, finishing the complex off with merlons (Fig.7).

Fig. 6 – *Tower of Cehegín Castle circa 1950* (Cehegín Municipal Archive).

Fig. 7 – *Current condition of Torre Girón* (Sandoval Gómez, 2024).

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Residential earthen architecture provides a wider range of case studies depending on factors such as the size and location of dwellings. It is important not to assume that this technique is exclusive to modest architecture, given the many cases of ancestral houses to be found in historic documents. There, rammed earth was combined with ashlar, coats of arms, and stone façades, suggesting a reduction in the cost of the work due to the lower cost of construction. In Campo de Caravaca some examples can be found, the most notable of which is again next to the Valencia-Granada route (Fig. 8), and its construction dates back to the 16th century (Sánchez, 1987). Urban centres also include some prominent buildings built using rammed earth. This can only be seen on back walls, in small gaps that have not been rendered or in party walls, as the main façade is completely rendered, in some cases with a traditional render and in others with a recently painted one.

4. Conclusion

Earthen architecture in the region of northwest Murcia is widely found despite not having been studied in depth. Documentary sources and buildings, primary sources, reveal the wide use of the rammed earth technique in defensive, religious, and residential construction. The current degree of abandonment is low in cases where there has been continued use, which has also led to transformations and changes of function. 14 of the 25 dwellings built in rammed earth which have been studied are still lived in.

The loss of knowledge relating to this type of construction in the last century has led to the demolition of important heritage buildings as well as substantial modifications which strip the buildings of value. Ancestral houses are also built in rammed earth, which can coexist with ashlar and stone façades. This technique is therefore not exclusive to modest architecture.

Fig. 8 – *Façade of a main house built in the 16th century, next to the Valencia-Granada route* (Sandoval Gómez, 2024).

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The different rammed earth variants in each of the building typologies offer proof of a survival of the technique, subject to changes and combinations with other materials, demonstrating the widespread use of earth as a constructive material in the area.

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Tips and Tricks to Study Mudbricks. Experiences from the Protohistoric Site of Casas del Turuñuelo, Spain

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Abstract

The main construction *technique during the Protohistory in the southwest of the Iberian Peninsula was adobe. However, to date, there have been few sites with the necessary state of preservation to conduct studies that provide a holistic view of the architecture. In contrast, the discovery of the Tartessian building at Casas del Turuñuelo (Guareña, Badajoz, Spain) with its exceptional state of preservation has enabled the application of a wide range of interdisciplinary analytical techniques and methodologies—many of which have never before been used together at a single site. In this paper, we present a detailed synthesis of all the strategies, techniques and analyses applied over ten years of excavation, as well as those currently under development. Our aim is to share the insights gained from this specific case study and, more importantly, to provide methodological tools that can be applied to other adobe-using sites, regardless of their chronology or cultural context.*

Keywords: *adobe; archaeology; construction techniques; earth construction; Tartessus*

1. Introduction

Within the framework of the Protohistoric period of the Iberian Peninsula, adobe is one of the most widely used building techniques. However few holistic and comparative studies have been conducted in a comprehensive manner. This may be due to the poor state of preservation of earthen structures and the preponderant research focus on movable materials; as a result, there is currently no standardized analytical methodology for the characterisation and study of Protohistoric adobe. However, in recent years significant progress have been made through case studies centred on the 1st Iron Age, generating valuable works which, although with different objectives and approaches, share a multidisciplinary vision as the path forward.

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Consequently, we are currently in a phase of experimentation and application of new methodologies, as well as the incorporation of resources from different disciplines.

Regarding the definition of adobe—a term that still generates some confusion—it refers to a construction technique involving the production of earth-based units mixed with both organic and inorganic additives. These units are shaped in molds (which may be standardized and suitable for mass production), are neither compressed nor fired, and are dried prior to placement. As such, they are prefabricated elements that can be stored and transported. They are typically assembled using mortar. Another important feature is its versatility allowing for its use in various types of constructions and contexts. The question of when adobe began to be used on the Iberian Peninsula remains a topic of debate (Belarte, 2011; De Chazelles et al., 2011; Pastor et al., 2024). While adobe has a long-standing presence in the eastern Mediterranean (Spencer, 1979), its widespread use in the Iberian Peninsula did not occur until the arrival of the Phoenicians, despite its occasional application in the Late Prehistoric period.

One of the most important discoveries in recent years for the for the study of earthen architecture in Protohistoric Iberia is the site of Casas del Turuñuelo (Guareña, Badajoz, Spain) (Figs. 1 & 2). It represents the best-preserved adobe building in the western Mediterranean (Rodríguez González et al. 2020: 426). This site is allowing us to delve deeper into the study of the architecture of the period (Celestino et al., 2023), and to implement both qualitative and quantitative methodologies, all organized according to the building's stratigraphy. Therefore, in this paper we offer a preliminary approach to the methodology and working protocol designed for the study of the adobes at the site. It is a proposal that, based on our experience, can be varied and adapted according to the results and peculiarities of each case study.

Fig. 1 – *Location of the site of Casas del Turuñuelo* (Proyecto Construyendo Tarteso).

2. Previous contextualisation, analysis and work carried out

In the Early Iron Age the construction techniques are, in general, easily identifiable, with adobe being present in the great majority of cases. Consequently, their study should be a priority, both because of the number of units available and because of the historical information they provide. To this end, the research objectives can be broadly divided into two main areas: 1. to investigate the process of manufacture, construction and architectural functions of the adobes; 2. to characterise the composition of the mortar and earth used, and to determine the chronology of each phase and event that left traces in the architecture in order to determine the evolution of constructions.

As a basis on which to carry out any study, we consider it essential to contextualise each of the adobes studied within the framework of the building, which implies identifying the construction element of which it forms part and its stratigraphic relationships through the application of the Archaeology of Architecture. It is true that the application of the theoretical and methodological principles of Archaeology of Architecture (Azkárate, 2013) encounters significant difficulties when applied to the study of earthen constructions. Thus, even if the state of conservation is good, there are always factors such as irregularities within the same constructive solution, the large number of repairs and

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Fig. 2 – *Plan and profile of the site of Casas del Turuñuelo* (Proyecto Construyendo Tarteso).

modifications or the continuous maintenance, intrinsic to earthen architecture (Carranza, 2022). However, these steps are the ones that will allow us to situate the adobes within a specific moment and constructive element.

2.1. Study of the constructive aspects, manufacture and architectural function of adobe bricks

Once the stratigraphic relationships between the various constructive units of the building are established and the constructive elements are defined, it is possible to begin studying of the adobe (aka mudbricks) present within them (Fig. 3). The first step is the individual identifycation of the mudbrick preserved in situ, which requires addressing specific challenges such as deformations, distinguishing the mortar joints between the bricks, etc. Atn this stage, recording the mudbrick's measurements is essential, as the ddimensions are a representative physical feature of the adobes, in addition to the fact that its correct delimitation is what will later allow samples to be taken for the analyses to be carried out.

In the case of the work carried out at Casas del Turuñuelo, we have so far been able to record measurements of more than a hundred pieces preserved in situ. A key innovation in our approach is the use of statistical methods to process this data, which has allowed us to establish several clearly differentiated modules, as well as to know their distribution and differential use within the different constructive elements and stages of the building.

In this sense, one of the objectives is the reconstruction of the operational chain, which includes two key aspects: the actual manufacture of the pieces and their modes of use within the architecture. To do this, we must begin by defining the soils used and the ways in which the raw material was exploited, using analytical studies of material composition.

With regard to the moulding, it is important to record the marks and impressions related to the demoulding and drying of the adobes, which allows us to clarify and detail the process with a high degree of precision.

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Fig. 3 – *Example of adobe facing analysed* (Carranza, 2022).

These lines of research are essential to determine the types of adobe used, their association with specific construction typologies, the various sources of clay supplies available and the estimated labour force involved at any given time. Through detailed documentation we can detect, among other aspects, the reuse of old adobe bricks and fragments for the remodelling of the construction in later phases, which undoubtedly leads to technological and cultural insights into the architectural and functional development of the building.

Ethno-archaeology and experiences derived from experimental archaeology are also valauble sources of information on the manufacture and use of adobes. In the first case, insights have been gained through the observation of vernacular architecture and fieldwork carried out as part of a research project in the Draa Valley in southern Morocco. The continued use of traditional land-based construction techniques in the region has offered a wide range of interpretative alternatives.

As for experimental archaeology, one of the future objectives within the framework of the 'Construyendo Tarteso' projects is the creation of a laboratory dedicated exclusively to the study of earthen architecture, given that the few works we have carried out so far have produced priomising results.

2.2. Physico-chemical characterisation of mortar composition: invasive methods

The application of archaeometric techniques for the physico-chemical study of archaeological materials is common for all types of movable artifacts. However, their use in the study of historic earthen architecture is relatively recent. As a result, a standardized protocol has not yet been developed, and each case is significantly influenced by the preservation state and specific conditions of the site.

In the specific case of Casas del Turuñuelo, which we will use in this section as an example of the work protocol put into practice, a methodology was designed using a combination of micro and macro approaches on the remains of different earthen constructive elements located at the site.

The basis of this recently published suite of techniques (Cutillas et al., 2024) was based on X-ray fluorescence (XRF), X-ray diffraction (XRD), thin-section petrography and combustion elemental microanalysis (CHN).

XRF and CHN elemental analysis were used to determine the chemical composition of mortar samples, and the data were processed through statistical modeling. XRD was also employed to identify the mineralogical composition of selected samples. These analyses enable us to establish a common "material fingerprint" among all the materials used in the construction of the building, which is particularly useful to know the different sources of raw materials (Cutillas et al., 2024, pp. 3-6, 12).

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From the different diffractograms generated by XRD we were able to determine the mineralogical composition of the adobes. By analyzing samples from various areas of the building alongside local soils, we were able to confirm the use of three distinct raw material collection zones. These were exploited simultaneously by different workgroups, even though the sources were located at varying distances from the site and not necessarily adjacent to the building (Cutillas et al., 2024, p. 9). This finding is significant as it demonstrates that, although earthen architecture generally draws on the materials adjacent to the building to be constructed, the modular nature of adobe allows it to be transported over very long distances, which, in this case, is ruled out. What has emerged is a clearer picture of the of the logistical complexity, operational chain, raw material selection and processing, and the differentiation of recipes used over time and across different parts of the building.

The petrographic analysis (Fig. 4) carried out via thin sections microscopy, allowed us to identify the different petrographic fabrics (TP) and sub-fabrics. The vast majority of the observations resulted in a homogeneous structure in terms of geological composition, but different substructures were also identified in terms of colour parameters, texture, groundmass and vegetal temper. Interestingly, the presence of dung spherulites and reed phytoliths was also recorded, suggesting that dung may have been used as temper (Cutillas et al., 2024, p.7-8), which shows the potential of this type of analysis to understand aspects such as palaeolandscape and palaeofauna.

At the macro level, our analysis of the samples revealed various traces left by organic additives in the adobe bricks. These include: cases in which neither the vegetal matter nor the pore space is preserved due to their decomposition and variation due to the compression forces; other burned adobes that lost the vegetal content and preserved the pore space, and experienced physico-chemical alteration due to fire; and unburned samples that contain vegetal matter with the problem that they appear as part of the fills, so that they cannot be securely located to a specific construction element.

In terms of composition, in addition to the analyses already described, we also explored the organic content of adobe bricks by leveraging analyses initially developed for the site's ceramic materials. Thus, we selected eleven adobe samples to analyse, by searching for traces of lipids, whether stabilisers of organic vegetable or animal origin were added to the mortar mixture. For this purpose, gas chromatography coupled to a mass spectrometer (GC-MS) was used.

The previous techniques have made it possible to characterise materials on the basis of their composition without using large quantities of sample, although we must not forget that these are destructive techniques. For this reason, in this section we consider incorporating the application of physical, chemical and mechanical tests into the methodology. These include plasticity tests, to determine the plastic and liquidity limit; permeability tests, to evaluate the clay's capacity to allow water to pass through; and compaction tests, to determine the maximum density and optimum moisture content.

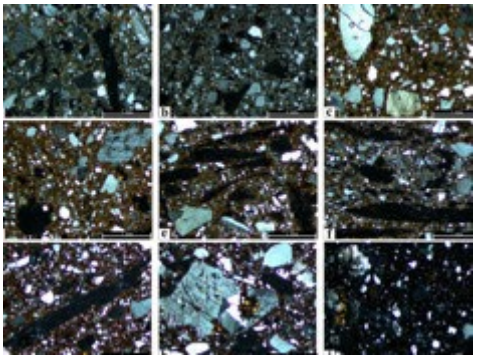

Fig. 4 – *Representative microphotographs of the petrofactories identified in the Casas del Turuñuelo building* (Cutillas-Victoria et al., 2024, p. 7).

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In the previous tests, we have ruled out, for the moment, compressive strength tests, since the oversizing nature of the walls of the building makes it difficult to identify which parts of the structure had a load-bearing function.

However, we have carried out tests to determine the relative density of the adobe mortars, which has provided us with results that are consistent with the usual parameters for adobes. They should also be considered with caution and new methods should be sought, since, as we have indicated, the porosity related to the vegetal additions may have undergone significant variations over time.

2.3. Dating of historical mortars

The application of absolute dating techniques to historical mortars remains an underdeveloped area, as no standardized method currently exists for dating earthen materials. Nonetheless, these techniques are crucial for determining the construction timeline of different building phases—particularly since buildings are often subject to expansion, compartmentalization, or repair based on evolving needs.

There is a wide range of dating techniques, but not all of them will be suitable to answer the original questions: when, for example, were each of the phases of the Casas del Turuñuelo building constructed? Radiocarbon dating pesents a challenge as the organic matter in the adobe is not consistenly preserved. Given this situation, Optically Stimulated Luminescence (OSL) dating has been selected, and the technique has been applied to various parts of the building as test, selecting points which, thanks to the paramental analysis, we know belong to the same construction phase.

The results from the adobe samples have yielded magnificent results, with an accuracy with arcs of ± 12-21 years and totally consistent with the stratigraphic readings. We have therefore extended these analyses to other parts of the building, as this is the only technique which, although not without its problems, is offering us guarantees to know the exact time of placement of the pieces and mortars used in the building.

In addition to the extension of the OSL, we are currently beginning the process of applying palaeomagnetism dating, both to ceramic material and to the architecture affected by the fire. This technique also presents important calibration problems for the 1st Iron Age; however, the results obtained will allow us to determine the exact chronology of the fire that put an end to the occupation of the building at Casas del Turuñuelo, thus complementing the results obtained thanks to the radiocarbon samples taken from the seeds and bones of the courtyard linked to the massive slaughter of animals excavated in this space (Iborra et al., 2023).

2.4. Other non-invasive tests

Finally, we also highlight the use of non-destructive research techniques, or those that do not require sampling or management of materials in the laboratory, which we believe can provide important additional information. Within this group we are currently working on the development of methodologies and strategies based on the use of infrared thermography, humidity recording and the use of ground penetrating radar (GPR).

Firstly, thermography captures the infrared radiation emitted by bodies as a function of temperature, providing an image visible to the human eye (Fig. 5). In our case, we intend to start monitoring temperature variations throughout the year for conservation purposes, while in the specific case of adobes, we are testing the technique to see if the different mortar recipes emit differential radiation or not, which would allow us to distinguish them from each other.

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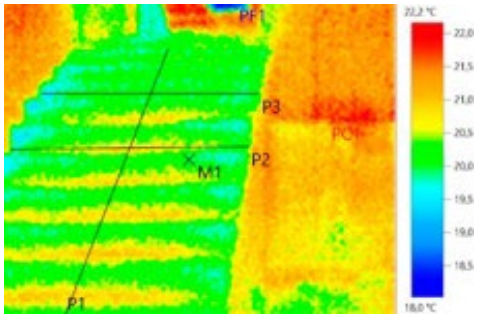

Fig. 5 – *Thermography applied to the west elevation of the site of Casas del Turuñuelo* (Proyecto Construyendo Tarteso).

Regarding humidity, we have also begun using the Munsell Color System tables as a quick method for the identification of mortars. These colourimetric parameters, recorded under specific light and humidity conditions, can indicate a wide range of characteristics of adobe mortars (Ferrer García, 2015), although they are proving particularly useful for the rapid differentiation of formulas used in a less subjective way. However, it remains to be assessed whether they are sufficiently accurate to differentiate formulae recorded through geoarchaeological studies.

Finally, within the framework of non-invasive analysis, we propose the application of ground penetrating radar (GPR). This portable device detects contrasts or variations in the density or compactness of a medium when electromagnetic waves are propagated. The georadar device allows a penetration of 50-60 cm, both in pavements and vertical surfaces. Similar to thermography and humidity, it is providing promising results for recording pavement overlays and possible buried structures at shallow depths. In the case of adobes, it does not allow us to differentiate the different recipes as they have densities within the same range, but it does clearly show the difference between quartzite plinths and adobe elevations, especially useful when they are not visible due to the preservation of the cladding.

3. Final reflections

The building at Casas del Turuñuelo and its exceptional state of preservation, together with the fact that it is an active site, offers a rare opportunity to develop and test methodologies for studying protohistoric earthen architecture. It is therefore time to contrast tools and methodologies whose results provide information on both the building itself and the broader cultural framework in which it is framed. For this reason, in addition to carrying out analyses at different points of the building, we have selected a specific area of the site on which we are applying all the analyses in order to centralise and directly compare the results across different techniques.

When it comes to adobe, our work has highlighted several ongoing challenges, such as the lack of standardized terminology and methodological consensus (Carranza, 2022). at the same time, it also shows the potential of the study of historical adobes to understand aspects such as the management of resources and raw materials, the degree of specialisation of the builders, the complexity of the work routines, the architectural function of the architectural elements and/ or the construction practices of the time.

The stratigraphic reading of elevations, the identification of constructive elements and the geoarchaeological characterisation are the basic works for the complete and precise study of earthen architecture. However, one of the most important questions to be resolved for the future, on which there is no consensus, is which parameters to choose for the characterisation of the adobes. The goal is to establish a set of criteria that will allow for the quick and reliable comparison of adobe characteristics across buildings. This will be critical for conducting comparative studies that group structures by chronology or cultural affiliation. From our experience, texture and colour may be the most

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accessible in relation to composition, while dimentions and architectural function are culturally significant and commonly available physical parameters.

In conclusion, this work offers a methodological proposal grounded in our fieldwork and ongoing research on historic adobes. Moving forward, dialogue between disciplines and openness to new tools and methodologies will be essential, comparing the results of the different techniques and observations in order to make more reliable historical interpretations.

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Comparative Study of Yikeyin Adobe Houses of the Han Ethnic Group in Central Yunnan, China and Rammed Earth Houses in Songyang, Zhejiang, China

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Topic: T2.2. Study of traditional materials, techniques and construction crafts

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Abstract

Under the circumstance of modern construction and rapid urbanization, there's still one-third of the global population resides in earth building,with various types of these buildings spread widely across China.In addition to the renowned cave dwellings on the Loess Plateau and Tulou in Fujian,there are also Tuzhangfang,Yikeyin(both are adobe houses) in Southwest China,Watchtower on the Qinghai-Tibet Plateau,and rammed earth houses in southern Zhejiang. This paper steers a focus on Yikeyin of the Han ethnic group in Central Yunnan and rammed earth houses in Songyang,Zhejiang,which are located in different regions, different climates, using different soil construction methods but both are deeply influenced by traditional Chinese patriarchal clan and Han culture. Through a comparative analysis of regional geographical conditions, climatic environments, spatial structures, and construction practices, this study summarizes the characteristics of each building type, as well as their strengths and weaknesses.To be precise, the manifestation of different soil construction methods in these two sites are explored as well as discussing the roles played by local government, social institutions and local residences during the protection process of traditional dwellings. The study emphasizes how restoration efforts can maintain traditional characteristics while enhancing building technology to better transform them for the sake of contemporary use.

Keywords: *adobe houses; rammed earth house; courtyard house; conservation of earthen building*

1. Introduction

This article selects the Kunming area in central Yunnan and the Songyang area in southwestern Zhejiang as its research subjects (Fig. 1). Both regions' traditional dwellings primarily utilize raw soil as the primary building material. As Han ethnic enclaves, their architectural forms are deeply influenced by traditional Chinese patriarchal concepts and Han culture. However, raw soil, as a building material intrinsically linked to nature, has resulted in two seemingly distinct types of raw soil dwellings due to variations in climate, terrain, and other factors across the two locations.

Currently, both areas are confronting the impact of modern construction systems, rendering the urgent need for the preservation and enhancement of traditional earthen buildings.

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Fig. 1 – *Geographic location of Kunming and Songyang* (Author, adapted from Ministry of Natural Resources of China, retrieved April 27, 2019, from http://bzdt.ch.mnr.gov.cn/).

The central Yunnan region is situated in the Diandong Plateau Basin, characterized by gentle terrain fluctuations. This study takes the Wolong Ancient Fishing Village (hereinafter Wolong) in Kunming as an illustrative case. Kunming experiences an annual precipitation of approximately 920 millimeters, with approximately 85% occurring between May and October (Fig. 2). Situated approximately 30 kilometers from Kunming's old city district, Wolong is currently being developed into a scenic spot by the Overseas Chinese Town Group. The village is now devoid of its indigenous inhabitants, and its traditional earthen buildings are completely enclosed by protective fencing. Currently, the open areas feature two types of restored adobe brick structures: temples, high-standard residences, and newly constructed adobe brick buildings, primarily serving exhibition or tourism-related purposes.

Songyang is part of the southern mountainous region of Zhejiang province. The annual precipitation in Songyang is approximately 1,700 millimeters, with about 70% of it occurring from April to October (Fig. 2). Songyang boasts the largest number and best-preserved ancient villages in East China, with over a hundred structurally intact traditional villages. This study examined representative villages, including Songzhuang Village, Yangjiatang Village, and Youtian Village.

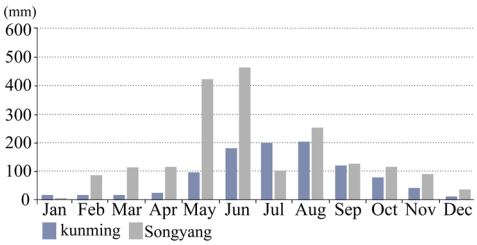

Fig. 2 – *Precipitation comparison* (Author, 2025).

Currently, within the academic community, there exist separate architectural and cultural studies focusing on the two, yet a comparative study that delves into their similarities and differences, as well as the development model most suitable for traditional earthen dwellings in contemporary times, remains absent. This paper will analyze their concrete construction practices in the second section. The third section delves into the reasons behind these similarities and differences. The fourth section examines the differing strategies and accomplishments of Wolong and Songyang in preserving traditional earthen dwellings. The fifth section presents a summary and reflection of this paper, contributing to the summation of strategies and directions for the preservation of traditional Chinese earthen dwellings, and offering insights for the conservation of traditional earthen architecture and villages in the future.

2. Distinctions and linkages

2.1. Comparison of layout

The Yunnan Provincial Annals from the Wanli period of the Ming Dynasty recorded: “Residential buildings in central Yunnan are all quadrangular tile-roofed houses (known as Yikeyin).”

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The “Yikeyin”, a hallmark of Han-style architecture in central Yunnan, features high external walls with sparse windows and a square layout resembling a seal. This enclosed quadrangle-style architecture reflects the fusion of Central Plains Han culture and Kunming's climatic conditions. Wolong preserves the largest number and most intact layouts of “Yikeyin” architecture near Dianchi Lake.

A typical traditional “Yikeyin” dwelling consists of three main rooms flanked by two side rooms on each wing (Fig. 3). Beyond this standard layout, Wolong also features adaptive variants such as “half-Yikeyin”, demonstrating flexible adaptations to local needs and topography. The settlement embodies a coexistence of architectural unity, diversity, and variation in spatial organization. Regrettably, most traditional “Yikeyin” structures have been destroyed, demolished, or collapsed over time. Today, only a limited number have been preserved, with a small portion of new constructions replicating the original style.

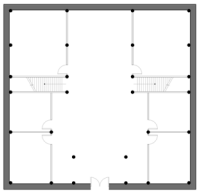

Fig. 3 – *Layout plan* (Author, 2025).

Songyang Villages were primarily established by ancient families seeking refuge from war in the mountains. Consequently, it is common to find villagers sharing the same surname and lineage. Take Youtian Village, for instance, which served as a migration site for descendants of Ye Mengde from the Southern Song Dynasty. This village was renowned for its mastery of traditional Chinese medicine, producing numerous distinguished physicians and becoming a Ye family settlement famous for its medical prowess. Influenced by the Huizhou style, the residential buildings in Songyang share similarities with Huizhou architecture in layout, functionality, architectural style, and form. Typically, smaller dwellings feature yellow mud walls and dark grey tiles, while some larger and medium-sized residences boast white walls and dark grey tiles. The “earth houses” have become a hallmark of the ancient villages in Songyang (Wei, 2021, p. 17).

Most residential buildings stand two to three stories tall, with typical architectural layouts including the “linear,” “tri-courtyard,” and “quadrangle” styles (Fig. 4). The most prevalent “linear” residential design features a three-bay layout, comprising a central living room flanked by bedrooms on both sides. This courtyard-less design, which occupies a relatively small footprint, is well-suited for high-density settlements in mountainous areas. The “tri-courtyard” serves as a medium-sized residential unit, equally demonstrating strong adaptability to various terrains. Meanwhile, the “quadrangle,” formed by the juxtaposition of two “tri-courtyards,” is typically inhabited by extended families.

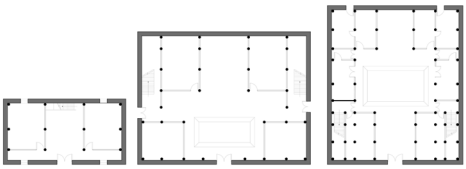

Fig.4 – *Layout plan* (Author, 2025).

Compared to ethnic minority dwellings, the most defining feature of Han traditional residences lies in their courtyard-style layout, deeply rooted in Han cultural ideologies of patriarchal clan systems, ethical principles, hierarchical order, and ritual norms. Courtyard-style layouts typically emphasize central axial symmetry, inward-facing enclosure, and minimal exterior windows, with main halls, side wings, and auxiliary rooms arranged hierarchically (Lv & Wu, 2018, p. 87). This approach is most prominently observed in “Yikeyin” dwellings. However, in mountainous villages like Songyang, where terrain constraints prevail, simplified “linear layouts” became more

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practical. Despite this simplification, Songyang's overall village structure retains a remarkably intact spatial organization governed by patriarchal clan principles. The village still preserves clan-centered public buildings such as ancestral halls and communal temples, which serve dual purposes: commemorating and venerating the village's shared ancestors, while also functioning as spaces for clan members to discuss important matters.

2.2. Comparison of specific constructions

Both the traditional dwellings of Wolong in Kunming and Songyang's historic villages employ column-and-tie timber framing as their primary load-bearing structure (Fig. 5). This system is characterized by minimal material usage yet exceptional stability, with hybrid use of column-and-tie and raised-beam frameworks reserved for large-scale buildings.

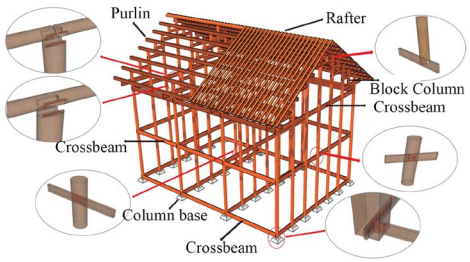

Fig. 5 – *Wooden structure* (Wang et al., 2024, p. 293).

The walls of "Yikeyin" dwellings are constructed from rammed earth bricks. Traditional local bricks measure approximately 330×110×160 mm and are made by mixing mud, water, and plant fibers in specific ratios, then compacting the mixture into wooden molds. After demolding, the bricks are thoroughly dried before use. Walls are approximately 670 mm thick, and refined techniques involve embedding wooden rods at regular intervals within the earthen walls to enhance structural integrity and deter theft. Contemporary brick production has replaced manual labor with mechanical pressing, though the dimensions remain similar to traditional bricks.

The walls of rammed earth dwellings in Songyang are constructed using a formwork-based rammed earth technique, with typical dimensions of approximately 1000×1500×400 mm. Locally sourced materials—yellow earth, stone, and straw—form the primary building components. Once the construction of the wall foundation is completed, the layers are compacted with staggered joints, and bamboo reinforcement or wooden rods are also incorporated within the rammed earth wall to enhance its strength (Fig. 6).

Fig. 6 – *Wolong (left) Songyang (right)* (Author, 2024).

Poor waterproofing capability is a significant drawback of raw earth materials, hence the colloquial saying "wear sturdy boots and a good hat," which graphically illustrates the two primary waterproofing measures for raw earth architecture: raising the plinth height and extending the eaves' projection. The annual precipitation varies significantly between Kunming, Yunnan, and Songyang, Zhejiang, and this difference is manifested in the specific architectural designs of both regions. The plinth height of Wolong in Kunming is lower than that in the Songyang area, with some being as little as the height of a single brick. Additionally, the "Yikeyin" earth brick construction often neglects the treatment of wall corners, which contrasts with the practices in Songyang. In Songyang, the stone or brick corners are comparable to or even taller than a person's height, providing substantial protection for the vulnerable parts of the building walls (Fig. 7).

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Fig. 7 – *Wolong (left) Songyang (right)* (Author,2024).

Analogous to the treatment of the feet, the eaves of Wolong are comparatively shallow, offering minimal shelter and protection to the adobe brick walls during rainy seasons. The eaves of ordinary dwellings are supported by horizontally projecting wooden structures embedded within the adobe brick walls, whereas more refined architectures employ the technique of brickwork with projecting courses, often using green bricks. In Songyang, the rammed earth houses feature more prominent eaves to accommodate higher annual precipitation, primarily relying on the overhang of rafters or the addition of wooden structural supports (Fig. 8).

Fig. 8 – *Wolong (left) Songyang (right)* (Author, 2024).

Fig. 9 – *Wolong wall plastering* (Author, 2024).

The exterior facades of most existing earthen buildings in Wolong and Songyang have lost their painted layers, which once served as waterproof protection for the earthen walls. Nevertheless, traces of lime plaster or clay plaster layers can still be faintly discerned in some buildings, albeit with varying degrees of peeling (Fig. 9). In order to emphasize the unique character of the local earthen architecture, no efforts have been made to restore the painted layers, and the exterior walls of newly constructed buildings have similarly remained unpainted for protective purposes.

2.3. Comparison of weak positions

The overall integrity of adobe brick walls is comparatively poor. In the Wolong, it is common to see buildings splitting from the middle and leaning towards both sides. Cracks predominantly emerge at the interfaces between civil and wooden structures, due to the differing shrinkage rates of wood and raw soil, making these joints structurally weakest. These include the junctions between adobe walls and wooden columns, as well as those between adobe walls and wooden roof structures.

During the construction of the “Yikeyin” style, the wooden structure is typically erected first, followed by the wall masonry, which complicates the laying of the final few brick layers at the wall-roof interface. Consequently, this area is prone to issues such as damage and gaps. The process of compacting soil at this location is even more challenging than laying adobe bricks, as the compaction force near the wooden structure is often weaker than that applied to the lower wall sections. Being situated at the interface of two materials, it is more susceptible to damage.

Without adequate protection at the base and roof, the torrential rains during Yunnan's rainy season cause significant damage to adobe brick walls (Fig. 10). Vulnerable areas such as the base and corners of walls frequently sustain damage, and

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in severe cases, can even lead to building collapse. Furthermore, the neglect of issues like staggering joints or varying gap widths during the masonry process exacerbates the wall's overall lack of integrity. Although rammed earth houses in Songyang exhibit greater overall integrity than adobe brick walls, the junctions between building blocks still pose a risk of cracking or complete collapse. When repairing damaged walls, individual bricks in adobe walls can be replaced without the need for comprehensive reconstruction. However, if a rammed earth wall collapses entirely, local repairs are extremely difficult and often necessitate substantial construction work.

In the Songyang area, the erosion effect of rainwater on soil walls is significantly stronger than in the Kunming area of Yunnan. A completely unadorned approach will greatly affect the service life of rammed earth walls, which are commonly eroded by rainwater in the Songyang area.

Fig. 10 – *Traditional Houses in Wolong* (Author, 2024).

3. Reasons for differences in two - place raw - soil construction methods

3.1. Natural factors

Raw earth serves as a building material significantly impacted by the natural environment, particularly by “water.” Songyang in Zhejiang Province experiences nearly double the annual precipitation of Kunming in Yunnan Province, necessitating more sophisticated waterproofing measures for raw earth constructions in the former.

3.2. Human factors

The production process of adobe bricks boasts simplicity and flexibility in size. Prefabricated manufacturing allows for mass production, while the decentralized construction model obviates the need for a simultaneous concentration of substantial labor force. In contrast, rammed earth walls necessitate on-site construction and continuous operation, with traditional techniques exhibiting lower efficiency, enabling only four individuals to complete 40-50 square feet per day. The ancient village of Songyang is predominantly inhabited by clans, fostering close-knit relationships among villagers, which provides an advantage in mobilizing a large workforce for construction endeavors.

For over two millennia, Kunming in Yunnan Province has served as the capital of the State of Dian, thriving as a bustling city with perpetual military garrison. Conversely, Songyang in Zhejiang Province is nestled in mountainous regions, with villages situated remotely from cities and garrison troops, thereby posing a higher risk. Rammed earth walls, being thicker than adobe brick walls, exhibit superior integrity, durability, and defensive capabilities, making them better suited to the demands of mountainous areas.

The Yikeyin architecture in central Yunnan represents a fusion of Han courtyard culture and Yi adobe brick dwellings during the Ming Dynasty's border defense era, continuing the local tradition of adobe brick construction since its inception. Similarly, in Zhejiang, rammed earth architecture boasts a lengthy history, with traces of early rammed earth structures evident at the Hemudu Site dating back to the Neolithic Age. This traditional craftsmanship has been preserved and perpetuated through subsequent generations.

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4. Contemporary protection strategies

Songyang Ancient Village surpasses Kunming Wolong Village in terms of its overall village appearance and the restoration and preservation of traditional architecture. In 2016, Songyang was designated as the first pilot county for the "Save Old Houses Initiative" by the China Cultural Relics Protection Foundation. With the backing of this initiative, Songyang County actively embarked on the restoration of traditional rammed-earth houses and the training of traditional craftsmen.

Meanwhile, the roles of the government, social forces, and villagers were clarified to enhance villagers" sense of participation, allowing them to reside comfortably in traditional rammed-earth houses while spontaneously preserving and transmitting their traditional village culture.

In contrast, the comprehensive preservation and development of Wolong commenced relatively late and on a smaller scale, with numerous traditional dwellings in a precarious state. All indigenous inhabitants have relocated, leaving only a handful of scenic area staff. Compared to Songyang's "acupuncture-like" preservation mechanism, Wolong's development model resembles more of an exhibition site featuring adobe "Yikeyin" houses rather than an authentic traditional village. Local residents lack a sufficient understanding of adobe bricks.

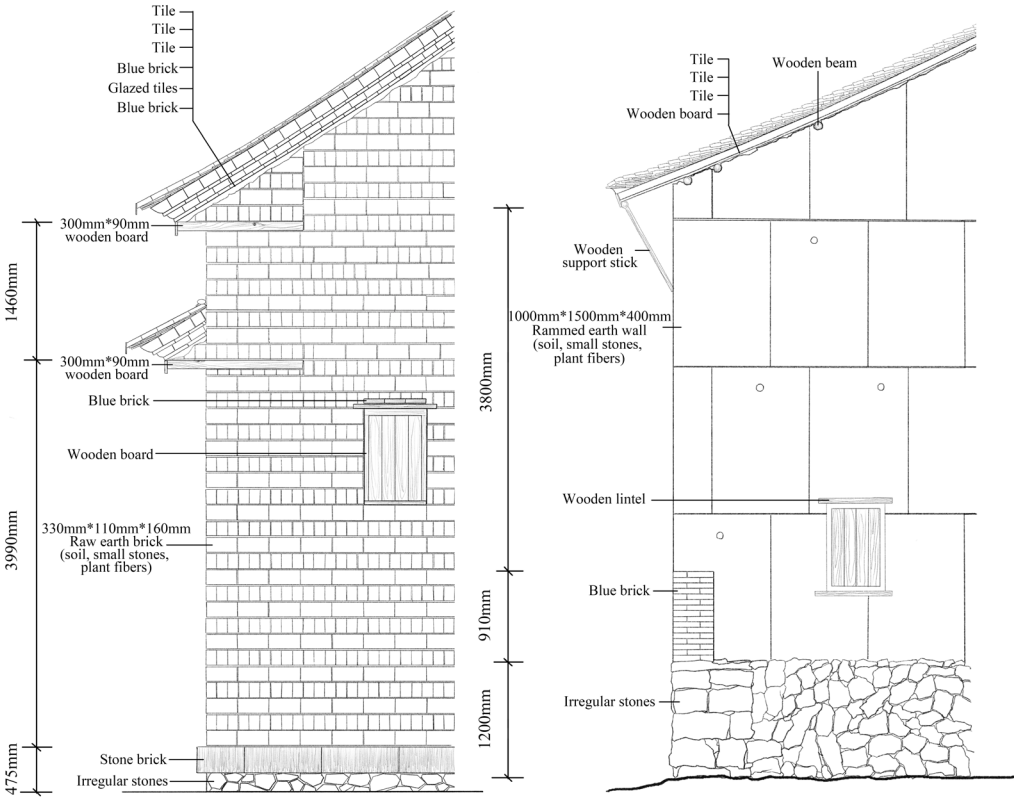

Fig. 11 – *Comparison of a seal of the Han Chinese in Dianzhong with a rammed earth house in Songyang, Southwest Zhejiang* (Author, 2025).

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Although mechanical brick production has replaced manual labor in newly constructed buildings, no improvements have been made to the soil mixture ratio. Consequently, within five years, the repaired buildings have already sustained damage.

While restoring Songyang, the government also invited numerous influential architects to engage in practical work there and hosted the "Songyang Architecture Competition". These modern buildings likewise utilize traditional natural materials such as soil, wood, and stone, yet they innovate in construction techniques. These architectural works seamlessly blend with local traditional rammed earth houses while accommodating modern aesthetics and requirements, thereby further enhancing Songyang's reputation and drawing a crowd of architectural enthusiasts to visit. Traditional materials and old buildings have undergone new developments in contemporary times.

Traditional folk houses evolve over time and space. While preserving their original characteristics, traditional villages require scientific and sustainable development to minimize destructive reconstruction. Songyang's approach of "architectural acupuncture and moxibustion" may represent a sensible means of preservation.

5. Summary and reflection

In both types of dwellings, raw earth walls do not serve as the primary load-bearing structures, and they share similarities in soil mixture ratios, both categorized as "raw earth" without the addition of chemical modifiers.

In terms of layout, both adhere to the traditional Han Chinese patriarchal system of hierarchy and precedence, utilizing the courtyard as a thematic element and evolving into forms such as the "linear" layout and multi-courtyard configurations based on specific needs.

In their specific constructions, both types of dwellings have adapted to local conditions, developing designs that integrate with the local ethnic characteristics.

In contemporary times, as traditional earthen dwellings gradually decline, Wolong and Songyang have taken different paths. Based on the current situation, it is evident that the preservation and inheritance of traditional dwellings should not solely focus on protecting traditional construction techniques and materials but should also encompass the preservation of the culture and lifestyle that have vanished alongside traditional earthen architecture. The preservation approaches of turning them into "museums" or "tourist attractions," as well as large-scale demolitions and reconstructions, lack authenticity and vitality. The vitality of rural areas and the diversity of traditional dwellings stem from the diversity and authenticity of life, emanating from the residents who have lived there for generations.

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Earthen Architecture in the Castle of Segart, Valencia (Spain)

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Abstract

The Castle of Segart is a small medieval fortification from the al-Andalus period (probably between the 12th and 13th centuries), which stands on a mount next to the town and in the Sierra Calderona. The castle has an irregular floor plan, formed by several walls that are sensibly adapted to the pronounced orography of the territory. Among the most significant elements that remain, it is worth paying attention to the towers, in particular those located to the north of the fortress. They are two square constructions, very close to each other and with a slight change of orientation. They are built with rammed earth walls with lime coating and reinforced with masonry bricks at the corners and other weak areas. To avoid direct contact with the ground, they are built on a base of masonry wall and lime concrete. As is the case with many fortifications in the Sierra Calderona, abandonment and natural risks, alongside with human intervention, have caused considerable deterioration of the castle, even to the point of losing the legibility of its volume development. In order to analyze the constructive geometry of this architecture and the pathologies that affect the structures, an exhaustive photogrammetric survey was necessary. On the redrawn plans, the singular constructive elements of the typology have been identified, the modulation used has been determined and a complete mapping of the pathologies has been studied. The constructive traces and the modulation used serve as support for the temporal location of the structures and would allow a stratigraphic study of this earthen architecture sample. The Castle of Segart is an example of the defensive constructions of the Sierra Calderona, with several singularities on which it is worth reflecting to determine its constructive phases and the outline of the walls that have shaped the fortress through history.

Keywords: *castle of Segart; rammed earth; constructive and metric analysis; putlog holes; degradation risks*

1. Introduction

The Castle of Segart stands on a hilltop north of town of Segart, in Valencia (Spain). It is located in Sierra Calderona, 300 meters above sea level and very close to Mount Garbí. It is a defensive compound of reduced dimensions, nonetheless, it has a high impact on its nearby territory due to the visibility of the remains of the towers. The population of the municipality of Segart amounts

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to 176 people, most of them living in the city centre at the foot of the mountain. However, it increases significantly during summer. Despite the loss of a considerable amount of the castle structures, its location, along with lack of high vegetation blocking the view and the exceptional height of the two rammed earth towers with lime coating, allows the fort to stand out and shape the landscape silhouette.

Fig. 1 – *Castle of Segart and its surroundings* (Jordi Vidal, 2021).

2. Historical context

The shortage of documentary references invites us to consider the historical context of the castle from a broader point of view, considering other fortifications located in Sierra Calderona. Both the castle and the nearby village are located in the Segart valley and they formed a frequently populated enclave since prehistory, due to its natural resources and location as a circulation point between the two slopes of Sierra Calderona.

The origin of the Castle of Segart is connected to an ancient fortification dating from the Andalusian period (*hsin* around the 12th and the 13th centuries). The historical urban core of Segart could have been developed on the slope near the castle since the village shows traces of the Andalusian structure nowadays. It presumably would have been a small area resembling an unfortified farmhouse (*qura*). In addition, burial sites (most likely of Islamic origin) have been found in the northern part of the castle slope. The findings of ceramic fragments dating from the 4th century B.C: points at the existence of a previous Iberian settlement.

Around 1233, the conquest of the Castle of Segart, along with other castles of the Camp de Morvedre region, has been documented although it was likely occupied by Muslims a short period afterwards. From then on, the fortification has been changing ownership until the expulsion of the Moorish in 1609, when it became temporarily uninhabited. In 1611 Segart was granted the Municipal Chart, which led to the resettlement of the region. There is no subsequent historical data aside from the 20th century photographs, showing an advanced state of decay.

3. Description of the building

The Castle of Segart is a medieval fortification featuring an irregular plan adapted to the orography of the region. It was composed by various walled enclosures among which we can highlight the three towers and the central cistern that are still preserved. These three towers probably were connected by a wall mostly disappeared nowadays. Together, the remains cover approximately a 1,122 m^2 area [1].

At top of the hill stand the three towers, arranged asymmetrically. North (T02) and northeast (T01) towers are very close to each other while the south one (T03) is farther away, both in terms of location and material nature. The two towers located in the northern area present a rectangular plan (5.02 x 4.68 meters according to the existing remains) and are about 10 meters away from one another. Both towers are built with the lime-crusted rammed earth construction technique and

[1] This graphic elevation, done by LEVArq, is included in the *Plan Director del Castillo de Segart.*

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are reinforced with masonry. Each of them has lost at least one of its boundary walls over time, especially towards the interior of the fortress. In contrast, the south tower (T03), located about 30 meters away from the other two, is built using coffered masonry walls and still maintains some important elements, including all its walls and the arched entrance. Thanks to this, it is possible to state that all the towers had a square floor (5.22 x 5.22m in the case of the south tower) and it is possible to identify the same modulation based in *codos geométricos* in all of them (1 *codo geométrico* equals 0.42 meters[2]).

Fig. 2 – *Castle of Segart plan* (El fabricante de espheras, 2021).

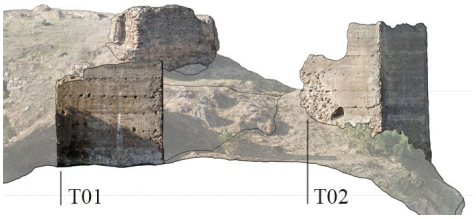

Fig. 3 – *East elevation of the Castle of Segart* (El fabricante de espheras, 2021).

Lastly, the central cistern is mostly preserved (although missing the vault) and there are some isolated wall fragments scattered on top of the hill. The cistern is located in the highest part of the hill, between the three towers. Its four walls have been partially preserved as well as some of its characteristic features. It presents a rectangular plan (4.98 x 3.40 meters) and its walls are built with coffered masonry. The lime mortar inner lining and the rounded corners support the hypothesis stated concerning its use. The subsequent repairs lead us to think that it has had a prolonged use over time.

4. Rammed-earth structures characterization. Construction analysis and state of preservation

The deep knowledge of the systems, construction techniques and material characteristics of this type of architecture allows us to improve the interpretation of defensive fortifications such as the Castle of Segart, which has been deeply neglected throughout its history. This article focuses on the specific constructive features of two of the castle towers, particularly, T01 and T02, both made of lime-crusted rammed earth and presenting similar features.

4.1. Characterization of rammed earth structures in the Castle of Segart

Fig. 4 – *East elevation of the northeast tower (T01) of the Castle of Segart* (El fabricante de espheras, 2021).

[2] A *codo geométrico*, also known as *codo común, codo antiguo o codo manual de 24 dedos*, equals 0,4179525 meters and, according to other authors, it also equals a measure of *media vara castellana, 1,5 pies y ¾ del codo oficial o rassasí de 32 dedos*.

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Both north (T02) and northeast (T01) towers are built using the rammed-earth wall technique. They have rectangular plan and are very similar in terms of size. One of the towers is rotated 62º with regard to the other (considering the highest part of the heap between both of them as the pivot point), most likely due to its location and the orography of the land. Their plan size is approximately 5.02 meters (equals 12 *codos geométricos* or *comunes*) x 4.68 meters. The height preserved is 7.05 meters in the north tower (T02) and 5.02 meters in the northeast one (T01).

In each tower, three elements are distinguishable in terms of construction. From bottom to top, there is a foundation plinth (clearly seen in the northeast tower), a coffered masonry and lime concrete base and, lastly the lime-crusted rammed-earth body. The foundation plinth is made of coffered *rodeno* masonry and lime concrete walls and protrudes from the tower wall around 1.15 meters. Above this, the coffered *rodeno* masonry and lime concrete base has the same width of the tower wall and a height between 1.17 and 1.5 meters. This item unifies the bearing surface of the wall and it is meant to protect it from water infiltration from the ground. Upon this base stand the lime-crusted rammed-earth walls which conform the majority of the towers. The corners of these walls are reinforced with *rodeno* masonry placed inside the coffered wall during its construction.

Due to the advanced state of deterioration, the thickness of the walls cannot be verified. However, in the top northwest corner of the north tower (T02), there is a small fragment that preserves the entire width of the rammed-earth wall, along with the inner side of its lime crust. This wall is 1.10 meters wide (2.5 *codos geométricos*) and, considering the similarities between the two towers and the almost square shaped plan, it would not be far-fetched to think that all walls would have been the same width, at least in the upper levels.Among the conserved construction elements made with rammed-earth, traces of the mobile wooden formwork can be clearly seen, showcasing its construction technique. By measuring the distance between horizontal formwork marks, it can be established that the walls were executed using formwork modules of approximately 84 cm tall (2 *codos*

Fig. 5 – *North tower metric and constructive analysis (T02) of the Castle of Segart* (El fabricante de espheras, 2021).

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geométricos). The preserved rammed-earth's formwork vertical marks (clearly visible in the northeast tower) reflect a 2.09 meters horizontal box size (5 *codos geométricos*) at the central part of the wall and a 1.46 meters size (3.5 *codos geométricos*) at the corners. Based on the number of horizontal traces, it can be concluded that the rammed-earth wall formwork would have been composed of four wooden side planks of different sizes.

As seen in the northeast tower (T01), the vertical marks on the rammed-earth wall do not show discontinuity with highlights, contrary to what happens with the horizontal union marks between the formwork modules. This uniformity indicates that some of the tower walls could have been built using a continuous rammed-earth wall system that prevents the corners from weakening.

Different types of putlogs used for the formwork hold have been identified attending to the holes left out in the walls: circular semi-detached rod putlogs and rectangular ones. The semi-detached rod holes are located in the lower part of the northeast tower (T01) and are presumable left by two flexible wooden rods most likely made of hazelnut or almond. Each hole has a diameter of 2 cm and the putlogs were placed in parallel, at a distance of 10.5 cm from each other.

In all likelihood, these putlogs had one single utilization, covering the full width of the wall and being set at a distance from 48 to 58 cm from each other. This type of putlog holes has only been found in the lower row of this tower, which leads to the hypothesis of a wider wall due to the general association of these kind of putlogs with thick wall widths.

From this row on, the rest of the walls show rectangular wooden putlog holes in different sizes. The most common ones were the slightly squared orifices (7 cm on each side), but narrower ones can also be found (of approximately 7 x 1.5 cm). These are inherent to thick walls and support the hypothesis that the walls had a similar width.

It is possible to see a separation between putlog holes of 0.48 meters (1 *codo geométrico)* or 0.627 meters (1.5 *codos geométricos*), although it does not seem to follow a consistent rhythm.

Fig. 6 – *Castle of Segart semi-detached putlog holes* (El fabricante de espheras, 2021).

Fig. 7 – *Caste of Segart rectangular putlog holes* (El fabricante de espheras, 2021).

Fig. 8 – *Caste of Segart rectangular putlog holes* (El fabricante de espheras, 2021).

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Fig. 9 – *Castle of Segart rectangular half putlog hole section* (El fabricante de espheras, 2021).

The hole left by one of these putlogs can be clearly seen in tower T02, showcasing the traces left in the section of the wall by the transversal wooden pieces used in the formwork. In this case, it is evident that the putlogs used in this part of the tower do not penetrate the full width of the wall since the hole is 45 cm deep from the outer side of the wall (figure 9).

The exterior finishing of the rammed-earth walls of the two towers' bodies (except for the base, where it cannot be seen) is the outer lime crust layer. This finishing mortar is executed as part of the construction process of the wall. A lime mortar wedge is placed against the formwork prior to the dumping in of the batch of tamped earth. With this process, a continuous coating is achieved on the outer part of the wall once the formwork is removed, acting as a protective layer. At the upper part of the towers, where the walls have lost most of its core, it is possible to measure the width of the outer lime crust, which goes from 10 to 12 cm. In some parts the batches of lime mortar wedged against the formwork can be found around 5 cm apart from each other.

4.2. State of preservation

When it comes to the analysis of the main pathologies that affect the structures of the Castle of Segart, it is crucial to consider both physical and atmospheric factors specific to its surroundings. In this respect, the two main disrupting factors are water and wind.

Undoubtedly, the most aggressive agent is water due to its dissolving and disintegrating capacities, as well as for allowing dissolved substances to travel through it. It is particularly relevant in this case given that the cornice of all structures of the castle no longer exists, revealing the earthen core of the walls. In most examples of lime-crusted rammed-earth walls in this castle, the loss of cornice has led to the erosion and deep loss of material due to water infiltration, as it is shown in the remaining structures. Particularly, in the case of the north tower, the top of the walls keep only the exterior lime crust (having lost both the interior one and the earthen core) and just the areas reinforced with masonry show a certain integrity.

Fig. 10 – *North tower (T02) of the Castle of Segart, interior* (El fabricante de espheras, 2021).

Fig. 11 – *Decorated cladding wall and semi-detached putlog holes of the northeast tower(T01) of the Castle of Segart* (El fabricante de espheras, 2021).

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Due to the effects of the water, the exterior part of the walls presents stains and runoffs, as well as a loss of lining and material weathering. The erosion of materials running through the walls has led to the loss of wall thickness, usually around the putlog holes and of small significance. Nonetheless, there are a few more severe cases that have caused major holes and material losses, especially in the areas next to the soil fillings.

Besides, despite the existence of a base which separates the rammed-earth structures from the ground, the soil fillings around the towers facilitate the water penetration through the base. This causes stains, humidity and even the presence of salt in the lower part of the towers. Furthermore, it also has caused the separation of linings from the facing of the walls, which means that only a few fragments in a very poor state have survived to the present day. The natural runoff of the terrain leads the rainwater through the more eroded areas, bringing it inside the towers and overflowing on the side walls. This explains the presence of humidity in the base of the towers and the important loss of the side walls in towers T01 and T02, contrary to the structural entirety of tower T03 (of coffered masonry and rammed earth).

In addition, two more environmental factors should be considered: the strong winds on the highest part of the hill and the lack of elements acting as a barrier against them (such as dense vegetated areas). Both of them favour a constant erosion of the remains of the Castle of Segart, as well as the accumulation of materials. One of the most significant hazards detected lies in the impossibility of adapting the preserved defensive structures to the lifestyle change as well as to the current needs of a village like Segart. As a preservation strategy, finding a use fitting the archaeological remains of the castle is essential to guarantee the care and investment required by a construction of this kind. It is worth mentioning that the resources available to rural villages, the size of the fortification and the already pointed difficulty in finding a use that meets the requirements of the modern population represent one of the biggest obstacles for the conservation of the defensive heritage.

5. Conclusions and future preservation

The study of the geometry of the formwork and of the putlog holes proves that both towers (T01 and T02) belong to the same construction period, while the differences with the third tower clearly point at a leap in the erecting of the fabric. In addition, this rammed-earth wall technique reinforces the current hypothesis that places the construction of the Andalusian castle in the late 12th century or early 13th century. To deepen our knowledge of the castle a comparative analysis could be made with other contemporary castles with similar characteristics, such as the Castle of Gestalgar or the Castle of Enguera. It is also advisable to carry out archaeological works located in strategic points (such as the potential access or the interior of the towers). Particularly, if it is proven that the thickness of the walls is greater at the base of the towers, these works would further validate the hypothesis that the semi-detached putlogs are associated with walls of greater thickness and whether this responds to the presence of an interior cistern or to reinforcement of the structure. When it comes to the removal of the soil filling in the inside of the towers, special attention must be paid to the possible change of its structural behaviour. Attending to this, the stabilisation of the walls becomes a priority. In this respect, the scantiness of specialized labour in this construction technique may hamper the intervention guaranteeing a good execution. Consequently, particular attention must be paid to the works by an expert follow-up. Given the state of deterioration of the preserved structures, especially the upper part of the walls, it is urgent to take measures for their protection. The loss of the cornice on top of the walls along with the continuous exposure to atmospheric agents (rain and wind particularly) present an ever-increasing risk given that the earthen core of the walls is the weakest part and could disintegrate when the

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outer facings are lost. An example of these hazards can be seen in the fragments in which only the exterior lime crust is preserved, particularly in the T02 tower. On the other hand, there is a risk of the castle being forgotten by the residents of Segart due to problems of accessibility and the persistent state of neglect, both material and in terms of visibility from the village. In order to ensure its global conservation and a better understanding of the compound, the measures of the 2021 Master Plan must be applied and a monitorization of the current state of its structures and the behaviour of the materials after the interventions should be guaranteed. For that, a tailored conservation and maintenance programme which includes periodic evaluations and treatments graphically documented must be followed. To improve the accessibility to the castle, the future works on the remains should facilitate its visualization from the urban setting. Also, as a way to increase the number of visitors and promote a sense of belonging among the population, the local govern could organize ephemeral socio-cultural activities in the castle grounds. In any case, a strategy of both physical and digital accessibility should be developed to place value on the castle.

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Exploring Earth-Building Techniques with Local Knowledge Holders in Siaya County, Kenya

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Topic: T2.2. Study of traditional materials, techniques and construction crafts

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Abstract
Earth construction techniques such as wattle and daub, adobe, compressed earth blocks (CEB), cob, and rammed earth offer sustainable and cost-effective solutions for building in various contexts. This study investigates the feasibility of implementing these methods with local citizens, focusing on the adaptability, accessibility, and challenges of each technique. The research evaluates the step-by-step processes and resource requirements, and skill demands involved in their execution. By conducting field experiments and engaging communities in hands-on workshops, the study identifies key factors influencing successful construction, including material preparation, tools, and supervision. The findings highlight the potential of these earth-building techniques to empower local communities, and promote environmentally friendly construction practices. Recommendations are made for optimizing workflows and community engagement strategies to ensure broader adoption and scalability. This work contributes to the discourse on sustainable architecture by demonstrating how individuals can play an active role in creating durable and culturally resonant structures using local resources.

Keywords: *earth building techniques; building process; community practice; Kenya; sustainable architecture*

1. Introduction

The demand for sustainable construction solutions has never been more urgent, as the global building sector faces increasing pressures from climate change, resource depletion, and rapid urbanization (Franziska Schreiber et al., 2023). In this context, traditional earth construction methods are regaining significant attention and interest (Dejeant et al., 2021). Time-tested vernacular techniques, such as wattle and daub, adobe, compressed earth blocks (CEB), cob, and rammed earth, align closely with principals of ecological balance, affordability, and low environmental impact (Rong & Bahauddin, 2023; Zawistowski et al., 2020). Especially, CEB is seen as a modern alternative to traditional techniques with benefits like consistency of quality, increased compressive strength due to compression, highly flexible in forming the brick design, and usable for rural and urban structures (Guillaud, 1995). Several studies underscore the potential of earth-based techniques to reduce carbon emissions and improve thermal comfort in buildings (Pacheco-Torgal & Jalali, 2012; Keena et al., 2022; Ouedraogo et al., 2024). The technical properties can also keep pace with

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industrial building products if they are designed and constructed correctly. The use of fibres or stabilizers like lime can even enhance them and reduce shrinking rations. The mechanical properties are also significantly improved by adding cement (Proterra et al., 2009). This should be viewed critically due to its poor life cycle assessment values and the contamination of the soil during deconstruction, as the two materials, cement and soil, can no longer be separated from each other. Despite their advantages, the scalability and broader adoption of earth construction methods remain limited. Challenges of building with earth such as inconsistent material quality, labour intensity, and a lack of standardized practices and technical skills often hinder their widespread application (Rojat et al., 2020). Another factor is the negative association of earth buildings with poverty among the population (Barbacci, 2020). These challenges can be countered with participatory building processes. Community of practices (CoPs) in building construction offers several positive aspects. It fosters connections among individuals, groups, and organizations (Weil, 1996); strengthens connections to places; and nurtures a sense of empowerment and self-worth (Melcher, 2020). The participants acquire technical skills and communication skills (Holmes & Woodhams, 2013). This also includes the transfer of knowledge, which takes place automatically and positively between participants of different or the same generation (Ruikar et al., 2009). Participative building processes have become prominent for involving local communities in designing and constructing their environments. This approach democratizes the building process and ensures structures meet users' specific needs and preferences. Citizen involvement fosters ownership, appreciation, and responsibility, resulting in more sustainable and accepted outcomes. ("Architektur – Gemeinschaft B.R.O.T.-Pressbaum," n.d.). This paper examines earth construction methods in local communities to promote sustainable architecture. In a workshop with Sauti Kuu Foundation participants in Nyangoma Kogelo, the study evaluated the efficiency, tool needs, and scalability of different techniques. By tackling practical challenges and enhancing adaptability, the research aims to develop strategies for wider adoption. The findings emphasize community-driven, low-impact practices that boost local resilience and inclusivity, offering scalable solutions to global sustainability challenges.

2. Methodology

2.1. Location

The workshop was collaboratively developed and conducted with the Sauti Kuu Foundation and local citizens actively involved with the Foundation. These participants are members of the Luo community from Siaya County in eastern Kenya, near Lake Victoria. The Luo are one of Kenya's most prominent ethnic groups, renowned for their rich cultural heritage. Traditionally, the Luo constructed their homes using the Wattle & Daub technique, which remains prevalent today. The building workshop was held on the grounds of the Sauti Kuu Foundation in Nyangoma Kogelo. The subsequent illustration (Fig. 1) indicates the orientation of the sample walls, highlighted in red, along with the workshop site.

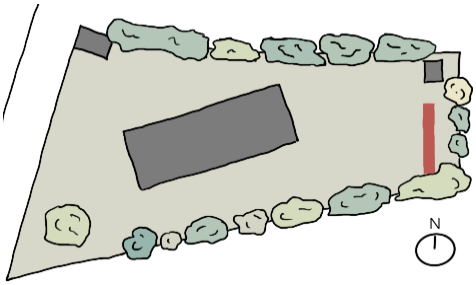

Fig. 1 – *Orientation of sample walls on workshop site.*

2.2. Workshop set-up

In this workshop, which was jointly facilitated with the Sauti Kuu Foundation, 5 different earth construction techniques were tested within the community, including wattle & daub, cob, rammed earth, compressed earth blocks and adobe.

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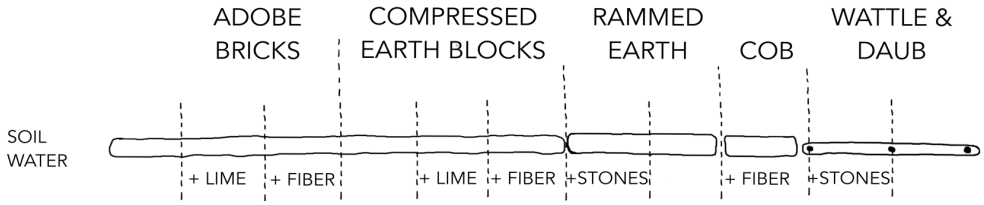

Fig. 2 – *Schematic sketch of test wall arrangement.*

Each wall sample measured 0.5m in height and 1m in length, with slight variations in width. The walls were built with the help of 61 people, all beneficiaries of the Foundation. This included adults (31) and children (30).

To accommodate the drying period for clay bricks and compressed earth blocks, the workshop was divided into two sessions, spaced seven days apart. During the introduction, building techniques were explained, supplemented by a YouTube video demonstration ("Building with Mud: A Continuum - YouTube," n.d.). Each construction process for the model wall was illustrated on A3 paper. Participants were divided into five mixed-age groups, each focusing on a different construction method. The test walls were built following the scheme in Fig. 2. For Adobe and CEB, three walls were made: one with only soil, one with lime stabilizer, and one with fibres. The two rammed earth samples, with only soil and with stone layers, were constructed together. Only one cob wall and two wattle & daub walls (one with stone infill and one with plain soil) were built.

2.3. Building processes

For the building process and time measuring it was ensured that the required building materials are available and ready on the construction site as well as the necessary tools.

- **Wattle and daub**: The wattle and daub technique is the most well-known and is widely used in both modern and traditional Luo construction. It requires minimal tools, namely a machete and a digging pole. For a sturdier wall, two wooden wattles were positioned about 15 cm apart and bound together with locally sourced sisal fibres. One section of the two-meter test wall was filled with stones and the other with soil (Fig. 3). After a week, it was plastered with a traditional earth and cow dung mixture.

Fig. 3 – *Wattle & Daub group with finished test wall.*

- **Cob:** For the cob construction technique, a 0.5-meter-deep hollow was excavated 2 meters away from the test wall site. Initially, the vegetation layer was removed and set aside. The loose soil was then combined with dry Vetiver fibres found on-site, which were trimmed to lengths of 10–15 cm (Fig. 4). This mixing process was done manually, using hands and feet. The prepared cob mixture was then carried by hand to the test wall location, where it formed a structure approximately 35–40 cm wide (Fig. 5). The mixed earthen lumps were placed layer by layer, both side by side and on top of one another. Finally, a machete was used to smooth the sides of the wall.

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Fig. 4 – *Preparation of Cob Mixture.*

Fig. 5 – *Cob building in process.*

- **Rammed earth:** For constructing the rammed earth wall, a two-meter-long formwork was created from wooden screen-printing panels. These panels were reinforced with Markhamia lutea (Siala) wood stakes, which were driven into the ground and secured with nails at the sides. The formwork's ends were enclosed with additional screen-printing panels, as shown in Fig. 6. The formwork was filled with 15 cm of on-site soil and compacted using a homemade wooden rammer. Soil was sourced 2–3 meters from the test wall, utilizing the subsoil after removing the top 30-50 cm. Per the ESRI geographical soil map, this soil is clay-rich (with approx. 50%) (Esri environment and GIS User Community 2023). Due to budget constraints, no additional sand was incorporated, though adding sand would reduce stress cracks and enhance compressive strength. The recommended practice is to analyse local soil samples in a laboratory to determine the optimal mixing ratio. However, to focus on practical construction and because the test wall was only 0.5 meters high, this step was skipped. After tamping the first layer, gravel was added to one 1-meter-long side, followed by the placement and tamping of another 15 cm of loose soil. This sequence was repeated until the wall reached 50 cm in height.

Fig. 6 – *Group of rammed earth building process with finished framework.*

- **Adobe:** The soil excavated from the construction site was prepared for the adobe bricks. This mixture was then placed into a handmade wooden adobe formwork (Fig. 7). Using a board, the adobe bricks were carefully lifted from the mold (Fig. 8) and placed on the nearby meadow to dry. To prevent direct sunlight exposure and minimize stress cracks, the bricks were covered with hay. For each variation - one with only soil, one mixed with lime (soil/lime 6:1), and one with fibre - 20 bricks were produced. After a week of drying, they were assembled using a soil/lime mortar.

Fig. 7 – *Adobe framework, fabricated by Jacob Wanjala Wakoli.*

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Fig. 8 – *Preparation of Adobe bricks.*

- **Compressed earth blocks (CEB):** The CEBs were produced on-site using the Makiga Press (Fig. 9). The soil was sourced directly from the construction site, adjacent to the test wall location, and was used without further processing. Three distinct test walls were constructed using this method: the first using only soil, the second incorporating fibres, and the third supplemented with lime (soil:lime - 6: 1). For each 1-meter-long test wall variation, 21 bricks were pressed. Once pressed, the bricks were left to cure on-site for a week. After this drying period, they were assembled using a slurry of earth-lime mortar.

Fig. 9 – *Infilling process of the "Makiga" CEB Press.*

2.4. Evaluation

Firstly, the time participants spent on each technique was analysed and compared. Using this data, the additional time needed to increase the height of a 1-meter wall to 2 meters was estimated to assess the work processes of different construction methods. The number of tools required, and formwork complexity were also evaluated. Formwork complexity was rated on a scale of 1 to 3 points: 1 indicates low complexity, 2 indicates medium complexity, and 3 indicates high complexity.

3. Results

3.1. Construction time during workshop

The graph in Fig. 10 illustrates the active construction time (excluding curing) from the workshop's first two days. On day 1, adobe and compressed earth blocks (CEB) were made and set to dry; on day 2, these dried bricks were assembled into the sample wall. Fig. 10 reveals that constructing a 1 m wide, 0.5 m high rammed earth wall is the most time-consuming compared to cob and wattle & daub. Though adobe and CEB production are quicker, they require curing time. Cob is the fastest method, but layer drying should be considered for taller walls. The traditional Luo wattle & daub technique is the second fastest.

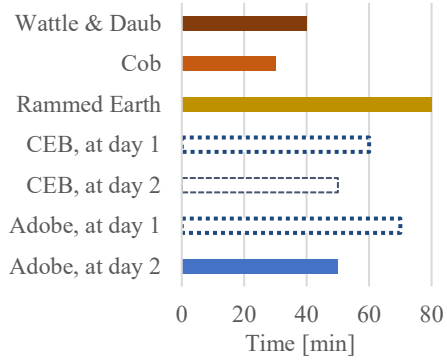

Fig. 10 – *Construction time of different earth building techniques during workshop day 1 and day 2.*

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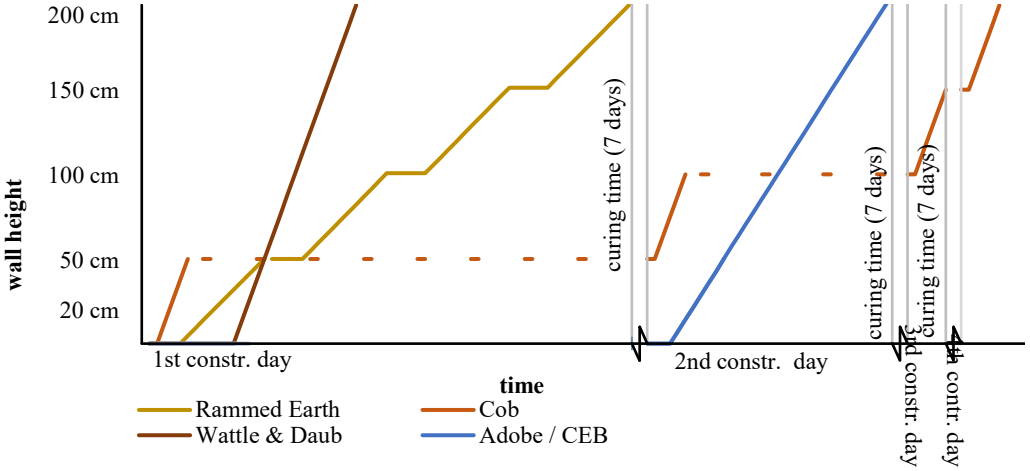

Fig. 11 – *Estimated construction time of different earth building techniques for building a 1 m wide and 2 m high wall.*

3.2. Estimated construction time for a 2 m high wall

The workshop time was used to estimate the construction time for a 2-meter wall using each technique. Since the methods involve different processes (active and passive construction time), the graph (Fig. 11) shows that faster initial construction leads to longer curing phases, resulting in a longer total process. For instance, the cob method builds in 50 cm layers, requiring each to dry before the next can be added, significantly extending the total construction time despite being the fastest method in the workshop. The production of adobes and compressed earth blocks (CEB) requires a drying period, with bricks made on one day and assembled the next. The fastest method is traditional wattle & daub, followed by rammed earth. An additional advantage of wattle & daub is that once the timber structure is up, the roof construction can begin, unlike with other techniques.

3.3. Tools required

All techniques use a digging pole for soil preparation (Tab. 1). Wattle & daub and cob require the least materials, needing only a machete for timber or fibre preparation; other tasks are done manually. Adobe involves a simple handmade mold, while compressed earth blocks use the "Makiga" machine, which is easy to operate with brief training. Rammed earth is the most complex, requiring numerous tools like a hammer, spanner, and tamper, as well as careful formwork assembly and disassembly to prevent damage.

4. Discussion

4.1. Optimizing & skill demand

- **Preparing Soil:** The use of additional construction machinery can accelerate building processes and reduce physical labour, particularly in soil preparation. However, it increases costs and requires skilled operators. Moreover, heavy machinery may compromise site safety—especially where child participation, essential for educational and empowerment goals of the Sauti Kuu Foundation, is intended.
- **Wattle & Daub/Cob:** These techniques are well-established and allow for rapid implementation. At this stage, process optimisation is not a priority. However, subsequent investigations may focus on enhancing the long-term durability of the construction system.

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Table 1 - *Required tools for each construction technique.*

	Digging pole	Machete	Shovel	Hammer	Tamper	Formwork Complexity
Wattle & Daub	•	•				
Cob	•	•				
Rammed Earth	•		•	•	•	•••
Compressed Earth Block	•		•			••
Adobe	•					•

- **Rammed earth:** To optimise the workflow of rammed earth construction, the experiment demonstrated that improved formwork design is essential to facilitate handling and assembly. Moreover, the presence of a skilled trainer on-site is critical to guide workers in achieving the appropriate soil consistency, which is vital for structural stability and long-term durability.
- **Adobe/CEB:** Both adobe and compressed earth block (CEB) techniques require initial training, particularly in determining the appropriate soil-to-binder mixing ratio and in the correct handling of equipment**,** whether operating the press or placing soil accurately within the formwork. However, CEB benefits from a more consistent brick quality by using the same pressing machine each time (Guillaud, 1995), whereas Adobe, which relies on manual techniques, can result in varying degrees of quality.

4.2. Community engagement strategies

As exemplified by the Sauti Kuu Foundation, community engagement is key to advancing sustainable construction.

Participatory design fosters ownership, preserves indigenous knowledge, and builds local skills, while reducing stigma around earthen materials. Integrating traditional knowledge with modern engineering enhances the durability and performance of earth-based structures.

5. Conclusion

This study explored the construction time of five vernacular earth-building techniques—wattle & daub, cob, adobe, CEB, and rammed earth—through applied research with the Sauti Kuu Foundation in Nyangoma Kogelo. The results underscore the efficiency and contextual appropriateness of wattle & daub, a traditional Luo method, which outperformed others in speed and simplicity. While techniques like cob showed promise in controlled environments, their full-scale application revealed limitations in time efficiency. These findings demonstrate the continued relevance of vernacular methods in contemporary construction, particularly when locally adapted and community driven. Moving forward, integrating indigenous knowledge with modern performance criteria—such as structural durability, resource efficiency, and self-build potential—will be crucial. A holistic, interdisciplinary approach is needed to translate vernacular principles into scalable, sustainable, and culturally resonant solutions for today's-built environment.

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Hakka Architecture in China: Analysis of Rammed Earth Buildings

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Abstract

The architectural techniques and styles of Hakka Tulou, rooted in ancient Chinese residential architecture, reflect a harmonious adaptation to the natural environment and a profound connection to local culture. These structures embody the cultural identity and spiritual heritage of the Hakka people, representing a unique aspect of Chinese architectural history. This study selects Hakka Tulou, a traditional Chinese architectural form with distinctive Hakka characteristics, as the research focus to better understand the ingenuity and cultural significance of this ethnic group and their contribution to Chinese architecture. Drawing on existing literature and visual materials, this paper investigates the site selection principles, architectural features, typological evolution, and construction techniques of Hakka Tulou. It examines how these structures balance practicality, cultural symbolism, and environmental adaptability. Additionally, the current condition of Hakka Tulou is analyzed, alongside the challenges these buildings face in modern society. By addressing these topics, this research aims to provide a solid theoretical foundation for further studies. It offers valuable insights into the preservation and sustainable development of Hakka Tulou, ensuring their legacy endures in the evolving landscape of Chinese heritage.

Keywords: *earthen architecture; rammed earth; Hakka; China*

1. Introduction

With the rapid development of modern urbanization, traditional Hakka *Tulou* can no longer fully meet people's living needs or the demands of economic growth. Many young people have left Hakka villages, leading to a decline in the preservation of *Tulou*. At the same time, cultural exchange often flows in one direction—from dominant to weaker cultures—causing minority traditions to face the risk of fading or even disappearing in the context of globalization. This decline can occur both spiritually, such as in beliefs and customs, and materially, such as in village forms and architectural styles.

Hakka *Tulou* are large, enclosed traditional dwellings built by the Hakka people in China using rammed earth. Unlike typical rural houses, they are multi-storied, highly defensive, and designed for communal living. *Tulou* are typically built in circular or square shapes, but their height and form can vary depending on regional geography, social conditions, and the financial resources of the builders at the time.

Their unique structure reflects the Hakka's collective lifestyle, spatial wisdom, and strategies for coping with social unrest and harsh environments. As a vital part of Hakka culture and even a recognized World Cultural Heritage, Hakka *Tulou* reflects the essence of traditional

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Chinese culture through its architectural style, internal structure, and *Feng Shui* principles. Known for their diligence and strong sense of community, they have developed a distinct language, customs, and architectural traditions—among which the *Tulou* stands out as a symbol of collective living and cultural resilience.

2. Methodology and objective

The Hakka people are a subgroup of the Han Chinese who originally migrated from central China and later settled in regions such as Fujian, Guangdong, Guangxi, and Jiangxi. Therefore, this study focuses on representative *Tulou* structures in these areas.

The research methods include literature review, field study, comparative analysis, and visual analysis of elements such as exterior appearance, internal layout, and historical context.

The aim is to explore the architectural and cultural features of Hakka *Tulou* and identify the risk factors affecting their preservation. Additionally, the study proposes conservation strategies that take into account their cultural and social significance.

To study and analyze rammed-earth architecture, exemplified by Hakka architecture, in order to propose effective solutions for its conservation and restoration, considering both its historical and cultural value as well as the technical challenges it presents.

3. *Tulou* Address Selection

Hakka culture is a tradition born out of mobility and migration, a characteristic reflected in the very origin of its name:

> The Hakka, literally mean 'guest families' in Chinese, are Han Chinese people thought to have originated from the lands bordering the Yellow River. In a series of migrations (five times), the Hakka settled their present areas in Southern China (Guangdong, Guangxi and Fujian) (Yang & Tang, 2020, p. 1).

Throughout the process of migration, in order to adapt to the needs of social production, the Hakka people gradually developed a distinctive cultural and architectural identity through evolution and innovation. This process gave rise to a unique form of traditional Chinese architecture with pronounced Hakka characteristics: Hakka *Tulou*.

Fig. 1 – Hukeng Tulou Cluster, in Yongding County,Fujian Province, geographically located next to mountains and water (Cai, 2021).

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From a historical perspective, the emergence of this architectural form is closely tied to the broader social context of China at the time. In traditional Chinese culture, clan-based communal living was the dominant mode of residence. Members of the clan shared a common ancestry, with kinship serving as the link between individual nuclear families. "The ancestral hall symbolized and centered the clan, genealogical records provided the relational framework, and clan-owned fields served as the material foundation —these were the main characteristics of the feudal family system" (Wang & Guan, 2021, p. 240).

Moreover, given the frequent wars and social unrest in ancient China, the need to defend against external threats became one of the fundamental concerns of the Hakka community. This communal living model significantly enhanced clan cohesion, thereby greatly improving the defensive capabilities of the Hakka people and ensuring the safety of its members.

Similarly, due to migration, the design and location of *Tulou* were, to a certain extent, tailored to "adapt to the particular local climate and environment where those dwellings were built" (Katayama, 2011). Natural factors were considered a fundamental criterion in the site selection of Hakka *Tulou*. The design of residential areas and the placement of individual structures took into account elements such as solar energy, wind energy, and water resources to ensure the basic survival needs of the Hakka community. This allowed the *Tulou* to fulfill essential economic functions, such as supporting agricultural activities, as well as basic living requirements.

As "the traditional Chinese art of designing environments and physical spaces" (Kryžanowski, 2021, p. 60), *Feng Shui* has been widely practiced in Chinese folk traditions for thousands of years. Its principles are also evident in the site selection of Hakka *Tulou*, characterized as incorporating "both scientific elements and strong superstitious overtones" (Luo & Lin, 1997, p. 61).

"*Feng Shui*'s fundamental rule in determining location for settlement is a landscape with abundant clear water and fertile land with good environmental conditions to provide good production, life and prosperity of descendants" (Katayama, 2011).

This reflects the inheritance of Feng Shui as a traditional Chinese philosophy with intrinsic ecological adaptability. It also embodies the Hakka community's ideal model of life, integrating cultural values into the natural environment to maximize the functionality and value of living spaces.

Furthermore, Lowe (2012), in his analysis of the structural elements supporting Hakka *Tulou*, pointed out that the architectural design not only prioritized defense and the shared use of courtyards and staircases among families of the same lineage but also ensured comfort with warm winters and cool summers. Thus, mountains (or farmland) and water (such as rivers or lakes) played an indispensable role in the site selection of *Tulou*.

4. The definition and characteristics of Hakka *Tulou*

- Space Utilization: the area of a circle with the same circumference as a square is larger, which means that constructing a round *Tulou* provides more usable space compared to a square one.
- Savings on Construction Materials: the round roof requires only two slopes, simplifying construction and reducing both labor and material costs.
- Uniform Size: the structural wooden components of a round *Tulou* are of uniform size, allowing craftsmen to calculate the necessary dimensions more efficiently during the design process.

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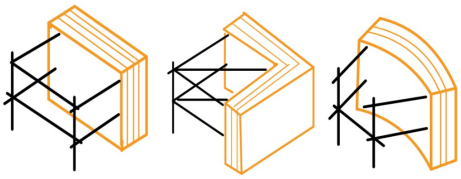

Fig. 2 – Square and round Tuqiang components (Ye, 2024).

5. Morphological changes of Hakka *Tulou*

The more primitive *Tulou* is surrounded by a circle of *Tuqiang* (which means a wall made of rammed earth).

Compared to ordinary residential buildings, Hakka rammed-earth buildings are larger in scale. The rear and side sections of a *Tulou* consist of four stories, while the front hall comprises two stories, connecting seamlessly with two horizontal rows of two-story houses at the front. This design aims to enhance the defensive capacity of the structure.

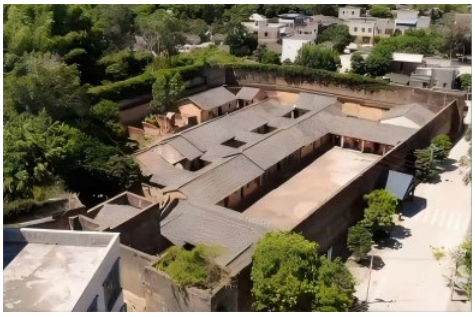

Fig. 3 – *Hepu County, Quzhang Township, "Weilong Building"* (Ye, 2022).

Fig. 4 – *Yongding County, Hukeng Town, "Fuyu Building"* (National Geographic Chinese, 2020).

Fig. 5 – *Yongding County, Gaopi Township, Shangyang Town, "Yijing Building"* (Jianshu, 2020).

Completely straighten both vestibules and the two horizontal roofs to minimize changes in the eaves, and enhance the lower corridor to make it appear simpler and more defensive.

Fig. 6 – *Yongding County, Hukeng Town, "Jiusheng Building"* (National Geographic Chinese, 2020).

As Huang (2013) pointed out in his related study, it evolved into a building with two vestibules and two horizontal sides of the same height, approaching the shape of a standard square building. However, the four sections of the roof have not yet been connected. As is typical in square *Tulou*, the roof will eventually be reduced to a single strip.Therefore, the square *Tulou* is a fully defensive building structure.

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Fig. 7 – *Zhencheng County, Hukeng Village, Yongding County, Longyan City, Fujian Province, China* (Wei, 2018).

Round *Tulou* are famous for their unique ring-shaped structure. Typically, they expand outward from a central point to form one or more concentric circles. Each circle represents a different living space, and there is usually a *Citang* (which means family ancestral hall) at the center.

This design makes this type of building uniform in terms of lighting and ventilation, and it provides strong defensive features. At the same time, the interior space of the round *Tulou* is spacious, which supports collective living and community activities among family members, reflecting the popular customs of the Hakka people to live together as a group.

6. Construction process Hakka *Tulou*

6.1. 打石脚 *Dashijiao* (Foundation and footing)

The foundation of a wall is constructed during the *Dashijiao* phase. Before laying the foundation, it is essential to determine the type and characteristics of the building, such as its shape (square or round), the number of floors, and the number of rooms, all based on the size of the base, the required number of rooms, and the available resources.

The foundation pit is commonly known as *Dajiaokeng* (大脚坑), which translates as trench located beneath the ground, while *Xiaojiaokeng* (小脚坑) refers to the foundation of the wall and the base of the waist-high wall situated above the ground.

6.2. 行墙 *Xingqiang* (Rammed earth wall)

In *Tuqiang*, bamboo or cedar branches are placed horizontally. Typically, two layers of wooden bars are laid in each *Hangtu*. Haangtu is a traditional construction technique in which moist earth is compacted layer by layer within temporary molds to form solid walls or foundations. It is known for its durability, thermal performance, and sustainability. The front and rear ends of the bamboo bars are aligned with each other, forming a circle, which in the Hakka village is known as *Tuogu* (拖骨), translating as "dragging bone," because bamboo or wood can be used as the skeleton of a building. The square corners of the exterior earth wall are also reinforced with a special weave, namely thicker cedar or thick cedar boards fixed in an "L" shape. In common parlance, it is said, “seven of bamboo, eight of wood,” because bamboo harvested in the seventh month of the lunar calendar and cedar harvested in August contain less water, making them less susceptible to moths and other insects. These reinforcement measures significantly enhance the integrity of the *Tuqiang*.

Some *Tulou* are equipped with defensive cannons and shooting holes, which are mainly made of chiseled stone in the shape of cannons or buried in the walls with bamboo tubes.

6.3. 献架 *Xianjia* (Wooden frame construction)

Each layer of the *Hangtu* wall must have a well-excavated groove at the top, where wooden layers, pillars, and beams are placed.

The exterior of each floor rests on a *Tuqiang*, which acts as a load-bearing wall, while the interior is supported by wooden pillars. Normally, a beam is raised between the wooden pillars, on which several joists are placed in each room. The other end of the joists rests directly on the exterior wall.

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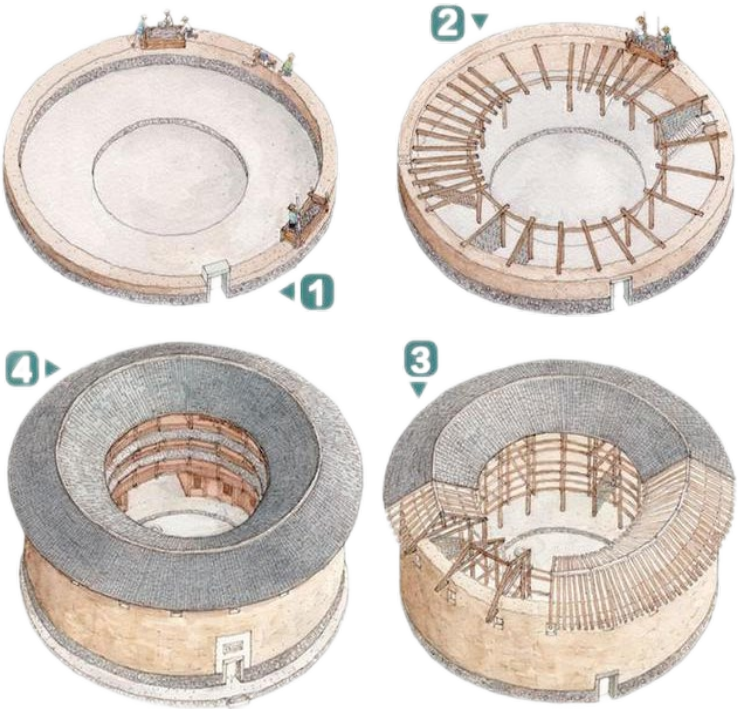

Fig. 8 – *Tulou's construction method* (Xie, 2021).

The end of the joist supported by the *Tuqiang* must be slightly elevated so that, when the wall dries and shrinks, the floor remains at the proper height. Each time a layer of high *Tuqiang* is tamped, a groove is excavated in the *Tuqiang* to insert the wooden keel of the floor. A pillar is placed at the opening gaps, and a beam is placed above it, a process known as "*Xianjia*."

6.4. 出水 *Chushui* (Tiling and sealing)

When the *Tulou* is built to the final floor, a large beam (commonly known as the "load-bearing beam") is placed in each gap, lifting the front and rear parts, serving as support for the eaves. The wooden frame used to support the cube-shaped roof follows a relatively simple method: the beams and columns are placed on the frame's belt, and the belt is fixed to the beams. Finally, the beams are placed on the lookout board, which is covered with cloth tiles.

They adopted the practice of *Jianwa* (剪瓦), meaning that round roofs are designed similarly to flat roofs, leaving the triangular roof to fill in. If the diameter of the round buildings is larger and the arch is smooth, the width of the tiles is properly adjusted to compensate for the difference.

7. Hakka *Tulou* spatial distribution

As shown in Fig. 9, the functional areas of the Hakka *Tulou* building structure are divided as follows: entrance (1), front yard (2), front hall (3), inner courtyard (4), back hall (5), hallway (6), storage room (7), and bedroom (8).

These functional areas are designed according to the spatial layout of traditional Hakka architecture, reflecting local residents' lifestyles and social structure.

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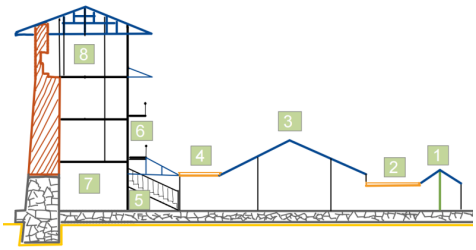

Fig. 9 – *Structural schematic of Hakka Tulou* (Ye, 2024).

The interior of the building is typically organized vertically, with shared staircases connecting different floors. These stairs serve continuous communal corridors, and each level provides access to individual living units.

At the center of the *Tulou* is usually a shared *Citang* , (symbolizing a common ancestor—like a node in a branching family tree). The first floor generally houses kitchens and grain storage rooms. Moving inward toward the central courtyard, there is usually a living room, while the outermost rooms are typically used as bedrooms.

8. Results and discussion

In conclusion, the decline of Hakka *Tulou* reflects a broader tension between cultural heritage and modern development. As construction of new *Tulou* ceased in the 20th century, many existing structures now face neglect, abandonment, and inappropriate renovations. Built in remote mountainous regions once ideal for security, these locations have become barriers to economic growth, prompting the younger generation to migrate to urban areas and accelerating the loss of traditional lifestyles.

While UNESCO's recognition has brought global attention to the value of *Tulou*, it has also led to challenges such as over-commercialization and insensitive alterations. The use of incompatible materials, removal of original structures, and tourist-driven modifications threaten the architectural authenticity and cultural significance of these buildings.

Fig. 10 – *Converted units in the secondary building of the Lianxin Village Revitalization Block, Pinghe County* (Aitachuanqi, 2019).

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Effective preservation must begin with respect for traditional materials and craftsmanship. Rammed earth, timber, and clay tiles should be prioritized, alongside selective use of modern sustainable materials. All interventions must be minimally invasive, reversible, and consistent with the original structure and style. Enhancing vertical circulation and infrastructure should be done without compromising historical integrity.

Tulou conservation should embrace a dynamic and community-based model. Local residents should be actively involved in the planning and revitalization process to strengthen social ties and ensure long-term sustainability. Spatial reprogramming can introduce new public functions—such as cultural spaces, community centers, or guest accommodations—allowing *Tulou* to serve both residential and communal roles in the modern era.

Most importantly, public awareness and cultural education are key. Through schools, exhibitions, media, and digital platforms, the younger generation should be encouraged to engage with and reinterpret *Tulou* heritage. By combining architectural sensitivity with cultural participation, we can ensure that *Tulou* remain not only standing structures, but living symbols of identity, resilience, and continuity.

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Knowing Earthen Architecture in Albania: Investigating some Case Studies in Tirana and Kavaje

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Topic: T2.2. Study of traditional materials, techniques and construction crafts

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Abstract

This paper investigates the building techniques and related materials of some earthen constructions in Tirana and Kavaje in the framework of a scientific collaboration project between Italy and Albania. This architectural heritage is at significant risk of disappearing for many common reasons: the perception of poverty and unhealthy conditions it generates in most citizens, building speculation whereby earthen buildings are considered an obstacle to urban development, and a lack of specific laws to protect it. Furthermore, following the many earthquakes that hit Albania, the last one in 2019, the damaged earthen dwellings were replaced with fired bricks and reinforced concrete constructions. Several unprotected buildings in Kavaje and Tirana were thus studied to collect data and materials that could represent the last existing documentation. This manuscript analyses data relating to construction techniques, mineralogical and granulometric characterisation of the earthen materials constituting the bricks and mortars, and decay phenomena of the built heritage.

Keywords: *earthen architecture; Albania; qerpiç; construction techniques; conservation issues*

1. Introduction

Earth is the oldest building material in the world because of its availability and ease of use. Despite the advent of more durable and versatile building materials, earthen constructions are still used daily in numerous regions, such as North Africa, the Middle East, Central Asia, and Central and South America (Mattone, 2021). This widespread earthen-built heritage, mainly vernacular architecture, has been re-evaluated because of its cultural value and the growing interest in human settlements that are inclusive, safe, resilient, and sustainable (United Nations, 2020).

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, this architecture manifests the world's cultural diversity”. Vernacular buildings characterise our nations’ territories, contributing to the definition of their genius loci. Unfortunately, globalisation has caused the

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progressive denaturalisation of the relationship between human beings and their surroundings. It has led to the increasing abandonment of small settlements, which, although partly uninhabited, still retain their identity features. The value of this heritage lies not only in being a testimony to the past and a valid reference point for planning the future but also in constituting a valuable architectural resource that can be used to (1) improve the quality of the rural landscape, returning an underused building heritage to the community, (2) to reduce land consumption due to new construction, (3) to enhance local particularities and (4) to promote the regeneration of territories and ancient knowledge. The 2025 World Heritage List ratified by the UNESCO World Heritage Convention certifies that 199 of the 1.200 recognised cultural properties are earthen structures. Nonetheless, earthen heritage is at risk worldwide. On the one hand, considered unhealthy, unsafe, and incompatible with modernity, earthen vernacular architecture has been gradually abandoned. Conversely, the push for modern building techniques has impacted the transmission of knowledge and skills, thus determining the lack of maintenance or unsustainable interventions. This is the central aspect of this paper since the disappearance of the earthen heritage is sometimes unnoticed, with the consequent loss of memory of this built heritage and the legacy of the communities. The knowledge, preservation and transmission of material evidence and technical knowledge are essential to safeguard this building culture and, thus, its value as an intangible heritage. This study was born from the need to address the critical issues related to the conservation of the earthen architectural heritage in Albania, which is at high risk of disappearing because this type of construction is no longer being built, and often a large part of the population does not recognise it as an integral part of their territory. In Albania and Italy, earthen buildings cannot be adequately valorised due to the perception of poverty and unhealthiness that they generate in most citizens, building speculation and the lack of specific laws for their protection. From a legislative point of view, only some Italian regions have enacted specific laws to protect earthen building heritage. At the same time, in Albania, some laws protect only the building heritage, which is defined as being of architectural interest, regardless of the material with which it was built. As a result, vernacular architecture, which is designed according to local needs and availability of building materials and reflects local traditions but does not have great architectural value, is not considered or protected. The predominant use of natural stone and wood characterises Albanian vernacular architecture. However, examples of earthen constructions can be found in some regions, where the availability and characteristics of the material determine its use for construction purposes. They are “fragile” architectures, little known or unknown at all, but no less valuable. This paper presents some of the results of a recent research activity carried out within a two-year bilateral collaboration between CNR (Italy) and MOES (Albania) and concluded at the end of 2024.

The bilateral research project entitled ‘Knowledge to protect and enhance earthen vernacular architecture’ aimed to promote the knowledge and conservation of the earthen building heritage, limited to the territory of Tirana and Kavaje, through a census and dissemination actions addressed to a broad public. The census tool allowed an estimation of the buildings present in the investigated territories and an analysis of construction techniques, building materials, and the state of conservation. The dissemination actions aimed to promote knowledge and stimulate their conservation over time by involving local authorities, conservation experts, and the population. The survey, which was conducted in the cities of Tirana and Kavaje, identified three types of housing made of earthen materials:

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- Ottoman houses protected by the Ministry of Culture and subject to recovery and enhancement (Fig.1).
- Elegant/stately houses from the early 20th century, some of which are protected by the Ministry of Culture (Fig. 2).
- Minor architecture without significant value and therefore not listed (Fig. 3).

Thus, although there are various types of earthen architecture (Figs. 1-3), the project focused on houses with little architectural significance. Consequently, these houses are not included in a conservation and safeguarding program, putting them at serious risk of disappearing (Fig.3).

This work concerns an overview of the building techniques and state of conservation of surveyed constructions, particularly those for which it was possible to sample earthen building materials (bricks and bedding mortar). The overall work on the research project will be the subject of another paper.

2. Materials and methods

The analysis of the construction techniques and state of preservation of buildings in Tirana (seven buildings) and Kavaje (three buildings) was carried out through visual inspection and documented with the acquisition of pictures. Samples of earthen brick (qerpiç) and earthen bedding mortars have been taken from the analysed buildings. Moreover, local soil has been sampled for comparison with the earthen building materials (Fig. 4). The following analyses have been carried out:

- The mineralogical composition of the earthen bricks, bedding mortars, and local soil was determined through X-ray diffraction (XRD) (X'Pert PRO diffractometer by PANalytical equipped with X'Celerator detector and HighScore software for acquisition and interpretation of data according to the following operative conditions: CuK α1= 1.545Å radiation, 40 KV, 30 mA, 2Θ = 3-70°);

Fig. 1 – *Tirana: Adem Toptani house* (Rescic, 2023).

Fig. 2 – *Tirana: stately home built in 1909* (Rescic, 2024).

Fig. 3 – *Tirana: house of no significant architectural value and therefore not protected* (Rescic, 2023).

- The mineralogical composition of the clay minerals was determined on the fraction <4 μm extracted through sedimentation according to the Stokes' law (Cipriani, 1958; Cipriani & Malesani, 1972) utilising the previous instrument according to the following operative conditions: CuK α1= 1.545Å radiation, 40 KV, 30 mA, 2Θ = 3-32°.

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- The determination of the grain size distribution has been done through sieving to separate the following fractions: sand (Ø > 63µm), silt (4µm < Ø <63µm) and clay (Ø< 4 µm) (ASTM D2217–85; ASTM D422–63).

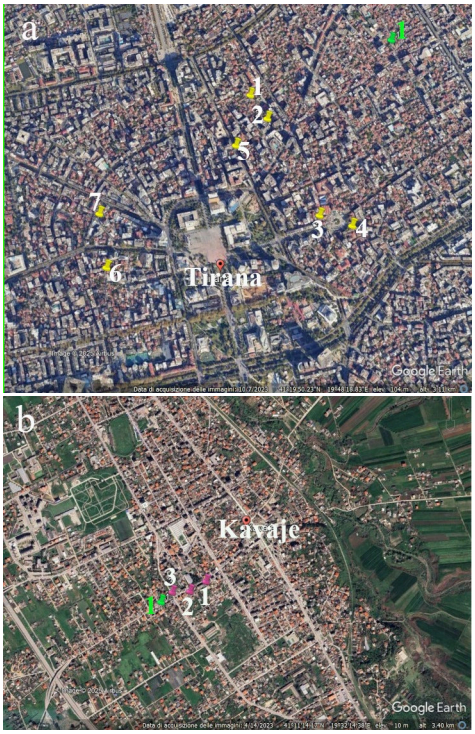

Fig. 4 – *Localization of sampled buildings (yellow and dark pink) and soils (green) in Tirana (a) and Kavaje (b)* (Edited from Google Earth, 2023).

3. Results and discussions

3.1 Building techniques and state of conservation

The surveyed buildings are mainly residential houses, generally one or two storeys above ground. The walls are about 50 cm thick and are characterised by a 40-50 cm high fired brick or stone foundation (Fig. 5). The building technique uses earthen bricks, known in Albanian as qerpiç (Dobjani & Papa, 2022), measuring approximately 20 cm x 12 cm x 10 cm and an earthen bedding mortar approximately 2 cm thick for the masonry (Fig. 5).

Fig. 5 – *Tirana: wall made of qerpiç (sun-dried earthen bricks) and reinforced with horizontal wooden beams, fired bricks are present at the base and below the roof* (Luvidi, 2024).

The earthen structures are fitted with 8-10 cm thick wooden battens to ensure greater stability in an earthquake. These are positioned horizontally along the entire length of the masonry. The battens, placed between 80 and 110 cm intervals, are made integral to the wall using minor wooden elements embedded transversely in the masonry (Fig. 6).

The walls are generally covered with lime plaster, which has been replaced by cement plaster in more recent works. The roofs are wooden double-beam structures covered with brick tiles. The roofs are slightly overhanging to protect the external vertical surfaces from water.

Fig. 6 – *Tirana: particular of wooden battens and slightly overhanging roof* (Rescic, 2024).

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In the town of Kavaje, buildings with less projecting roofs are probably observed for two reasons: in some cases, the earthen wall was protected with a single row of fired bricks; in other cases, which are more recent houses, the earthen wall was protected with a thick layer of cement mortar (Fig. 7).

Fig. 7 – *Tirana: intervention with cement mortar on qerpiç* (Rescic, 2024).

Interventions to cover the walls with cement mortar can be seen (Fig. 8). Sometimes, instead of the traditional wooden roof, metal sheets are used as a covering in what appears to be a hasty but later permanent intervention (Fig. 9).

This construction technique makes it difficult to identify earthen buildings without a collapse. The 2019 earthquake in Kavaje brought many earth structures back to light. Other examples of interventions not compatible with the earthen building technique can be seen in Fig. 9, where the roof is sometimes supported on the raw wall by reinforced concrete beams.

The plaster on the walls is often detached, leaving the earthen wall exposed to the elements (Fig.5). In buildings that have been completely abandoned, the roof is often torn off, and the walls are missing, leaving only the remains of the perimeter wall of the house (Fig. 10). In some cases, the building has been rebuilt, maintaining the external appearance of the house but using modern materials (cement and fired bricks) (Fig. 11).

Fig. 8 – *Kavaje: building after the 2019 earthquake, the collapse of the plaster shows the layer of earthen bricks and the thick layer of cement plaster; the roof does not excessively overhang* (Rescic, 2023).

Fig. 9 – *Tirana: sheet metal roofing and concrete beams in the attic* (Rescic, 2024).

Fig. 10 – *Tirana: building where roof is torn off* (Luvidi, 2024).

Unfortunately, the failure to recognise the value of the earthen building heritage and the desire for modernity has led to its rapid deterioration over the years, due both to a lack of maintenance and to interventions which, far from guaranteeing its conservation, have often led to the irretrievable loss of a significant part of this expression of material and immaterial culture, knowledge and traditions.

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Fig. 11- *Kavaje: building completely rebuilt in baked bricks and concrete after the effects of the 2019 earthquake in Fig. 6* (Çapeli, 2024).

3.2 The building materials

The main mineralogical composition of earthen building materials for both Tirana and Kavaje shows the presence of common minerals such as quartz, feldspars, and phyllosilicates. Also present in Kavaje are carbonates such as calcite and dolomite, indicating a light "marly" earthen material. Phyllosilicates include clay minerals such as illite and kaolinite for both territories, while smectite is typical for Kavaje and chlorite for Tirana (Table 1). Smectite is an expandable lattice mineral that shrinks with drying and swells with hydration. If repeated cyclically, this behaviour can induce decay phenomena caused by the mechanical stresses established by volume changes, resulting in fracturing or exfoliation. The mineralogical composition of the soil collected from some of the gardens matches that of the building materials, confirming the use of local raw materials. Regarding grain size composition, the soils in both Kavaje and Tirana are sandier than the earthen building materials (Table 2). The raw material soil was likely modified by removing some coarser fractions to make the mortars and bricks. In addition, almost all bedding mortars are slightly more clayey than bricks, following their binding function. In detail, it can be observed that:

Table 1 – *Clay minerals composition: I = Illite; K = Kaolinite; Chl = Chlorite; Sm = Smectite* (Rescic, 2025).

Sample	I	K	Sme	Chl
Tirana brick	x	x	-	x
Tirana mortar	x	x	-	x
Tirana soil	x	x	-	x
Kavaje brick	x	x	x	-
Kavaje mortar	x	x	x	-
Kavaje soil	x	x	x	-

Table 2 – *Grain size distribution* (Rescic, 2025).

Sample	Sand	Silt	Clay
	Ø> 63 µm	4 µm < Ø <63 µm	Ø < 4 µm
Tirana mortars (1-5)	27±3	40±3	33±2
Tirana mortars (6-7)	38±1	39±1	24±1
Tirana brick (1-5)	27±3	44±2	30±1
Tirana brick (6-7)	32±1	42±1	27±1
Tirana soil	48±1	31±1	21±1
Kavaje mortars	22±2	47±5	31±3
Kavaje brick	24±2	46±5	30±3
Kavaje soil	40±1	36±1	24±1

- Tirana's mortars and bricks can be divided into two groups based on the buildings investigated: 1-5 and 6 -7. Samples from 6 and 7 buildings are poorer in the finer fraction (silt-clay) than those from 1-5. There were probably different master craftsmen who adopted different modifications of the earth to make the building materials.
- Mortar and bricks from Kavaje have a more homogeneous grain composition, although the building materials from building 3 are slightly less silty with respect to the others.

Plotting the grain size distribution of the analysed samples in a ternary diagram (sand-silt-clay) makes it possible to classify the soils as silty clay for the samples from buildings 1-5 in Tirana and the Kavaje sample from building 3. While the remaining samples from Kavaje, though falling in the same field, are slightly siltier. The samples from 6 and 7 buildings of Tirana fall on the boundary between silty clay and silt (Fig. 12).

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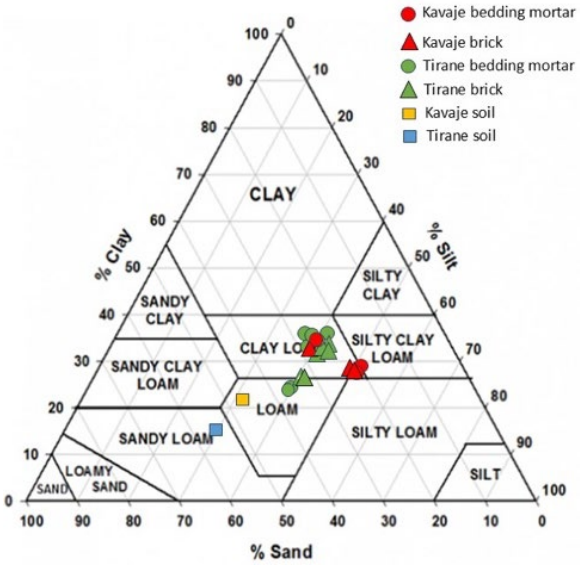

Fig. 12 – *Sand-Silt-Clay ternary diagram, showing the grain size composition of building materials and earthen soils* (Modified from FAO, 2006).

The soil falls in the sandy loam and loam fields, respectively, for Tirana and Kavaje, as had been noted, are sandier than the building materials. Overall, for both Tirana and Kavaje, this is a medium-fatty earth with a high clay content (~30-34%) and, in the case of Kavaje, the presence of expandable lattice clay minerals (smectite). In Kavaje bricks, the addition of fibres is noted, probably due both to the need to have a higher flexural strength of the brick and to decrease shrinkage due to the presence of smectite-type expandable lattice minerals (~2-5% by weight).

4. Conclusions

Earthen buildings are an architectural heritage often not recognised by the citizens or not valued. The lack of recognition of its cultural and architectural value leads to an inevitable loss of evidence of this construction technique. Tirana is experiencing a period of significant growth and urban development. Therefore, many earthen architectures have disappeared in just a few months to give way to the construction of modern skyscrapers made of materials such as cement, aluminium and glass.

The cooperation between researchers from the two countries, with different skills (urban architects, restoration architects, geologists and chemists specialising in the study and conservation of raw construction materials), has enabled the integration of various aspects, thereby improving the quality of the work. Indeed, the Albanian researchers' knowledge of local construction techniques has been complemented by the Italian researchers' knowledge about construction techniques and conservation issues of the earthen heritage.

It was possible to appreciate the important and extensive earthen heritage in Tirana and Kavaje and to promote a comprehensive census of unlisted buildings in the Tirana area by the Faculty of Architecture and Urbanism at the Polytechnic University of Tirana (UPT-FAU).

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The survey was undertaken using census forms adopted in Italy, modified and adapted to the specifics of Albanian cases. The forms proved to be a practical and user-friendly tool, even for training students. One hundred thirty-four adobe buildings were identified and analysed at the end of this process. Documentation was carried out through photographic files and GIS localisation on a map for each of them.

Furthermore, diagnostic studies on samples taken from earthen buildings have made it possible to analyse technical aspects, such as the characteristics of the building materials. Within Tirana, differences were found in the grain size of earthen samples, probably due to how workers operated. Differences were also detected in the mineralogical composition of the earthen material taken from the two cities. The analysis has shown that in Kavaje, the earth used for the bedding mortars was made up of a mixture of earth and straw. In some cases, the masonry is protected by a wall of fired bricks, thus probably influencing the type of roof adopted, which, contrary to the entire territory of Tirana, is not very protruding. These aspects allow us to affirm that those who built with raw materials knew perfectly the characteristics of the local materials and used them to the best of their ability.

Aware of the need to undertake further analyses, the research carried out so far is a first helpful step in promoting knowledge and safeguarding this heritage by re-evaluating a construction typology that is increasingly deserving of attention for its good qualities as a nature-friendly, thermally insulating and ecologically recyclable building material.

Fundings

This work was carried out within a bilateral collaboration project entitled ‘Knowledge to protect and enhance earthen vernacular architecture’ founded by CNR (Italy) and Moes (Albania), 2023-2024.

Acknowledgements

We want to thank Professor Pirro Thomo for the invaluable insights he provided about the earthen heritage of the Albanian territory.

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Preliminary Study on Traditional Chinese Cob Buildings and Their Construction Techniques: a Case Study of Yaozhuang Township

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Abstract

This study focuses on cob construction as a traditional earthen building technique, examining the current status of cob architecture and techniques in China. The research is geographically limited to Yaozhuang Township, Jia County, Henan Province, and employs literature review, field surveys, and data analysis to systematically organize information. It summarizes the preservation status of cob buildings in Yaozhuang Township, presenting findings in illustrations and tables; documents craftsmen collaboration in cob construction; and analyzes spatial types and architectural details. A comparative study of vernacular and public building techniques is conducted. Data on construction processes, materials, traditions, and tools are collected and analyzed, alongside geometric measurements of cob walls. The study identifies two distinct spatial forms—cob dwellings and workshops—and illustrates two key wall construction techniques: "ba-shi" (reinforcement with long red stones) and horizontal cob wall jointing. These findings provide foundational data for improving cob construction and developing contemporary earthen building standards.

Keywords: *earthen wall construction; spatial forms; cob wall technique; geometric measurement*

1. Introduction

Ever since man learnt to build homes and cities around 10,000 years ago, earth has undoubtedly been one of the most widely used construction materials in the world. There is hardly an inhabited continent, and perhaps not even a country, which does not have a heritage of buildings in raw earth (Houben & Guillaud, 1994). Over the long history of earthen architecture, diverse regional construction techniques have developed, forming distinct building traditions. These techniques have been systematically compiled into manuals and guidelines, among which Earth Construction: A Comprehensive Guide by Houben, H., and Guillaud, H. (1994) remains one of the most comprehensive works. This book classifies earthen construction into twelve techniques (Fig. 1), with the cob technique, the focus of this study, corresponding to the French BAUGE (or terre empilée).

As one of the oldest earthen construction methods, cob has nearly vanished. Existing studies focus on North Africa and France, with no systematic research in China. During China's 2018 rural housing renovation, most cob buildings were demolished. However, a few examples persist in Henan Province, serving as critical references for both Chinese and global cob research.

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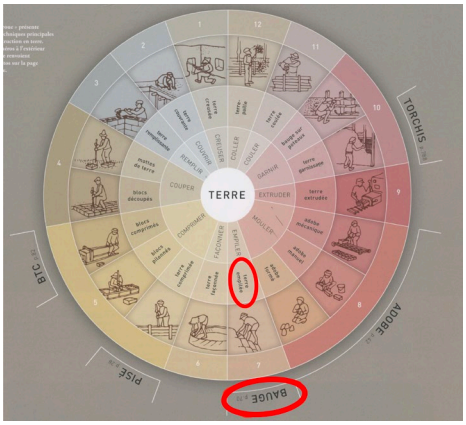

Fig. 1 – *The classification of raw earth construction* (Houben, H., & Guillaud, H,1994. Earth construction: a comprehensive guide. [French]).

Fig. 2 – *The location of the raw earth house (33.86-33.88N°, 133.26-133.31E°)* (Xie, 2024).

This study examines Yaozhuang Township, Jia County, analyzing techniques and spatial forms, providing a foundation for future improvements and applications.

The paper is structured as follows: the introduction presents the research background, significance, and objectives of cob construction. The materials and methods section outlines site selection and analysis scope, followed by research findings, categorized into spatial characteristics and construction techniques.

2. Materials and methods

Based on literature research and field investigations, this study mapped all earthen buildings in 14 villages of Yaozhuang Township (Fig. 2). To facilitate data presentation, each building was assigned a code and listed in this paper (Table 1).

Through interviews with craftsmen, the study documented local cob construction techniques and collective building practices. The research primarily analyzes the spatial characteristics of traditional cob houses in Yaozhuang Township, as well as their structural composition and key geometric parameters.

3. Results

A visual survey of 14 villages identified 32 cob buildings, concentrated in seven villages. These structures fall into residential and workshop spaces, sharing similar construction steps but differing in architectural details. The following sections present findings on spatial organization and construction techniques and materials.

3.1 Spatial and organizational features of Cob Houses

Local cob buildings include residences and workshops. Residences are mainly three-room houses, with four-room and five-room houses abandoned, and row houses and courtyard houses demolished. Workshops are primarily standalone *kangyan* houses.

3.1.1. Cob Residences—Three-Room Houses, Four-Room Houses, Five-Room Houses, Row Houses, and Courtyard Houses

The three-room house is the standard residential unit and smallest living space (Figs. 3 & 4), with gable walls measuring 5.6m–6.5m and facade walls 10.5m–11m (Fig. 3).

Fig. 3 – *Plan of Three-Room Houses* (Xie, 2024).

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Table 1 – *The Cob buildings' list* (Xie, 2024).

Location	No.	Geographical coordinates	Code	Wall Material	Analyze	Sampling
Zhangbulang	1	33.86925, 113.29695	ZBL-1	Red stone, Cob, Red brick	-	+
	2	33.86935, 113.29697	ZBL-2	Red stone, Cob, Blue brick	+	+
Sanlangmiao	3	33.87747, 113.27409	SLM-1	Red stone, Cob, Red brick	+	-
	4	33.87726, 113.27424	SLM-2	Red stone, Cob, Blue brick	+	-
	5	33.87606, 113.27418	SLM-3	Cob(collapsed)	-	-
	6	33.87571, 113.27456	SLM-4	Red stone, Cob, Blue brick	-	-
	7	33.87521, 113.27360	SLM-8	Cob, Hand-moulded adobe	+	-
	8	33.87543, 113.27413	SLM-9	Red stone, Cob, Blue brick	-	-
Yaozhuang	9	33.87594, 113.27270	YZC-1	Cob	-	-
	10	33.87560, 113.27364	YZC-2	Cob, Blue brick	+	-
Jiezhuang	11	33.86943, 113.26488	XZC-1	Cob, Blue brick	-	-
	12	33.86949, 113.26466	XZC-2	Cob, Blue brick	-	-
	13	33.86921, 113.26589	XZC-3	Cob, Red brick	-	-
	14	33.86914, 113.26645	XZC-4	Cob, Lime (collapsed)	-	-
	15	33.86908, 113.26693	XZC-5	Cob, Red brick	-	-
	16	33.86898, 113.26739	XZC-6	Cob, Hand-moulded adobe, Concrete	-	-
	17	33.86859, 113.26730	XZC-7	Red stone, Cob (on the top), Blue brick	-	-
	18	33.86727, 113.26443	XZC-8	Cob	-	-
	19	33.86810, 113.26461	XZC-9	Cob	-	-
	20	33.86781, 113.26385	XZC-10	Red stone, Cob, Hand-moulded adobe	-	-
	21	33.86747, 113.26668	XZC-11	Red stone, Cob	-	-
	22	33.86770, 113.26655	XZC-12	Red stone, Cob, Blue brick	-	-
Xiaozhangzhuang	23	33.86832, 113.29184	XZZC-1	Red stone,the Cob,Blue brick	-	-
	24	33.86844, 113.29232	XZZC-2	Red stone,the Cob,lime	+	-
	25	33.86788, 113.29182	XZZC-3	Red stone,the Cob,Red brick	+	-
	26	33.86914, 113.28904	XZZC-4	Red stone, Cob	-	-
	27	33.86987, 113.28993	XZZC-5	Red stone, Cob	-	-
Libaisi	28	33.86264, 113.28145	LBSC-1	Modern Cob	-	-
Mazhuang	29-32	33.86803, 113.30516	MZC-1-4	Cob	-	-

When additional space is needed, side rooms are added, forming a four-room or five-room house.

The row house consists of three-room units built in succession, with shared gable walls. The five purlins of two houses are connected using mortise-and-tenon joints and reinforced with large steel nails. Courtyard houses are rare in Yaozhuang Township; the Changshou House, built around 1950, is a two-entry four-courtyard residence now used for exhibitions. The advantages of cob construction are evident in *kangyan* houses, where high structural strength and thermal insulation make cob ideal for tobacco curing.

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Fig. 4 – *Three-room house* (SLM-1) (Xie, 2024).

Fig. 5 – *The Kangyan House (XZZC-3)* (Xie, 2024)

Compared to rammed earth, cob requires no formwork, reducing construction costs and accelerating building speed. Its low technical difficulty allows for wider rural adoption.

Kangyan houses (Figs. 5 & 6) typically cover 15–20m². The sample XZZC-3 measures 3.8m × 4.5m, with a height of 3.2m–4.2m and 50cm-thick walls, covering 17.1m² with an interior space of 9.8m². An E-shaped dual-layer heat pipe (Fig. 6) distributes coal-fired heat, while five wooden roasting racks (Fig. 6) support tobacco leaves.

3.1.2. Cob Workshop—*Kangyan* house (Standalone Tobacco-Curing Chambers)

Walls are mud-sealed for airtightness, with small windows and no continuous lintels. Each wall base has two evenly spaced air inlets (Fig. 6), while the gable base includes a coal inlet, ash outlet, and chimney. Observation hole (Fig. 6) is trapezoidal, and a manual sliding ventilator window (Fig. 6) aids ventilation. Even sintered brick *kangyan* houses require mud sealing. Among traditional tobacco-curing structures, cob remains the most economical, durable, and practical material choice. Although electronic tobacco-curing equipment is now used, *kangyan* house design and cob wall construction remains adaptable, cost-effective, and practical.

3.1.3. Brief summary

The cob construction techniques for residences and workshops differ in window design and foundation treatment. Residential windows are larger, with pre-cut openings reinforced by red stone or wooden lintels, while workshop windows are smaller, typically excavated post-construction with a trapezoidal cross-section for better interior observation.

For foundations, residences may lack red stone bases, and if used, no adhesive is applied. In contrast, workshops, due to structural demands at dense openings, require red stone foundations, with all joints tightly filled with mud for stability. The design and construction of *kangyan* houses particularly highlight the advantages of cob architecture.

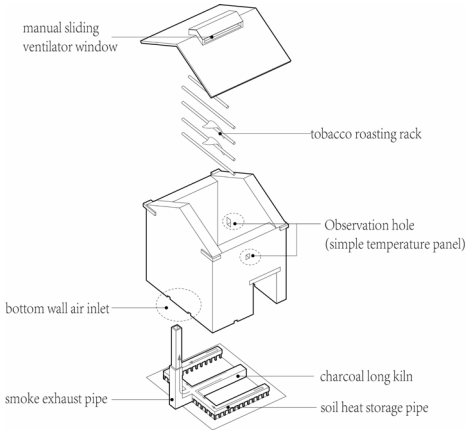

Fig. 6 - *Exploded-view drawing of the Kangyan House* (*XZZC-3*) (Xie, 2024).

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3.2. Construction Details and Materials

Cob construction skills have been passed down orally through generations, with no written records, and the craft is now largely discontinued. Most surveyed buildings use a combination of cob, adobe bricks, sintered bricks, and red stone, with stronger materials like sintered bricks and red stone used for reinforcement and structural elements. Local construction utilizes locally sourced materials with minimal processing, and the construction process is described in terms of (i) foundation, (ii) walls, (iii) openings, and (iv) roof and gable structures.

3.2.1. Foundation

Fig. 7 – *Foundation with no mortar joints* (Xie,2024).

Cob buildings typically use two to five layers of red stone as the foundation (Fig. 7). Red stone, a ferrous-rich sandstone and shale, is quarried and shaped into rectangular blocks measuring 15–25cm in height. Two foundation methods are commonly employed: (i) excavating 20cm into the ground and embedding a layer of red stone or (ii) compacting the soil using a 1 m-high, 1.7m-circumference stone roller before laying staggered red stone blocks. Regardless of the method, no mortar is used; instead, interlocking stones ensure stability, with mud applied around the base for wind protection.

3.2.2. Walls

The construction of the cob walls can be analyzed in four aspects: (i) material preparation, (ii) building process, (iii) collective cob construction technique, and (iv) facade treatment technique.

Fig. 8 – (left) *Three-finger rake. (right) Three-fingered fork* (Xie, 2024).

The primary materials for cob wall construction include loess (lower cohesion, coarser texture), clayey soil (brown, finer, higher hardness), and sticky clay (dark yellow, highly cohesive). The additives consist of 30 cm long wheat straw or grass, which enhance material elasticity and prevent shrinkage cracks (typically 20–30 kg of straw per cubic meter). A measured amount of water is added to the mixture, which is then trampled by foot or mixed using a three-finger rake (Fig. 8). The optimal consistency is achieved when a three-fingered fork (Fig. 8) can lift the mud without it falling apart or dripping. The mixed material must rest for 12–24 hours to improve homogeneity, allowing straw and fiber to soften.

Cob buildings rely solely on cob walls for load-bearing, with no column support. The walls are approximately 50cm thick, slightly thicker than the red stone foundation, and the total wall height does not exceed 9 chi (1 chi ≈ 0.33m), typically ranging from 8.5 to 9 chi. Construction begins by layering cob onto the red stone foundation, filling gaps with mud, and building upward in layers. The wall height is divided into three sections (Fig. 10), with each full perimeter layer constituting one construction cycle. After each cycle, work pauses for 10–11 days to allow for drying and settlement before proceeding. The first cycle reaches 1.2m–1.5m, requiring 1–2 days. The second cycle, limited to 1m, takes 1 day. The third cycle completes the remaining height, taking 1–2 days, ensuring gradual wall consolidation.

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Fig. 9 – *Rack car* (Xie, 2024)

Cob construction requires at least two workers: one throws cob blocks onto the wall using a three-fingered fork, while the other receives the blocks, presses them into place by foot, and adjusts vertical and horizontal alignment (sometimes using a water tube or plumb line for accuracy). When more labor is available, workers are divided into six teams (each 2–5 people), with each team assigned a rack cart for soil transport (Fig. 9). All six teams work simultaneously, with four handling corners and two working on straight walls. Corner teams require higher technical skill, as precise vertical alignment is more difficult. To ensure strong wall connections, teams must coordinate jointing techniques. Faster teams shape a sloped connection (Fig. 10A) at joint sections, allowing the adjacent team to seamlessly integrate their cob layers (Fig. 10B), ensuring structural integrity.

Fig. 10 – *The horizontal connection of the Cob wall* (Xie, 2024).

After wall construction, the surface is refined by removing excess mud and trimming protruding wheat straw fibers. This process uses a louzi, also known as a brush, rake, or trowel (Fig. 11). The louzi resembles a large steel comb, with a 1m-long wooden handle and 5–6 cm long metal teeth arranged in a 15 cm wide row, typically made from steel rods or scissor blades. During use, the craftsman holds the handle vertically, pressing the teeth against the wall and scraping up and down to achieve a smooth surface (Fig. 12). For aesthetic purposes, depressions may be filled with additional mud, but those facing interior or courtyard spaces are often left untreated.

Fig. 11 – *The louzi* (Xie, 2024)

Fig. 12 – *Marks left by the louzi finishing* (Xie, 2024)

After cob wall construction, wealthier households enhance aesthetics by applying lime and sintered bricks around door and window openings, corners, gables, beam-supporting stones, and eave stones. Finally, an exterior mud plaster is applied. The straw fibers in the plaster are shorter and finer, about 1cm long. By this stage, the cob wall is fully dry, so no water is added. A single craftsman uses a mudboard, trowel, and mud cap (wooden or metal) to spread the straw-mixed mud from top to bottom, forming a 1 cm thick finish layer. The plastering process for a standard three-room house takes about one day.

3.2.3. Windows and door openings

During cob wall construction, window and door openings are left unfilled. Doorways are typically 1.5 m wide, while windows measure 1.2 m. A 15–24 cm thick red stone lintel is placed atop each opening. After the walls are built, 6 cm of cob is trimmed from both sides of the openings, and sintered bricks are installed, forming a 48cm-wide brick frame (Fig. 13). Some households use adobe bricks for the interior to reduce costs. The brick-cob connection is reinforced using the "ba-shi" technique (illustrated in the next section). Wooden door and window frames are installed afterward, with a gap left at the top to accommodate settlement deformation.

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Table 2 – *The data of buildings' openings* (Xie, 2024).

Sample Coding	Length, width and thickness	Space and wall height	Size of door and window
SLM-2	1100/630/50	480/390	150*200/120*150
XZZC-2	1100/1260/48	490/390	150*190/80*100
SLM-1	1050/560/53	460/360	150*190/100*150
XZZC-3	380/450/50	460/390	120*180/20*35

Geometric measurements were conducted on several standard three-room houses and *kangyan* houses, with wall and opening dimensions systematically recorded (Table 2). Since no national standard exists for cob construction, buildings that have remained intact for over 60 years were classified as successful cases, providing reference data for future structural analysis and standard development. All four samples are still in use. The ratio of opening area to cob wall area is approximately 0.153, 0.103, 0.154, and 0.150, respectively. Further large-scale data collection and experiments are needed to analyze its impact on wall strength and establish an optimal construction standard.

3.2.4. Roof and Gable Wall Structure

The triangular gable top of cob buildings is constructed using adobe, red bricks, or blue bricks, with sintered bricks typically used outside and adobe bricks inside. Notably, due to material differences, cracks may form between sintered and adobe bricks, compromising wall strength. To prevent this, long red stones are inserted every five layers, a technique locally known as "ba-shi" (Figs. 14 & 15). These stones press down on the underlying bricks, integrating the wall into a cohesive structure. This method enhances both aesthetic appeal and structural stability.

Fig. 13 – *The brick frame* (*SLM-2)* (Xie, 2024)

Windows are constructed using brick arching techniques (Fig. 15), with eave stones embedded for support. Both eave stones and beam-supporting stones are typically long red stones, placed directly on cob walls to increase roof component contact area. The roof structure, from bottom to top, consists of purlins, rafters, decorative blue bricks (ba-zhuan), plastered mud, lime, and visible roof tiles.

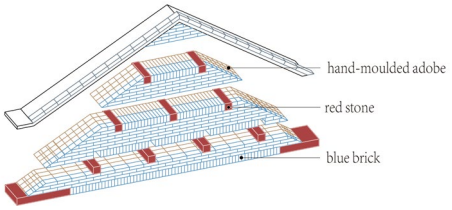

Fig. 14 – *The "bashi" technique* (Xie, 2024)

Fig. 15 – *Gable wall structure* (Xie, 2024)

3.2.5. Brief summary

This section summarizes material composition, construction process, collaboration, and tools; provides geometric analysis of structurally robust cob walls; and illustrates the key construction techniques such as horizontal cob construction and the "ba-shi" technique. In Yaozhuang'cob construction, adobe bricks are used for gable tops and openings, with sintered bricks replacing exterior facades, balancing efficiency, aesthetics, and structural integrity.

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4. Discussion and conclusions

The study found that cob blocks contain 20–30 kg of straw per cubic meter, with a 5% wall settlement rate. Construction is faster than rammed earth, requiring only 2/3 to 4/5 of the labor. Once dry, cob walls form a monolithic structure, exhibiting strength comparable to cast adobe walls and superior to rammed earth and adobe brick walls. Proper horizontal jointing is crucial during construction. Cob walls serve as load-bearing structures and are typically finished in three ways: 1) exposed after surface smoothing with a "louzi" tool, 2) lightly smoothed and covered with plaster, or 3) brick-clad exterior, with other areas plastered or lime-coated. Cob construction remains economically significant in the area, with its physical properties ideal for tobacco-curing spaces. The "ba-shi" technique is used in mixed construction with red stone or sintered bricks, enhancing both strength and aesthetics. This study provides the first data on cob houses in central China, based on 27 buildings across 14 villages. It documents soil composition and wall properties, aiding analysis of cob structures' responses to temperature, moisture, and seismic effects, supporting national standards and earthen building conservation guidelines.

This study represents the first phase of a broader investigation. Future work will involve laboratory testing and data analysis to identify damage mechanisms in Yaozhuang's cob buildings and develop mitigation strategies. A detailed study on cob connections with other materials will guide maintenance and design improvements. Additionally, this research lays the foundation for comprehensive cob wall standards. Further studies will expand to neighboring villages, increasing sample size for robust data analysis. Integrating modern prefabrication and material innovations can enhance construction efficiency, allowing low-skilled workers to participate in specific building tasks. This approach addresses economic and social challenges in contemporary rural contexts while preserving traditional cob architecture and cultural heritage. To the best of the author's knowledge, there is currently no dedicated literature on cob architecture in Henan, China. Most studies on cob techniques come from North Africa and France. This research confirms the existence of cob buildings and cob construction knowledge in China, addressing the academic gap on cob architecture in the region. The findings will contribute to the development of national guidelines and standards, support the preservation of regional traditions in Henan, and promote the protection and restoration of earthen architecture globally.

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Ancient Solutions for Earthen Architecture in Humid Tropical Environment

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Abstract

Conventional wisdom considers earthen architecture unsuitable for very humid climates, unless stone foundations and waterproof roofs can be implemented. Archaeological evidence does not always support this assumption. There are thousands of major earthen architecture sites in the humid tropical lowlands of Mesoamerica starting 3000 years ago, using only earth (no stone or lime), that show that it was a preferred and viable technique. This paper addresses three aspects of pre-Columbian construction, derived from 20 years of research in the AD 1 to 1000 archaeological site of La Joya, on the Gulf Coast of Mexico: the absence of foundations, the use of bituminous additives, and the use of continuous surface coatings. These traits appear to have been key factors to ensure the stability of the buildings and the resistance of exposed (unroofed) surfaces for centuries. Interpretation is based on construction systems identified through stratigraphic excavations, chemical analyses (organic and inorganic), and micromorphological study of construction samples, complemented by studies of mineralogical composition and mechanical properties, as well as replication experiments with local clays. These ancient solutions were effective, even though they would probably not be deemed appropriate in conservation or modern construction.

Keywords: *Mesoamerica; archaeology; Mexican Gulf Coast; foundations; additives; facings*

1. Introduction

Monumental earthen architecture has been known to exist and endure for millenia in humid and/or flood-prone regions: examples are from pre-dynastic Egypt, Mesopotamia, China, early Amazonian mounds and Sambaquis, Mississippian Mound-Builders, and the Olmec in Mesoamerica. Yet modern construction clearly favours arid to semi-arid conditions, with emphatic warnings about stone foundations and impermeable roofs in other climates. Little attention has been paid to the factors that allowed this early architecture to last so long in supposedly adverse environments. The surprising discovery in 2008 of sophisticated architecture on the coastal plain of the Mexican Gulf Coast, between 1000 and 2000 years old, at the archaeological site of La Joya, a first rank center with monumental architecture, led to an extended research program, still ongoing, to understand the building systems and the technology that made this architecture so efficient, not only at this site, but also elsewhere in Mesoamerica during the Classic period (Daneels & Guerrero, 2011; Daneels et al., 2013, 2020; Mateu et al., 2022).

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Some of the findings have been counter-intuitive (the absence of foundations), others reveal technologies thought to be modern (the use of bituminous additives) or different from contemporary practice (continuous facings). Each of these aspects appear to have had a positive effect on the endurance of the buildings.

2. Absence of foundations

Archaeological reports recurrently observe that Mesoamerican buildings are raised from the surface level: either the actual humic level (in the case of deep soils, such as in La Joya) or on bedrock, after stripping the surface soil (such as in the northern sector of Teotihuacan). The surfaces are not levelled and there is no evidence of foundation trenches or driven wood piles, the current practices in historic and modern architecture. To achieve a level building surface, the strategy is to raise a platform, creating sides of different heights to compensate for the uneven surface.

This technique has consequences for the upper stories in terms of controlling the internal pressure of the fill that must support the vertical pressure of the building. In the case of La Joya, as in other sites, the solution was found to be the use of alternating textures of fill material (sandy loam *vs* clayey loams), a system that allows building at inclines steeper than the angle of repose (Daneels & Guerrero, 2011; Daneels et al., 2018).

In terms of the absence of foundations, this system has the advantage of enhancing the circulation of internal humidity, as it allows capillary water to evaporate and precipitation to percolate towards the subsoil. This is important, as the core of the construction maintains a certain degree of humidity, crucial for the cohesion of the earthen materials. Excessive reduction of humidity leads to disaggregation. This was observed by Guerrero (2020) at Cacaxtla, where the site was completely roofed over; after some years, increasing drying caused the basal platform to crack.

Modern construction principles recommend stone foundations and/or impermeable layers (asphalt or plastic) before raising a mud-brick wall, but that will lead to a drying out of the material. Thus, the Mesoamerican technique of building directly on the surface, without foundations, ensures a constant humidity in the building core, which may be an important factor for its longevity.

The closest parallel in modern construction to the ancient technique would be ground-bearing [concrete] slabs, on which buildings are raised. But there are fundamental differences: such slabs require the underlying surface to be level, either by excavation or by fill contained by piers or walls, and once poured, such slabs will impede the rise of capillary humidity. Yet the ancient technique was effective in many sites for many centuries, even for massive constructions.

3. Stabilizing additives

In specialized literature, the most common additives reported and analysed from archaeological samples are mineral (lime, sand or gravel), vegetal (straw, grass, or even seaweed; Lorenzon, 2021), or animal (dung, milk, etc.; Vissac et al., 2017). Asphalt emulsion, a technique reportedly developed in the early 20th century, is also recognized as an effective stabilizer (Hall et al., 2012). In the case of the coastal plain of the Mexican Gulf Coast, it was possible to demonstrate the use of bitumen as a component of mudbricks and facings (Daneels et al., 2020). In the region, petroleum seeps were available and exploited by the Olmec since 3000 years ago for paint, glue, and waterproofing canoes and floors (Wendt & Lu, 2006). Floor and facing samples from Classic period La Joya, as well as paleosoil samples, were processed using GC-MS in SIM mode, combined with $\delta^{13}C$ Isotope Ratio Mass Spectrometry, showing the presence of fossil hydrocarbons that did not occur in the paleosoils (thus discarding natural contamination) (Daneels et al., 2020). This

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technology appears to have been regional, as petroleum biomarkers were present in other sites from the Gulf Coast that had local seeps available, but is absent from earthen construction samples in other sites of Mesoamerica, even those in contact with the Gulf coast sites.

The presence of asphalt emulsion in construction is a proven stabilizer in modern construction, giving a better resistance against water, without sealing the pores (Hall et al., 2012). It has added advantages as a herbicide and insect repellent, as observed on the field. Experimental reproduction shows it is effective at very low concentrations, between 1% and 8%; all samples containing petroleum derivatives performed better in laboratory experiments (Peraza et al., 2022), as well as *in situ*, monitored over 12 years (see Kita & Daneels for an experiment and monitoring until 2017). A series of bricks with bituminous additives at 1%, 2%, 4%, 6% and 8% shows a good performance at 4% after 9 years (Fig. 1).

The investigations have several implications. On the one hand, it shows that at least 2000 years ago, Mesoamerican builders already understood the properties of bitumen as an additive and its advantages for earthen construction in humid tropical environments. The concentrations must have been low, as no raw bitumen globs were observed in the construction. The presence of a degradable additive was inferred from the fact that antique surfaces, when recently excavated, were pristine (no sagging, cracking or weathering), but would rapidly degrade after a rainfall; the hypothesis of petroleum derivatives was explored when the usual additives did not come up in the exploratory analysis series (Daneels & Guerrero, 2011).

On the other hand, the presence of bitumen in ancient construction affects conservation. As an oily substance, it will not allow a lime additive.

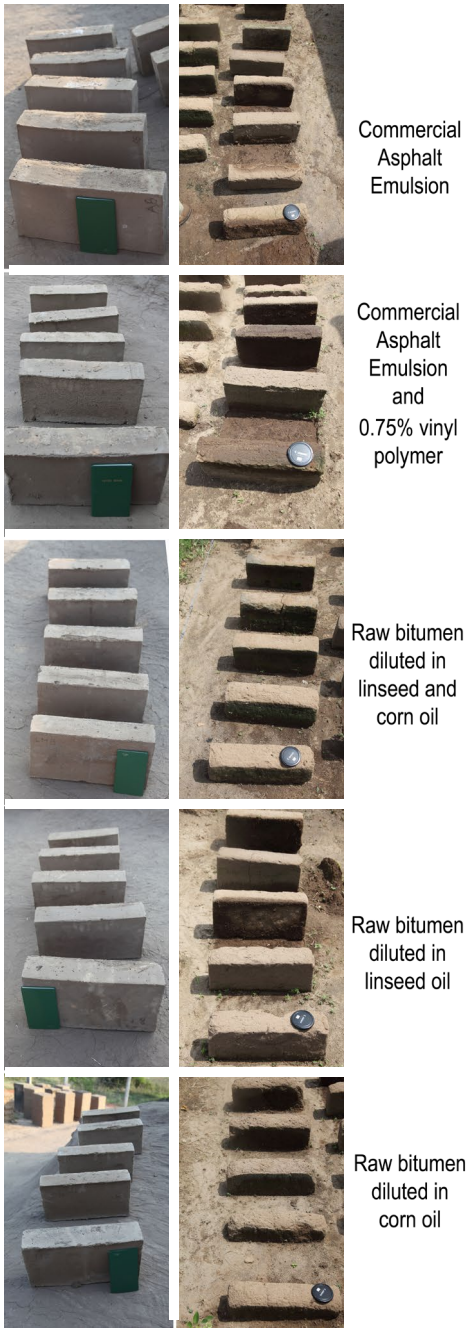

Fig. 1 – *Experimental mud-bricks with bituminous additives at 1% (front), 2%, 4%, 6% to 8% (back)* (left: Y. Kita, 2015; right: A. Daneels, 2024).

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During the first intervention, lime was added to stabilize a sacrificial layer applied to preserve the la Joya pyramid, but the lime surfaced, cracked and was washed away. Experiments with lime stabilizer had a much lower performance than the bituminous additives, probably as effect of the natural contamination by petroleum carried during seasonal flooding from the seeps 30 km upriver. As a consequence, La Joya is an example where an otherwise proven lime stabilizer will not work.

While bitumen stabilization is commonplace in modern construction, in conservation it was tested and used during the 1940's to the 1990´s, but later abandoned due to the darkening effect it had on the surfaces. As indicated above, this was not observed in the archaeological samples, and only in the experimental samples above 6% a slight darkening was apparent, though no blobs. These negative effects occur when asphalt emulsion is used in high concentration 10-15% (Oliver, 2000; M. Taylor, personal communication, June 10, 2022) the main reason for which it was abandoned. Another problem that has been reported (M. Taylor, personal communication, June 11, 2022) is the flaking of additional layers applied on top of a bitumen-stabilized surface. This flaking was observed in certain cases during the intervention at la Joya, but attributed to the presence of biofilm. When biofilm was scraped off, before applying a new layer of bitumen-stabilized render (coating), it did not flake (Fig. 2).

Thus, the preservation program at La Joya showed that stabilizing earthen renders with bitumen is an ancient technique, that requires advanced analytics to prove, but also that the use of bitumen in very low concentrations (as little as 4%) is effective in cases of soils that are contaminated with oily materials.

4. Continuous facings

Since excavations started at La Joya, a recurrent observation was the presence of 3 to 4 superposed layers of facings, between 1.5 and 2 cm thick, made of clayey loam and well compacted. In the case of La Joya, no sand was added, but often there was finely chopped grass, 1-3 cm long segments. The grass content, up to 30% by volume, would act as a mechanical binder and avoid the clayey render to crack. A render with a high content of expansive clay will react immediately to high humidity or rain and produce a swelling at the surface level that would make it impermeable (T. Matsui, personal communication, December 21, 2010). Laboratory tests of mechanical properties are currently in process, both on experimental and archaeological samples.

In several cases, chronology was sufficiently fine-grained to estimate that each render lasted for 50 years or more, without evidence of regular maintenance (as is the case in modern earthen construction) (Daneels & Guerrero, 2011). Micromorphogical analysis of render layers bears out the macroscopic observation: there is no presence of superposition of thin layers between several renders (Mateu et al., 2022). Only on exterior floors is it possible to observe thin layers of graded, fine to very fine sand particles at the foot of the buildings and on exterior floors, product of surface erosion by rain. These depositions were not swept away by the ancient inhabitants, as they formed a level dry surface of indurated sand that preserved the original clayey render surface.

High clay content earthen renders are ubiquitous in Mesoamerica, from the earliest periods, both in humid and semi-arid environments, with or without vegetal temper (Mateu et al., 2022). An alternative to this type of render emerges some 2000 years ago in Mexico's Central Plateau. The oldest evidence is in Tlalancaleca (López et al., 2021): clayey earth is mixed with over 50% fine gravel, often ground volcanic scoria (*tezontle* in nahua) or less dense pumice, and mixed with clayey soil. It becomes the hallmark of the Teotihuacan renders (called *concreto teotihuacano*), where it is covered by a very thin layer of lime stucco, though the render itself

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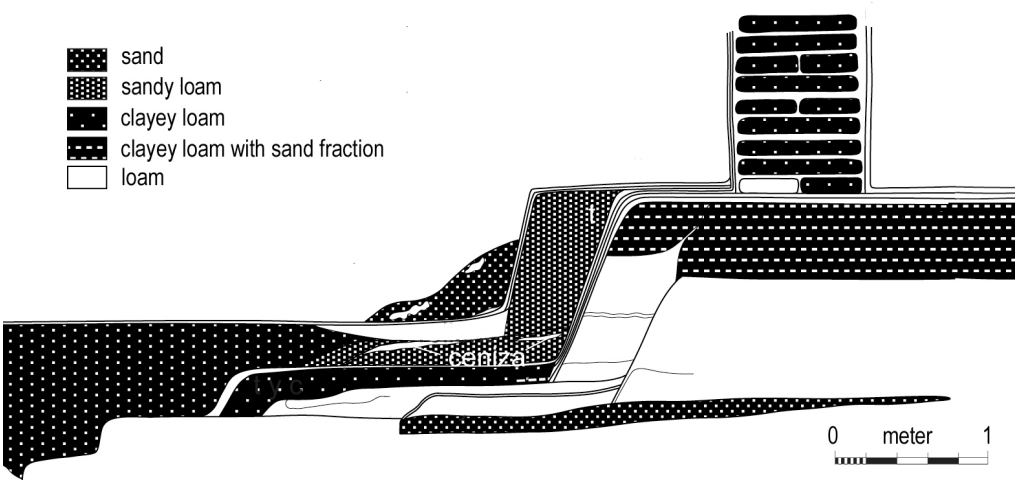

Fig. 2 – *Example of continuous facings and of structured fills, North Platform, La Joya.* (drawing by A. Daneels; digitilization by M. Mateu).

contains no lime. This render recipe is copied in many sites influenced by this major Mesoamerican capital, both in the highlands as in humid lowlands. It is extremely resistant.

The renders, both the clayey ones and the gravel-tempered ones, would start at the top of the walls, continue on interior and exterior floors, down staircases or platform taluses and plaza surfaces. These facings or renders showed no change in their thickness along their long course (Fig. 2). Subsequent layers often have different colors, resulting from the earth mixes selected for each facing, proving they were applied at the same time over the whole construction. It was impossible to achieve such thick renders (1.5 to 2 cm) when doing experimental archaeology at La Joya.

The high amount of organic additive in the La Joya renders represented a huge inversion of labor to chop the grass and prepare the amount of render required for each facing event (Daneels & Vernucci, 2017). It is therefore obvious that the technique was well understood and recognized as of major importance in the building process.

The success of the Mesoamerican renders does not appear to depend on additives. As indicated above, in the case of La Joya, the use of bituminous additives was certainly a factor that increased resistance in the humid environment, but our comparative study of 13 other Mesoamerican sites shows that bitumen was not used beyond the Mexican Gulf Coast (Daneels et al., 2020). Yet in these other sites, the renders were also very effective.

It is the continuous quality of the render that appears to have been a major factor in the good preservation of the buildings, as any rainwater would be diverted over the surface towards the plaza floors (or the underground terracotta drainage pipes used to drain closed spaces). There are no joints or cracks where water could penetrate the building's core (mud-bricks or fills). This is quite different from the modern construction practice, in which wall facings, interior floors and exterior surfaces consist of different materials, placed at different moments in the building sequence. All these surfaces are connected by joints that are weak points where water or vegetation can penetrate.

5. Discussion and conclusion

The archaeological evidence presented in this paper shows solutions that were highly effective for centuries, in an environment considered

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nowadays as highly adverse for earthen architecture. These solutions were developed by Mesoamerican builders through sustained observation, understanding of their local environment and its resources, and systematic experimentation that led to a body of knowledge consolidated and transmitted by specialists through generations to create major, long-term urban programs. This kind of knowledge and specialization goes beyond what is usually understood as "vernacular". Yet these solutions are not receiving the consideration they should in modern preservation practices for earth-built heritage. Most research on traditional knowledge from the conservation sector relies heavily on ethnographic information, much less so on archaeological evidence.

Roofing is a recurrent practice to protect sites that were not roofed over originally. In the case of pyramids, or acropolis palaces like Cacaxtla, only the buildings (temples or residences) had roofs, but their supporting platforms and plazas were exposed, and built with that in mind. The absence of foundations, combined with effective continuous facings, may be the strategy developed to maintain an adequate level of humidity in the construction fills. Roofing over the whole site would upset that balance, as reported here for Cacaxtla, but it is a problem encountered in many other earthen heritage sites.

Bituminous additives (asphalt emulsion) were discarded almost 20 years ago as an option for sacrificial renders. Yet the evidence that it was understood and employed in antiquity should lead to reconsideration of this decision, especially in the case of regions with petroleum seeps that can affect the performance of other types of additives (as the case of lime at La Joya). The Joya experimental program shows that asphalt emulsion is effective even in very low proportions (4%), thus avoiding the darkening of the earthen render, and it is not directly related to flaking.

Continuous facings must have been an important factor in the conservation of the buildings during their use. They could be effective as sacrificial renders, at least for monuments that lack surface decoration like reliefs or polychrome murals. Bitumen-stabilized renders were used effectively in La Joya, without deterioration of the substrate (until the pyramid was reburied at the injunction of the National Institute of Anthropology and History of Mexico).

The lesson that should be derived is that there is much to learn from the sophisticated solutions found in the building systems and technologies in monumental archaeological sites. A more comprehensive study of these ancient solutions may reveal practices that have been lost over the centuries because they were not necessary for simple family housing, that represents the major part of contemporary "vernacular architecture". Understanding this ancient knowledge may then benefit both the research and the policies for preserving earthen architectural heritage.

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Approximation to the Environmental Impact of the House of Gongora, Cehegín (Murcia, Spain): an LCA Perspective

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Abstract

This paper deals with an approximation to the environmental impacts of constructing the historic House of Góngora in Cehegín (Murcia), originally built in the 16th century using traditional earth architecture. By analyzing historical construction methods, materials, and energy use, the study approximates the environmental footprint of the house during its original construction. It then compares this with the estimated impacts of building an equivalent structure today, which would imply changes in techniques, methods and regulations. The comparison considers key environmental indicators such as carbon emissions, resource extraction, obtained using the Environmental Footprint LCA methodology. The paper highlights the sustainability inherent in traditional earth architecture and contrasts it with the challenges and benefits of contemporary construction practices. The findings question the idea of sustainability as a contemporary issue and reveal insights into the ecological trade-offs between historical and modern construction methods, emphasizing the potential for re-integrating sustainable practices from the past into modern architecture. This study contributes to ongoing discussions on sustainable construction and the relevance of traditional methods in reducing environmental impact.

Keywords: *rammed earth; life cycle assessment; house of Gongora; Cehegín; sustainable construction*

1. Introduction

In the 21st century, characterized by climate change and resource over-exploitation, the construction industry has consolidated as one of the primary contributors to carbon emissions and environmental degradation (IPCC, 2023).

In response to this crisis, the pursuit of sustainable materials has led to a renewed interest in ancestral techniques, namely rammed earth and locally sourced stone construction.

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Vernacular architecture, characterized by the use of natural and locally sourced materials, has historically served as a model of environmental efficiency (Merino Pérez, 2022). However, with the process of industrialization during the 18th and 19th centuries and, specially, during the 20th century, new construction systems emerged, prioritizing speed and mass production over locally sourced materials, addressing the rising housing demand driven by exponential population growth (Sandrine Dixson-Declève et al., 2022).

Sustainable materials such as rammed earth are re-emerging as a viable alternative to reducing the environmental impact of the construction sector (Dethier, 2019). In this regard, prior to industrialization, there were remarkable architecture works built using this technique, including a variety of examples developed worldwide such as the Forbidden City in China, the Taroudant Fortress in Morocco, and the city walls of Seville and Granada in Spain. All these structures have withstood the test of time with minimal environmental impact.

At the national level, within the residential sector, the house of Góngora in Cehegín, Murcia, stands as a key case study for analyzing the evolution of this technique and its viability in the contemporary context. From this perspective, this research aims to determine the environmental impacts of residential rammed earth construction using 16th-century techniques and how they compare to those of the same technique when implemented with contemporary methods.

The study evaluates the environmental footprint of the historic house of Góngora, which relied on traditional earthen architecture techniques, and compares its ecological implications with those of modern constructions that employ rammed earth enhanced by technological innovations.

2. Methodology

This study is carried out by mixing three different methodologies. The first one, a case study, the House of Góngora in Cehegín. This house allows for a comparison in the way rammed earth construction has changed over the years. Then, the next methodology is an inventory analysis of the possible processes that took place during the different life cycle stages of the house and compare it with the way in which such a house would be built today. Lastly, a comparison of the impacts through bibliographical analysis.

Fig. 1 – *South view of the tower* (Peñalver, 2004).

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Fig. 2 – *Ground floor plan. Current state of the house of Góngora* (edited from the original drawing of arq. Juan Antonio Durán Blázquez).

2.1. The house of Gongora

The house of Alonso de Góngora, also known as the Boticarians' house of the last people who used the building, the Ortega sisters, is a historic building located in the heart of Cehegín, Murcia. It forms a single historical complex alongside the Placeta de los Carros' tower.

These interconnected structures represent distinct yet complementary architectural periods and functions. The tower (Fig. 1), originally built between the 12th and 13th centuries as part of the town's fortifications, served a defensive role before being repurposed for residential and storage use. Its construction evolved over time, with a solid lower section of irregular stone blocks bonded with lime mortar, walls up to 4 meters thick, and interior openings appearing on the second level. The third section, added in the 16th century, transitions to rammed earth reinforced with gravel and lime, while the final level, dating from the same period as the House of Góngora, features a sloped roof that structurally integrates both buildings.

Primarily built in the 16th century, the House of Góngora (Fig. 2) follows a style layout centered around a courtyard. Its original walls, constructed from rammed earth, contrast with later masonry additions from the 18th and 19th centuries. Some sections still incorporate medieval masonry from the 12th and 13th centuries, illustrating its continuous transformation alongside the Placeta de los Carros' tower and the surrounding fortifications. The ground level features

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subterranean cisterns with reinforced herringbone-patterned brick walls, while the roofing system consists of wooden beams, a cane framework, and a compacted earth mixture known as "*alcatifa*", which enhances insulation.Over the centuries, the tower became an integral part of the House of Góngora, with structural modifications facilitating its incorporation into the residence. Notably, sections of the tower's northeast wall were removed to create a seamless connection between the two structures.

The use of traditional materials, such as rammed earth and locally sourced stone blocks, reflects the evolution of construction techniques and the changing needs of its occupants over time (Peñalver, 2004). As a result, the house serves as a living palimpsest of Cehegín's architectural history and transformation.

2.2. Sustainability in historical context

The methodology used to carry out the sustainability evaluation consists of an inventory analysis combined with an impact determination based on bibliographic analysis. The bibliographic analysis was developed by contrasting modern day technologies with the techniques used at the time of the construction. This analysis is done stage by stage incorporating information from the EN15804+A2 (*Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*). The stages of this norm structure the results of this study, which are presented in the next section divided into 4 parts, which coincide with the four stages of the life cycle of buildings: Stage A, product stage and construction process, Stage B, use stage, Stage C, end of life, and Stage D, benefits and loads beyond the system boundary.

The Life Cycle Inventory (LCI) has been developed using the software Simapro v9, the most commonly used commercial software for LCA studies. The database of the contemporary solution has been Ecoinvent v3. Ecoinvent is the most comprehensive database for environmental studies. It includes industry data and its reliability is achieved through a careful peer review process prior to the incorporation of any process into the system (ecoinvent, 2020). The study of the LCI of the traditional construction has been made through a bibliographical analysis.

3. Results

As it is indicated in section 2.2, the possible environmental impacts are structured following the structure of the EN 15804.

3.1. Stage A

At the time the building was constructed, at least prior to the part built in the XIX century, raw materials were sourced locally. Rammed earth and the rest of the materials were extracted directly from the site, stones quarried nearby, and gypsum burned in small-scale kilns (Bel-Anzué & Elert, 2021; Wouters et al., 2018). These processes required minimal energy input, relying on manual labor and traditional tools. The embodied carbon of stage A1 (Raw materials supply) could be considered negligible, due to the absence of industrial processing. In the case of Stage A2 (transportation), the impacts were insignificant since materials were carried by hand or with the assistance of animal labor (Bel-Anzué & Elert, 2021).

In contrast, if the same building were constructed today, even while using the same materials, the environmental burden would vary significantly. When it comes to stage A1, industrial processing methods for gypsum and stone require substantial energy input, often relying on fossil fuels (Pedreño-Rojas et al., 2020; Quintana et al., 2018; Suárez et al., 2016). Stabilizers such as cement are often introduced into the rammed earth to improve durability, but this would substantially raise carbon emissions (Ávila et al., 2022a; Kariyawasam & Jayasinghe, 2016; Toufigh & Kianfar, 2019). However, that's not always the case, as many times lime or other natural materials are used as stabilizers (Ávila et al., 2022b; Gomes et al., 2016).

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When talking about A2, modern transportation methods for the building industry use hydrocarbons as fuel, which highly increase carbon emissions. This effect will further increase if materials are not sourced from the immediate vicinity (Hadjiiski et al., 2022).

During the construction phase (A3), historical methods relied solely on manual techniques, with workers compacting rammed earth using wooden or metal formworks. Stone carving was done on-site using hand tools. These methods extended construction time but maintained a low environmental footprint. In contrast, modern construction often employes mechanical tampers for compacting rammed earth walls(Calvetti et al., 2021; Udomiaye et al., 2025). For stone masonry stone-cutting machines are currently widely spread. While these approaches would reduce labor intensity and speed up construction, they would increase energy use. Also, nowadays, these earth walls incorporate a damp proof course to avoid the risk of moisture from the ground rising in a capillary way. That course, typically containing butyl rubber or hot bitumen also increases the environmental impact of the construction.

Figure 3 shows the carbon emissions of a rammed earth wall built today compared to an approximation of a masonry wall built in the XVIth century.

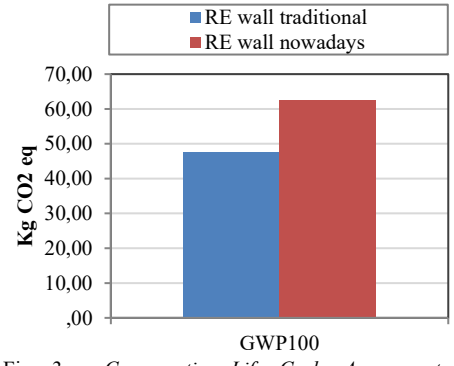

Fig. 3 – *Comparative Life Cycle Assessment of traditional vs contemporary construction of rammed earth walls (Stage A).*

3.2. Stage B

The impacts produced during the use phase of buildings depend solely on the context. In the case of energy consumption (B6), historical buildings were not built with the idea of using modern day HVAC (Heating, ventilation, and air conditioning) techniques to control the inner temperature. However, many of those buildings are now equipped with such systems. Therefore, it only makes sense to compare old and current ways of controlling temperature. While back in the day there was no way of refrigerating buildings, although its morphological conception with patio and gallery allow passive cooling of the house, heating was commonly achieved burning wood, which can be considered a carbon intensive way of heating, comparable to modern day fuels such as natural gas (Punhagui & John, 2022).

In terms of energy efficiency, modern day constructions using earth usually incorporate thermal insulation in the outer layer. That reduces thermal losses while increasing the impacts of Stage A.

Introducing these kinds of external insulation systems also increases the impacts of maintenance (B2-B5), as the insulation layer needs to be replaced after 25 years(Davis et al., 2025). If not for that layer, these kinds of constructions can be considered to be low maintenance (Kariyawasam & Jayasinghe, 2016).

In contrast, modern day stabilized rammed earth would likely require less frequent maintenance than its traditional counterpart, but any necessary repairs might involve industrially processed materials rather than locally available earth.

3.3. Stage C

At the end of its life cycle, the historical building could be deconstructed with minimal environmental impact. Had it reached the end of its lifespan prior to the twentieth century, it would have been dismantled with manual labor,

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which does not directly have carbon emissions. Tearing down the same old house nowadays would incorporate fuel powered machinery, which does increase carbon emissions. Rammed earth walls could be reintegrated into the soil, while stone and gypsum could be repurposed for new construction. Due to the lack of synthetic materials, waste generation would be minimal, and almost all materials would remain biodegradable or reusable(Arrigoni et al., 2017).

A modern reconstruction, however, would present additional challenges. Stabilized rammed earth containing cement or polymers might not be as easily reintegrated into the soil. Transportation emissions from removing demolition waste would also be higher, and any synthetic insulation systems used in the construction process could introduce non-biodegradable waste (Arrigoni et al., 2017).

3.4. Stage D

Analyzing the stage D of both current and ancient buildings is not an straight forward matter. One way of doing so is from a circular economy perspective. As mentioned in section 3.3, in the case of the original house, materials could be fully reused or naturally degraded without leaving a lasting environmental footprint. Rammed earth could be recycled directly into new walls, and stone elements could be repurposed without significant reprocessing.

The integration of modern techniques in rammed earth construction, however, might reduce the potential for full recyclability. If stabilizers or industrial additives are present, rammed earth might require additional processing before reuse. While modern tools allow for precision-cut stone elements to be reused efficiently, the overall complexity of modern waste management systems increases the environmental burden. Even though some materials could be reintegrated into future projects, the additional energy required for reprocessing would need to be accounted for in the LCA.

4. Conclusions

The article analyzes the environmental impact of rammed earth construction by comparing historical techniques used in the 16th-century House of Góngora in Cehegín, Murcia, with contemporary forms of rammed earth construction, assessing their sustainability through a life cycle analysis structured by the EN 15804 framework.

The 16th century rammed earth construction method shows a significantly lower environmental impact than modern adaptations due mainly to the use of locally sourced materials, manual labor, and carbon-based energy input.

While contemporary techniques enhance time and human labor efficiency through stabilizers and mechanized processes, they also introduce higher embodied carbon and waste. The LCA reveals that historical buildings present more local and naturally sourced materials that may be easier to reintegrate into the environment, whereas modern versions require additional processing, reducing their sustainability potential.

Despite advancements, traditional rammed earth remains a viable low-impact alternative, especially when combined with careful material selection and passive design strategies.

Future studies could expand the comparison between traditional and contemporary rammed earth construction methods and the most used modern techniques, such as reinforced concrete structures and masonry with perforated bricks. This analysis could yield valuable insights, particularly regarding environmental impact, with a focus on carbon emissions.

Historically, buildings like the case study analyzed in this research did not have a definitive end-of-life. The integration of *Placeta de los Carros*' tower into the house and the 19th-century additions highlight an approach that

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currently is gaining great momentum, such as adaptability and flexibility in building use. During these periods, such adaptations had minimal environmental impact.

As industrialization continues to depend on mechanized, energy-intensive processes and products, and given the ongoing climate crisis and slow decarbonization of our economy, bio-based, local, and traditional methods offer a promising alternative for sustainable construction and building adaptation.

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Landscape, Memory, and Sustainability: A study of Troglodytic Architecture in the Canary Islands (Spain)

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Abstract

Troglodytic heritage represents a significant global legacy, found across diverse regions from the Americas to Asia, Europe, the Mediterranean Basin, Africa, and notably the Canary Islands. Famous examples such as I Sassi di Matera (Italy), Les Eyzies in Dordogne (France), Cappadocia (Turkey), and Guadix in Granada (Spain) have become international benchmarks for the conservation, rehabilitation, and promotion of this unique architectural style. In contemporary contexts, troglodytic spaces are increasingly recognized for their potential in high-end tourism or as viable alternatives to large-scale urban housing and horizontal developments like the garden city model. This is largely due to the human fascination with returning to primitive habitats, particularly caves, which drives contemporary efforts to revive this architectural heritage by adapting ancient living spaces to modern lifestyles. This research aims to provide a conscious approach to the values of troglodytic architecture and its potential as an alternative model for preserving architectural heritage. As a modest and historically rooted habitat, troglodytic dwellings make use of natural terrain resources, creating a unique synergy between architecture and environment, which can be considered a precursor to modern bioclimatic design. The thesis highlights the typological and constructive features of these excavated dwellings, which reflect historical, social, and economic shifts in their surrounding contexts. These dwellings, with their mimetic architectural language closely tied to the landscape, present exceptional potential for contemporary residential living. Given the widespread existence of such settlements worldwide, the study begins with a general overview before focusing specifically on the Canary Islands. A comparative analysis is also undertaken with southern Italy to understand shared characteristics and differences. The research proceeds with an in-depth historical review of troglodytic habitats in the Canary Islands, addressing current challenges related to these dwellings and proposing constructive solutions to preserve and revitalize them within modern urban planning and heritage conservation strategies.

Keywords: *troglodytic; conservation; bioclimatic design; Canary Islands; cultural revitalization*

1. Introduction

Troglodytic architecture, with its ability to harmoniously integrate into the natural environment, offers a valuable opportunity for the renewal of rural fabrics today. These structures, which have proven to be sustainable over time, take advantage of the characteristics of the terrain and local climatic conditions, making them exemplary models of bioclimatic design. By utilizing indigenous materials and construction techniques adapted to the landscape,

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these dwellings not only minimize environmental impact but also promote a lifestyle in tune with nature. In a context where urbanization and unchecked expansion threaten cultural identity and architectural heritage, the recovery of these troglodytic structures emerges as a viable strategy for revitalizing rural areas. By reimagining and adapting these spaces to contemporary needs, it is possible to foster sustainable development that respects local history and culture. This approach not only preserves architectural legacy but also contributes to the creation of resilient and dynamic communities capable of facing future challenges. Research in this area is crucial to understanding how these constructions can be reintroduced into the social and economic fabric of rural regions.

2. Bioclimatic design in excavated architecture

Over the years, a true and unique "art of construction" has been developed; a symbiosis between the local climate, the characteristics of the physical environment, and the construction materials, based on the regional character specific to each place. The typologies, forms, construction techniques, components, and materials used, all reflect formal solutions of "architecture without architects," the result of human intelligence and a deep understanding of environmental factors.

The cave house in the Canary Islands continues to be one of the forms of habitation within its broad traditional architecture in rural areas, thanks to its favourable thermal conditions.

Bioclimatic architecture, understood in generic conceptual terms, is based on the adaptation and positive use of environmental and material conditions, maintained throughout the design and execution process of the project. It follows a logic that starts with the study of climatic and environmental conditions and the adaptation of architectural design to protect inhabitants by utilizing various natural processes. These include taking advantage of available resources such as sunlight, vegetation, rainfall, winds, and the earth to reduce environmental impacts, aiming to minimize energy consumption.

Although it appears to be a new concept, bioclimatic architecture has traditionally been used since ancient times. Excavated architecture can boast of adapting perfectly to the climatic conditions of its surroundings through specific, traditional construction elements and solutions that are sensitive to environmental impact, attempting to minimize energy consumption by using locally sourced materials (zero-kilometer houses), thus contributing to a reduction in environmental pollution.

Conventionally, the main difficulty of bioclimatic design in a built home is providing an integrated solution for the hygrothermal conditioning, both in winter and summer conditions. That is, to self-regulate in order to remain within the comfort zone despite external conditions, not too cold (where heating is necessary), nor too hot (where energy expenditure is required for cooling). However, the cave house, as a bioclimatic model, is very close to achieving perfect environmental conditions, with suitable temperature, humidity, airflow, and indoor air quality, all while integrating into the environment and promoting environmental sustainability.

The bioclimatic strategies used in troglodyte architecture are very diverse; below we list the most important ones.

2.1. Thermal regulator

Its high thermal mass acts as a good insulator, self-regulating the temperature inside the space thanks to heat and humidity. Due to the thickness of its envelope, temperature fluctuations are imperceptible indoors, achieving thermal stability. Indoor temperatures closely approximate the annual average of the local air.

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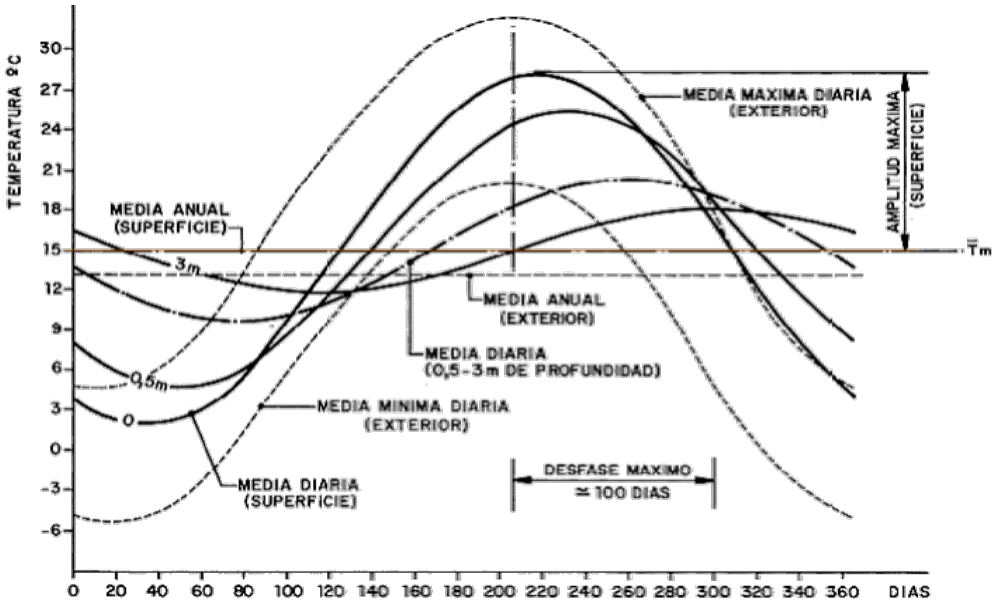

Fig. 1 – *Graph showing the variation of ground temperature as a function of depth* (Esteban Sainz, 1986).

> "It is commonly believed that at a depth between 0.5 and 1.5 meters, the temperature does not vary throughout the day and coincides with the daily average. At 15 meters, the temperature does not vary throughout the year" (Farfán Manzanare, 2013)

However, as we will see later, these conditions could be modified by the practice of openings in the enclosure as a strategy necessary to address other factors such as ventilation and lighting inside the cave.

It is important to make a distinction and highlight the difference between the concepts of thermal inertia and thermal mass of materials. Thermal inertia is understood as the property of a material that indicates the amount of heat it can retain and the speed at which it gives off and absorbs heat. This depends on the material's thermal transmittance (surface area), conductivity (thickness), etc. However, thermal mass refers to the ability of a material to store heat depending on its characteristics: density, heat capacity, and thickness.

Fig. 2 – *Photographic image and section sketch of the courtyard in a cave house in Gran Canaria* (Author).

Therefore, in the case at hand (cave houses), we will refer to the concept of thermal mass. Unlike conventional enclosures, the large thicknesses that constitute this model dissipate, before reaching the interior of the cave, the heat

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accumulated on its surface. This capacity allows the ground to absorb the heat generated by occupancy, equipment, and internal lighting during the day, achieving a sense of comfort.

2.2. Humidity and ventilation

The Canary Islands enjoy a subtropical climate, both dry and humid, with a dominance of the Trade Winds. These winds are very constant, blowing from the east-northeast, with a frequency of up to 90%, while in winter this proportion drops to 50%. The uniqueness of these winds lies in their stratification into two layers: one low and humid, and another high and dry. This circumstance generates a thermal inversion that prevents the rise of humidity, so the lower layers of the atmosphere have a high relative humidity, especially between 500 and 1,200 meters. The location of these settlements benefits from this climatic advantage, ensuring a constant and slightly higher humidity inside compared to the outside.

Another strategy used in cave houses is the application of lime on the exterior facade. Lime is a permeable material that allows the substrate –the ground– to transpire, absorbing water during rain and evaporating it during heat periods, keeping the interiors cool. Meanwhile, ventilation plays a fundamental role in ensuring the evaporation of excessive moisture, both from the ground and generated within the construction itself.

In Gran Canaria, inhabited caves are located on the slopes of the rugged landscape surrounding them, where natural ventilation is ideal. Additionally, the typological configuration around a courtyard, acting as a cooler accumulator thanks to the shade and humidity of the vegetation, helps regulate the temperature of the interior spaces.

Externally, small openings in the facade help, through differential pressure, to allow air to enter and circulate. Wooden joinery ensures constant air renewal inside the cave due to its low airtightness, thus maintaining its salubrity. In the past, the absence of joinery facilitated airflow between all rooms, but today this traditional strategy has been affected by the enclosure of many alcoves, where moisture condenses, leading to the formation of patinas on the substrate. Solutions adopted in other typologies include a vertical shaft that allows air to exit, thus eliminating excess moisture.

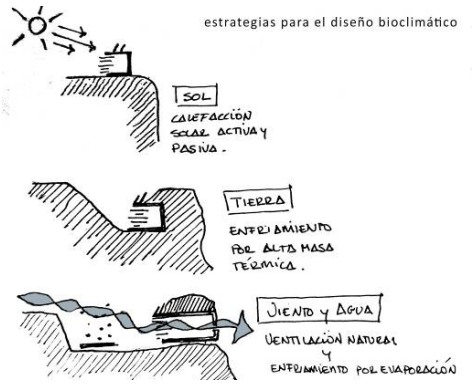

Fig. 3 – *Diagram of bioclimatic design strategies based on the position of the buried house* (Calvi Rollino, 2011)

2.3. Lighting

To address lighting issues in an underground inhabited space, two traditional techniques come into play. On one hand, there is the pursuit of light colors on the interior surfaces of the cave, either through whitewashing or whitening the walls. On the other hand, excavation in supports whose tone favors the reflection of light inside, such as the cream-colored pumice materials typical of the southeast and south of Tenerife, is employed.

It should be noted that the typology of homes in the Canary Islands typically features no more than two rooms in depth, with the farthest rooms from the facade being the sleeping quarters, which do not require significant lighting.

2.4. Protection from sun and wind

The orientation of the excavated architecture is a crucial factor in its design, as the use of solar energy and wind in different seasons is a determining factor when choosing the location,

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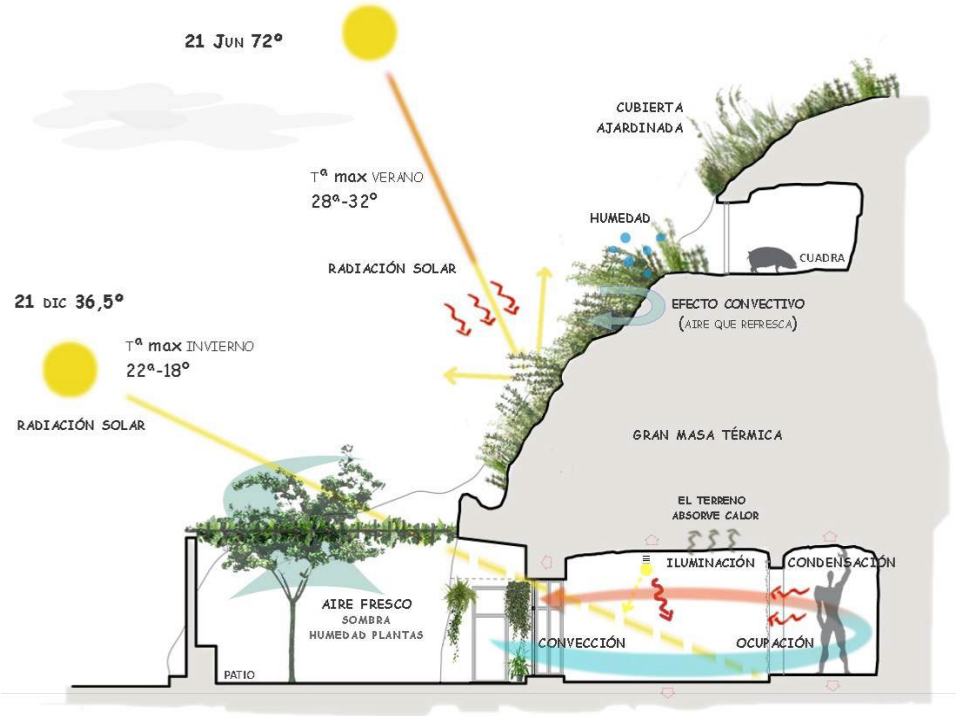

Fig. 4 – *Bioclimatic strategies in a "typical cave house" in Gran Canaria* (Author).

preferably on the southern or southwestern slopes. However, finding the ideal location is not always easy, and caves are sometimes found in positions meant for other functions (storage, production, livestock, etc.).

2.5. Acoustic insulation

Thanks to the thickness of the surrounding support material in a cave house, its insulation from external noise is ensured, which is particularly important in areas where the constant sound of the wind could cause discomfort.

2.6. Recycling of Construction Materials

When constructing a cave, many advantages arise from recycling the excavated material, which can be used in elements like the cave's enclosure, leveling the ground, or making furniture and decoration for the cave or adjacent buildings. In the Canary Islands, the material extracted is reused, either to condition the land in front of the cave entrance or for its agricultural use, placed on certain crops, thereby helping conserve moisture.

2.7. Relationship with territorial resources

Troglodytism has maintained a close relationship with the available resources in the territory since ancient times, forming the basis of the economy and the way of inhabiting the rural landscape.

Its adaptation to the environment, occupying the driest and most barren areas and leaving the more fertile land for exploitation, makes it an excellent example of symbiosis between the natural environment and the human-modified landscape, minimizing the energy impact necessary to achieve the best comfort conditions required for survival.

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Tipo de uso	Residencial
Clase de higrometría	3
Área	36.47 m²
Altura	2.25 m
Volumen	82.047 m³
Tablas de actividad	Vivienda_01 (Ocupación, Iluminación, Equipos y Infiltraciones)
Temperatura de verano, con ocupación	25 °C
Temperatura de verano, sin ocupación	27 °C
Temperatura de invierno, con ocupación	20 °C
Temperatura de invierno, sin ocupación	17 °C

Fig. 5 – *Screenshot illustrating the starting data specifications for the evaluated model. Extracted from the trial with EnergyPlus software.*

3. Case Studies

In this research, the testing and simulation of a three-dimensional model for each of the caves under study have been carried out, in compliance with the CTE (Spanish Technical Building Code) and comfort parameters, to verify if the cave-house model meets the efficient model.

3.1. Methodology

For the selection of the case studies, at first, we have created a table of all the caves inspected throughout this research (more than 200 units), each of which has undergone a detailed architectural study (Table 1).

The caves were classified based on common parameters such as orientation, material, surface area, number of excavated and built rooms, existence of a bathroom (excavated, external), private quarry for extraction, existence of a kitchen (excavated, built), presence of a patio (open or closed), cistern/water tank, number of floors (levels), and cave use.

Once the table (Excel) was created, a 50th percentile formula was applied, allowing us to determine which caves, based on the number of parameters common to them, are the most representative. As a result, we obtained: in Gran Canaria, caves nº29 and nº51 from Juncalillo, Gáldar, and cave nº1 from Las Arvejas in Artenara. As the research was extensive, this short paper focuses solely on the results from one of the models tested. For full details, including all other models and their comparison to research conducted in Italy, please refer to the author's doctoral thesis. Once the caves were selected, preliminary files were created providing data on relative humidity and daily ambient temperature for both locations.

3.2. Software, calculations and results

The software used in this research procedure is CYPE Ingenieros CYPECAD MEP, a tool for verifying energy demand and consumption requirements of buildings. After creating the model, the EnergyPlus software was accessed for energy demand limitation simulation and to obtain verification and compliance results for the studied models.

Simulation involves creating a model of a real system and subjecting it to a set of conditions to understand the original system's behavior. In this way, the necessary strategies can be adopted to ensure the real system operates based on expected conditions.

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Table 1 – *Table of resulting data (GC) from the analysis of values obtained in the trial conducted on Gran Canaria caves* (Author).

Cueva 29 Juncalillo	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	18.65	18.78	18.97	19.33	19.61	20.17	21.09	22	20.93	20.44	19.33	18.84	
Max	20.2	20.16	20.35	20.7	21.62	22.15	23.9	24.07	23.8	22.24	20.8	20.15	**3.61**
Average	19.425	19.47	19.66	20.015	20.615	21.16	22.495	23.035	22.365	21.34	20.065	19.495	
Cueva 51 Juncalillo Room 1	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	18.65	18.77	18.92	19.27	19.52	20.07	20.99	21.94	20.8	20.33	19.23	18.81	
Max	20.13	20.03	20.18	20.5	21.37	21.97	23.7	23.84	23.69	21.96	20.6	20.05	**3.5**
Average	19.39	19.4	19.55	19.885	20.445	21.02	22.345	22.89	22.245	21.145	19.915	19.43	
Cueva 51 Juncalillo Room 2	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	18.25	18.4	15.57	19.02	19.36	19.97	20.97	21.83	20.65	20.15	19.04	18.45	
Max	20.15	20.04	20.19	20.61	21.55	22.18	24	24.11	23.86	22.02	20.75	20.08	**3.77**
Average	19.2	19.22	19.38	19.815	20.455	21.075	22.485	22.97	22.255	21.085	19.895	19.265	
Cueva 01 Las Areyas Room 1	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	22.25	22.59	23.01	23.89	24.31	24.8	24.92	24.93	24.89	24.57	23.58	22.75	
Max	24.89	25.02	25.14	25.26	25.37	25.42	25.51	25.51	25.48	25.39	25.29	25.01	**1.6**
Average	23.62	23.805	24.075	24.575	24.84	25.11	25.215	25.22	25.185	24.98	24.435	23.88	
Cueva 01 Las Areyas Room 2	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	21.58	21.6	21.67	22.18	23.38	24.05	24.56	24.58	24.41	23.56	21.96	21.64	
Max	22.81	22.9	23.62	23.92	24.83	25.03	25.1	25.11	25.08	24.96	24.35	22.93	2.65
Average	22.195	22.25	22.645	23.05	23.605	24.54	24.83	24.845	24.745	24.26	23.155	22.285	

Figure 7 presents the data for one of the caves studied in Gran Canaria including a first document with starting data, floor plans, sections, dimensions, surfaces, and images of the excavated structure.

4. Conclusions

Based on energy simulation results, this research demonstrates that implementing setpoint data from specific building regulations enables cave house architectural models to meet the parameters established by their bioclimatic design strategies. They maintain nearly constant internal temperatures year-round, with differences not exceeding 4 °C. Therefore, none of the tested models exceed the limits required by the standard for indoor comfort, with a maximum of 27 °C and a minimum of 17 °C.

Consequently, the variations recorded do not require heating or cooling, as they remain within the ideal comfort parameters these dwellings autonomously provide.

The orientation of these prototypes plays an important role; almost always facing south, this architectural strategy helps mitigate low winter temperatures in settlements with significant seasonal climate variation.

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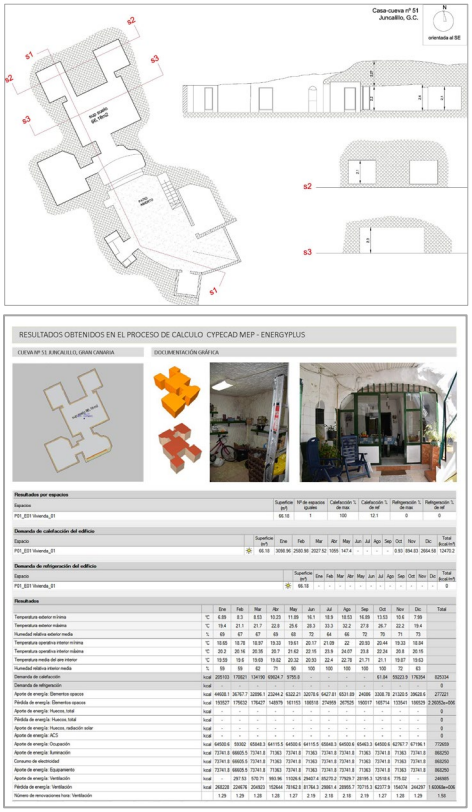

Fig. 6 – *Screenshot illustrating dates of model, from EnergyPlus software.*

Thus, cave houses, as primitive models, prove efficient due to their typological and construction configuration, intrinsically incorporating passive architectural design strategies that positively influence occupant thermal comfort.

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Rammed Earth as an Alternative to Conventional Construction Methods in Valencia: a Comparative Life Cycle Assessment Perspective

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Abstract

This paper uses a single-family housing model as a case study to evaluate the environmental and thermal performance of rammed earth construction compared to conventional building materials. This study aims to determine which construction method presents a lower environmental impact while maintaining comparable thermal performance. The research begins by defining the physical properties of the earth material used for rammed earth walls through an extensive literature review. Once characterized, construction solutions for the foundation, walls, and roof are proposed. These solutions are validated using thermal transmittance, condensation, and thermal lag analyses, following UNE EN ISO 13786:2000 standards. A single-family housing model is then developed considering local climatic recommendations provided by the Climate Consultant tool. Its thermal performance is assessed by performing a steady-state energy simulation across three distinct climate zones in the Valencian Community: warm and humid (Valencia), cold and dry (Comarca Esport, Utiel-Requena), and warm and dry (Alicante). A comparable model built with conventional materials is also analyzed and adjusted to achieve the same thermal transmittance. The environmental impact is assessed through a Life Cycle Assessment of the A (production) and B (use) phases for both construction methods. This comparative analysis provides insights into the environmental trade-offs between traditional and conventional construction techniques. By quantifying the environmental impacts and thermal performance, this study contributes to the growing discourse on sustainable construction and highlights the potential of rammed earth as an environmentally favorable alternative.

Keywords: *rammed earth; life cycle assessment; energy efficiency; building physics; sustainable construction*

1. Introduction

As the climate emergency becomes more of an issue worldwide, all productive sectors are trying to find ways to reduce, not only their carbon footprint, but also their overall impact on the environment. Although many industry

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practitioners focus on developing new and emerging technologies, others look at the past for answers in vernacular architecture.

In architecture, one example is the use of rammed earth for building walls. This technique, which consists of compacting layers of moist soil into a rigid formwork to create durable walls (Serrano et al., 2016). The exact composition varies significantly depending on the area and the availability of materials. Rammed earth has been used for centuries worldwide to build houses.

The modern ways of construction have displaced this method despite its interesting characteristics (Jiang et al., 2023). However, many researchers and other industry professionals are testing their suitability for present-day necessities (Samadianfard & Toufigh, 2020). Many researchers have tested their mechanical, acoustic, and thermal characteristics, also (Ávila et al., 2021; Marzal, 2018). So far, most studies indicate that rammed earth allows transitioning to a more sustainable building industry (Arrigoni et al., 2017).

However, to the author's knowledge, no study has yet analyzed the environmental impacts of single-family rammed earth constructions in the Mediterranean climate. Given the considerations explained in previous paragraphs, this article seeks to answer the question: Can rammed earth be a sustainable and energy-efficient practice in contemporary architecture in different parts of the Valencia region?

This question is answered through a case study house established in different locations in the Valencia community, studying its energy efficiency and Life Cycle Assessment.

2. Methodology

This study is conducted using a case study methodology. A single-family rammed earth house is explicitly designed for this study, and its environmental impacts and energy efficiency are analyzed. In this sense, the family house is analyzed as if it were built with conventional, present-day methods and rammed-earth construction. Both models are developed to achieve similar thermal transmittance and local climatic recommendations provided by the Climate Consultant tool.

The house of conventional construction consists of double ceramic brick walls, an air chamber, rock wool insulation, and an interior plaster finish. The roof is made of ceramic tiles over a waterproofing layer, rock wool insulation, and a resistant reinforced concrete slab support.

The other housing typology consists of rammed earth walls, straw insulation between two air cavities—designed with sufficient structural rigidity to remain stable—and an interior finish of laminated timber panels. All components include fire-retardant treatment. The roof is made of ceramic tile and a layer of straw insulation, on a resistant base of laminated wood board and wood joists. Plans of the house and construction details of the two typologies can be seen in Figures 1, 2, and 3.

2.1. Energy simulation

The Energy Simulation was conducted using the Herramienta Unificada Lider Calener (HULC), a software developed by the Ministry of Public Works and the Institute for Energy Diversification and Saving (IDAE), and the Thermotechnics Group of the Industrial Research and Cooperation Association of Andalucia (AICIA), with the collaboration of the Eduardo Torroja Institute of Life Sciences Construction, IETCC in Spain (Ministry of Public Works et al., 2024).

This software verifies energy efficiency requirements in buildings according to the Technical Building Code – Basic Document – Energy Savings - HE (Ministry of Housing and Urban Agenda)., 2019) and obtaining the energy rating of a new and/or existing building.

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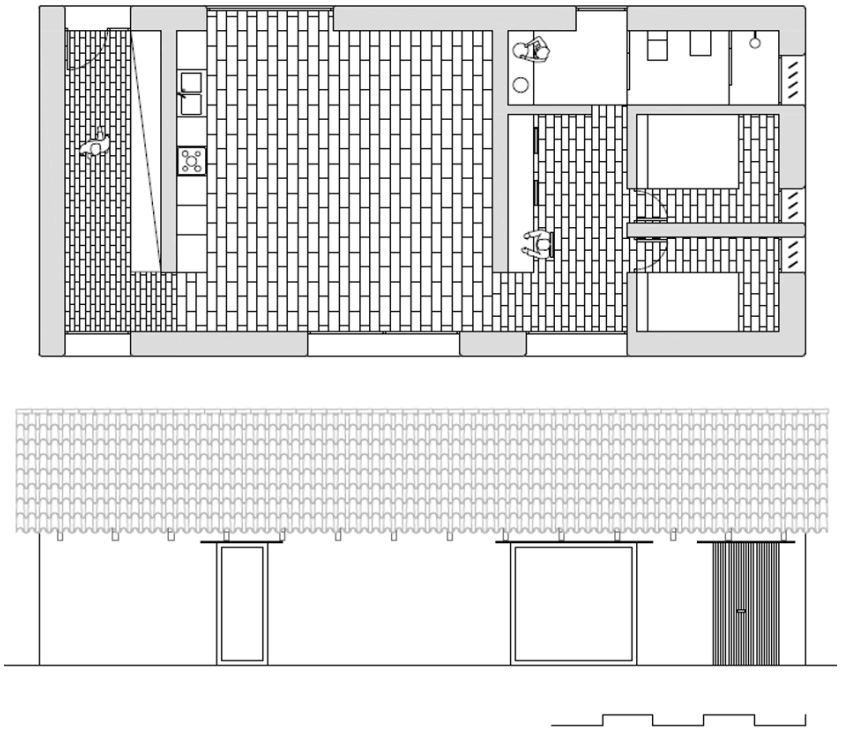

Fig. 1 – *Floor plan and elevation of the house.*

HULC is composed of several tools: CCDEW (Thermal calculation USA), ESTO2 (Simulation of y ACS air conditioning installations USA), CALENER-GT (Tool for the definition of large Tertiary buildings, as an adaptation of American eQuest software), DOE-2.2 (Calculation Engine -DOE – USA), and PostCALENER (Tool for the analysis of the results obtained) (James J. Hirsch & Associates (JJH) et al., 2016) (Coronel Toro, 2017). In this study, HULC is used to evaluate the energy demand of a rammed earth construction compared to conventional construction materials, using a single-family housing model as a case study in three different climatic zones of the Valencian Community. In this sense, a specific workflow must be followed, from project creation to regulatory compliance verification. The software interface is organized in sequential menus to facilitate data entry, which are described below:

- Project Creation and Description: Administrative data, location, applicable regulations, and general building characteristics, including type and year of construction, are defined.
- Geometric and Constructive Definition: The building is modelled in 3D, including materials, enclosures, glazing, frames, openings, and thermal bridges. Databases can be imported, and thermal properties can be configured.
- Heating and Cooling Demand Calculation: Compliance with heating, cooling, and energy efficiency requirements is verified, with the possibility of exporting data to CALENER-GT.

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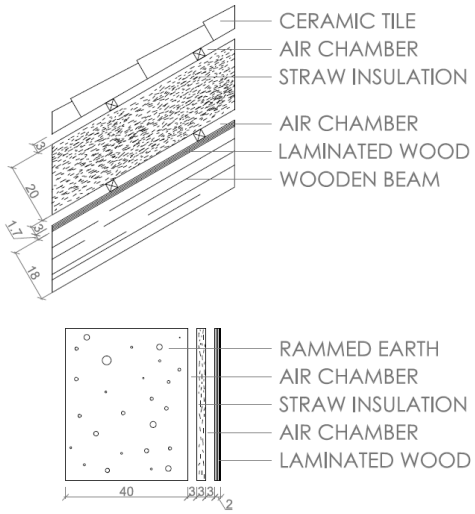

Fig. 2 – *Construction details - Rammed earth house.*

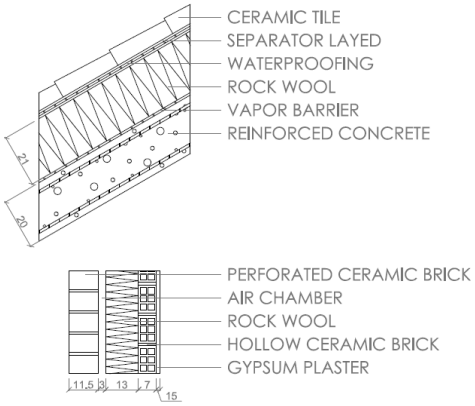

Fig. 3 – *Construction details - Conventional house.*

2.2. Life Cycle Assessment Methodology

The LCAs were conducted according to ISO 14040:2006 (ISO 14040, 2006) and EN 15804:2020 (European Committee for Standardization, 2020) standards.

The study considers the following life cycle modules:

- Stage A (Product and Construction Process Phase)
- Stage B (Energy use during the lifespan of the house)

The assessment follows a cradle-to-gate + energy use approach given the selected modules. The C (End-of-Life phase) is considered outside of the scope of this study.

This decision is based on the limited availability of reliable data regarding the actual end-of-life scenarios of the materials, which could introduce a high degree of uncertainty in the results.

Moreover, the manufacturing and use phases represent critical stages, and it is essential to analyze and compare the environmental impacts of both construction systems.

- **Functional Unit:** The functional unit defines the reference basis for comparison in an LCA study. In this analysis, the functional unit corresponds to the entire life cycle of an 86 m² dwelling.
- **Allocation Principle:** The allocation method follows the end-of-life (EoL) allocation approach, as specified in EN 15804:2020. This methodology was applied by (Baldassarri et al., 2017) and (Lavagna et al., 2018).
- **Life Cycle Inventory (LCI):** The LCI was developed using Simapro v9.6, which integrates the Ecoinvent v3.10 database (Wernet et al., 2016), one of the most comprehensive sources for LCA calculations. The environmental impacts of each material were adjusted based on the country-specific electricity mix, ensuring alignment with regional energy production technologies.

3. Results

The thermal performance and environmental impact assessment results of the rammed earth house and the conventional materials house are presented in the following sections.

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Table 1 – *Environmental Footprint Characterization results.*

Impact category	Unit	Conventional construction	Rammed earth house
Acidification	mol H+ eq	137.89581	65.42596
Climate change	kg CO2 eq	33878.633	11372.872
Ecotoxicity, freshwater	CTUe	215123.54	52873.505
Particulate matter	disease inc.	0.008037628	0.007225072
Eutrophication, marine	kg N eq	35.756358	20.766339
Eutrophication, freshwater	kg P eq	0.68043821	0.56505205
Eutrophication, terrestrial	mol N eq	409.98584	223.7621
Human toxicity, cancer	CTUh	0.000424132	7.34E-05
Human toxicity, non-cancer	CTUh	0.000264112	0.000145576
Ionizing radiation	kBq U-235 eq	361.44367	437.79909
Land use	Pt	473651.34	1194501.5
Ozone depletion	kg CFC11 eq	0.000372009	0.000179838
Photochemical ozone formation	kg NMVOC eq	145.15793	68.265052
Resource use, fossils	MJ	347910.58	146035.76
Resource use, minerals, and metals	kg Sb eq	0.1958887	0.12134543
Water use	m3 depriv.	10125.092	13866.638

3.1. Energy Simulation results

The case study presented the same thermal properties in rammed earth and conventional materials. Therefore, the results of the energy demand KWh/m^2.year for climatization obtained are equal in both models but these change according to the climate zone in the Valencian Community.

Figure 4 shows the energy demand values obtained in each climate zone. In this sense, if the model is in Alicante, the demand is 4,34 KWh/m^2.year for heating and 6.05 KWh/m^2.year for cooling. In Valencia, the demand changes to 0.13 KWh/m^2.year and 6.46 KWh/m^2.year respectively. In the case of Utiel, the values obtained are 10.61 KWh/m^2.year for heating and 1.86 KWh/m^2.year for cooling, which accounts for the more severe winters in the area.

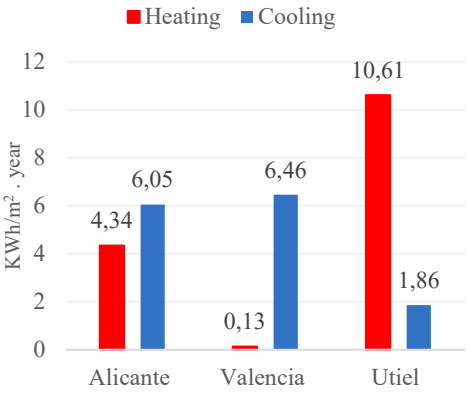

Fig. 4 – *Energy demand of the case study.*

The rammed earth and conventional materials models in all climate zones present energy demand lower than the maximum accepted for the Passive House Certifications. Therefore, both models present good thermal performance.

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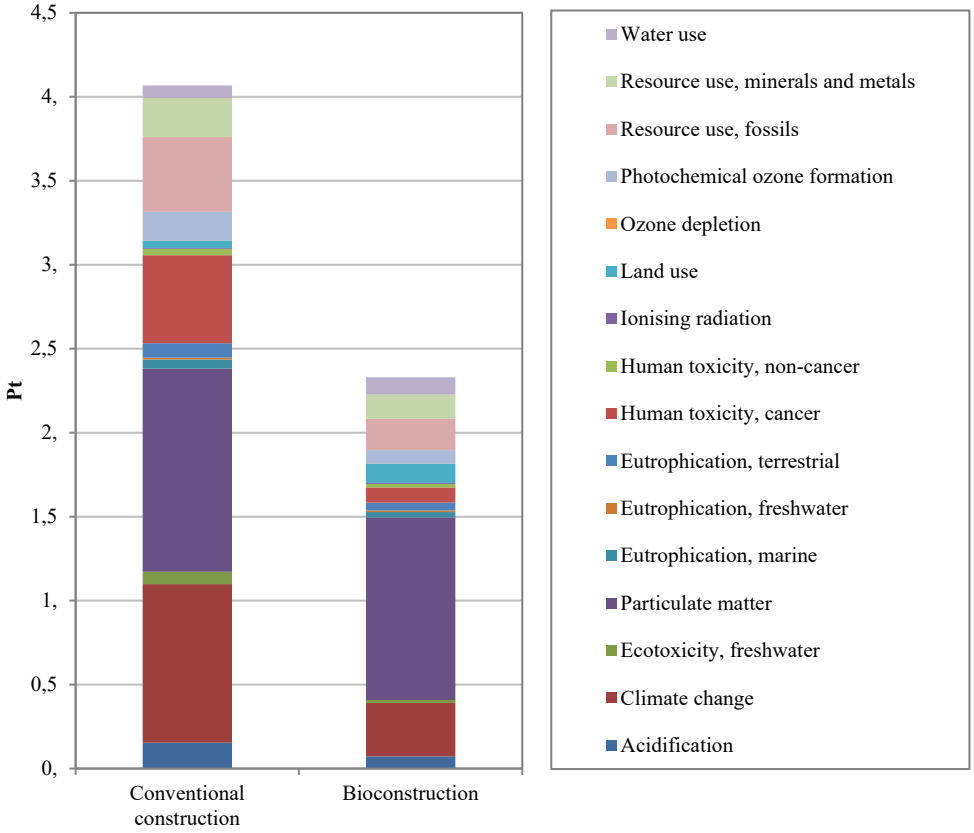

Fig. 5 – *Environmental Footprint Single score result.*

3.2. Life Cycle Assessment results

As shown in Table 1, almost all categories show lower environmental impact results in the case of the rammed earth house, most of them being at least 50% lower than the conventional construction.

The most well-known category, the carbon footprint, is around 70% lower in the case of the rammed earth house. Other categories, such as

acidification and ecotoxicity, show similar trends, reducing the impacts by at least 50%. The only categories in which the results are higher in the bio-based option are ionizing radiation, land use, and water use. To analyze the significance of these results in the overall environmental impact of the house, the Environmental Footprint methodology offers the possibility of normalizing and weighting the results. That allows for category comparison and obtaining a Single Score result. The Single Score result can be seen in Figure 5

4. Conclusion

The results allow for drawing the following conclusions:

- It is possible to build rammed earth houses in the Valencian climate that maintain equal energy efficiency performance as conventional housing.

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While the energy consumption simulation result for heating is almost zero in València (0.13 KWh/m^2.year), in Utiel the result reaches 10.61 KWh/m^2.year.

Which means that it is critical to ensure good thermal insulation to reduce impacts related to energy consumption and passively improve thermal comfort.

- Regarding energy consumption for cooling, the results are much higher in València and Alicante (around 6 KWh/m^2.year) than in Utiel (with 1.83 KWh/m^2.year).
- The environmental impacts of the Rammed Earth house are lower in every major impact category. This is especially true in categories such as Climate Change potential, in which it reduces carbon emissions by around 70%.

This study is limited by the exclusion of the end-of-life phase due to the lack of reliable data on real-life disposal scenarios. However, as a future line of research, we propose collecting data on potential end-of-life scenarios to conduct an inventory analysis with our data that would allow for a rigorous analysis of this highly significant stage.

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Seismic Risk Analysis of the Rammed Earth Residential Buildings in Niebla (Huelva, Spain)

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Abstract
Niebla is the oldest monumental city in the province of Huelva, located in an area of high seismic hazard in the region of Andalucía, in the South-East of Spain. The walled historic centre, declared historic-artistic site in 1982, has a rich earthen heritage. The Almohad walls, the largest and best-preserved in Europe, are certainly noteworthy. However, equal attention should be given to the traditional earthen residential houses built using the rammed-earth technique. This study is focused on the analysis of the seismic vulnerability of a sample of the traditional earthen rammed earth residential dwellings in the historic centre of Niebla, which would suffer from significant damages in the event of an earthquake of intensity VII in the region. The vulnerability has been assessed with the Vulnerability Index Method (L1 Risk-UE VIM) adapted to take into account the specific characteristics of the earthen residential buildings. Additionally, considering the heritage value of the historic built ensemble, losses have been obtained in terms of damaged built area, as the economic value cannot be calculated. The research highlights the significant impact an earthquake could have on these buildings. It also underscores the urgent need to develop strengthening solutions to reduce their seismic vulnerability, ensuring their long-term conservation and preservation.

Keywords: *seismic vulnerability; rammed earth; vernacular heritage; Niebla; VIM (Risk UE)*

1. Introduction

Niebla, the oldest monumental city in the province of Huelva (in Andalucía, South-East of Spain (Fig. 1a, 1b), has a rich earthen heritage. The city centre, surrounded by a 2 km rammed-earth wall (Fig. 1c) from the Almohad period (the largest and well preserved in Europe), was declared a historic-artistic site in 1982 (RD 559/1982; BOE 66, 18 March 1982). Apart from the walls, the traditional earthen residential houses built with rammed-earth technique must be highlighted, as part of the genuine heritage of the city which must be preserved.

The building stock of Niebla is characterized by one to three-storey semi-detached single-family houses, covered with plaster or tile cladding, most of which are skirted by a 90 cm high plinth. In these circumstances, it is difficult to determine the structure of the fabric (rubble masonry, brick masonry or rammed earth), and the function of the plinth (load bearing, waterproof covering or to prevent moisture in the lower part of the wall).

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Fig. 1 – a*, b) Location of the city of Niebla in Spain; c) Almohad walls* (SEC).

For these reasons, the sample analysed in this research comprises a series of buildings (Fig. 2) with visible earthen walls identified through ocular inspection, as well as others currently covered but documented in historical images as having earthen walls. It also incorporates buildings previously identified by other authors as rammed-earth structures (Canivell et al., 2014; Pérez Vila et al., 2022), along with others that are likely rammed-earth dwellings based on their similar characteristics with the confirmed examples.

Fig. 2 – *Example of analysed buildings* (SEC).

Being Niebla located in an area of high seismic hazard, these traditional dwellings, assuming to be classified as an EMS-98 vulnerability class A or B (Grünthal, 1998), would suffer from significant damage in the event of an earthquake of intensity VII, likely to happen in the region (IGN, 2002). To guarantee their conservation and preservation as well as to establish criteria to define strengthening solutions when needed, the seismic risk has been assessed determining the seismic vulnerability, adapted to their specific characteristics and obtaining losses in terms of the percentage of the expected damaged built area.

2. Methodology

To assess the seismic vulnerability of the earthen residential buildings in Niebla, the L1-Risk-UE VIM (Milutinovic & Trendafiloski, 2003), has been used. This method, adapted to earthen structures (Arto et al., 2020, Basset-Salom & Guardiola-Víllora, 2023), was proposed to evaluate the seismic performance of seven European cities with different levels of seismic risk (Mouroux et al., 2004) and applied to many other urban areas, in Europe and beyond (Feriche et al., 2009, Vicente et al., 2011; Irizarry et al., 2012, Maio et al., 2016, Cherif et al., 2017, Guardiola-Víllora & Basset-Salom, 2020, Liu et al., 2023).

The first step is to identify the structural typologies according to the Building Typologies Matrix (BTM), which, sometimes, turns to be difficult in the case of masonry buildings, as it is not easy to determine the construction and quality of the masonry without damaging it. Secondly, each structural typology is assigned an initial vulnerability index, V_I*, representing the most likely value (Giovinazzi & Lagomarsino, 2004), which is then adjusted by means of the behaviour modifiers.

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Then, after calculating the probability of suffering a certain grade of damage for the seismic scenario and defining the damage probability matrices (DPMs), the seismic risk of the earthen dwellings is obtained, showing the expected damaged built area to be rebuilt or repaired in the event of an earthquake in Niebla.

3. Description of the analysed buildings

This research is focused on a sample of 178 residential dwellings that showed some evidence of being built with rammed earth. The analysed residential buildings are represented in Fig. 3.

The figure identifies those confirmed to have structural rammed-earth load-bearing walls and those assumed to be rammed-earth buildings based on their observed characteristics. In the authors' opinion there are more earthen dwellings in the city which cannot be confirmed, given the impossibility of taking samples for testing and also because of the renderings and coatings hiding the structural materials.

The sample is formed by semi-detached buildings of one, two or three storeys built, according to the cadastral database (SEC) from the end of the 19th century to the end of the 20th century. Data about their age and number of storeys (Fig. 4) have been retrieved from the SEC.

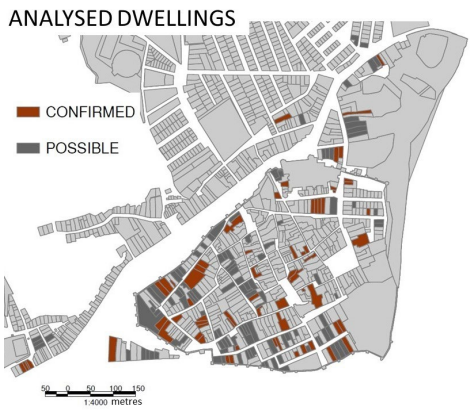

Fig. 3 – *Analysed residential buildings*

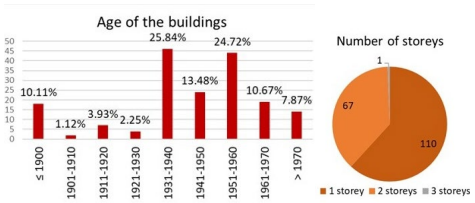

Fig. 4 – *Age and number of storeys*

Only simple rammed earth (SRE) typology has been considered as there is no evidence of lime-crusted rammed earth walls or rammed earth walls reinforced with brick courses. As shown in Fig. 5, the existence of brick quoins cannot be disregarded, however they have only been considered when they are obvious, since it is not possible to ensure that they exist when they are hidden.

4. Evaluation of the seismic vulnerability

The value adopted for the initial vulnerability index (V_I^*) of the SRE typology, assigned to all the buildings in the sample, is 0.78 (Basset-Salom & Guardiola Víllora, 2023).

To tackle the specific characteristics of rammed-earth residential buildings in Niebla that may improve or worsen their seismic performance, several behaviour modifiers (Vm) have been considered, calculating the total value of the vulnerability index VI with Equation 1:

$$VI = V_I^* + \sum Vm \quad (1)$$

The behaviour modifiers applicable to the buildings under study, refer to the number of storeys, the aggregate relative building position and elevation, the length of the load-bearing façades, the geometric horizontal and vertical irregularities, and the state of maintenance. See in Fig. 6 different states of maintenance in the analysed sample.

The number of storeys influences the ductile behaviour of these buildings (Ortega et al., 2018); therefore, a modifier has been defined penalising three-storey houses (+0.02) and benefitting one-storey ones (-0.02).

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Fig. 5 – *Example of brick quoins* (SEC)

Fig. 6 – *Example of analysed houses with different state of maintenance* a) good, b) medium, c) bad, d) very bad (SEC)

The aggregate relative building position (middle, corner, header) in the block, influences the seismic performance as well as the relative elevation provide there is a difference (greater than or equal to two) in the number of storeys with the adjacent dwellings which may cause damage due to pounding.

In this study differences of one storey (Fig. 7) have also been considered, adapting the coefficients from Lantada (2007).

The horizontal and vertical irregularities along with the length of the load-bearing façades (when it exceeds 15 metres), are factors to be considered. In these cases, behaviour modifiers, as defined by Lantada (2007) have been used.

Fig. 7 – *Houses with different number of storeys* (SEC)

Finally, given that the state of maintenance plays a crucial role in either reducing (when good) or increasing (when poor) a building's seismic vulnerability, a modifier has been assigned to the four identified maintenance conditions: good, medium, bad, and very bad.

The map representing the final value of the seismic vulnerability index of each analysed building (VI) as well as the bar chart with the distribution of percentages within the sample are shown in Fig. 8.

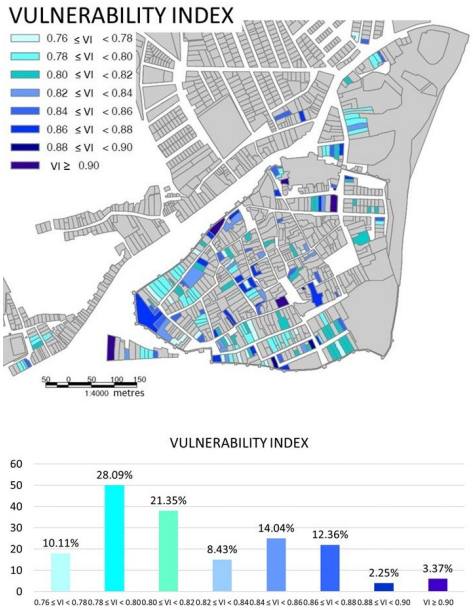

Fig. 8 – *Map of Vulnerability Indices of each analysed building and percentages with respect to the sample.*

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The vulnerability classes according to EMS (Grünthal, 1998) are mapped in Fig.9, with 39% of the houses classified as class A (VI greater than 0.82) and 61% as class B. This distribution is mainly due to the state of maintenance.

5. Seismic Scenario

The largest historical earthquake recorded near Niebla is the 1755 Lisbon Earthquake.

The effects of this event, the strongest that has ever affected Niebla, have been described by Martinez Solares (2017). This earthquake which reached a maximum EMS-98 intensity of X in Lisbon, had in Niebla an intensity of VII (Martinez Solares & Mezcua, 2002, Peregrín Pizarro, 2022).

This is also the value of the intensity reflected in the IGN 2002 map of seismic hazard in Spain (Fig. 10).

Therefore, a seismic scenario of intensity VII has been considered in this study.

6. Assessment of the heritage losses

For the adopted seismic scenario, the damage probability distribution has been defined (Equation 2) with the binomial-equivalent beta probability density function (Giovinazzi, 2005).

$$p_\beta(x) = \frac{\Gamma(t)}{\Gamma(r)\ \Gamma(t-r)} \frac{(x-a)^{r-1}\ (b-x)^{t-r-1}}{(b-a)^{t-1}}$$

$$a \le x \le b \quad a = 0 \quad b = 6 \qquad (2)$$

Then, the probability of reaching each damage grade has been computed assuming a beta cumulative density function, resulting in the damage probability matrix (DPM) for each of the 178 analysed buildings.

The DPM of the representative buildings in the sample is shown in Fig. 11. Each column displays the probable distribution of damage grades in the building (D0: No damage, D1: Slight, D2: Moderate D3: Substantial to Heavy, D4: Very Heavy, D5: Destruction).

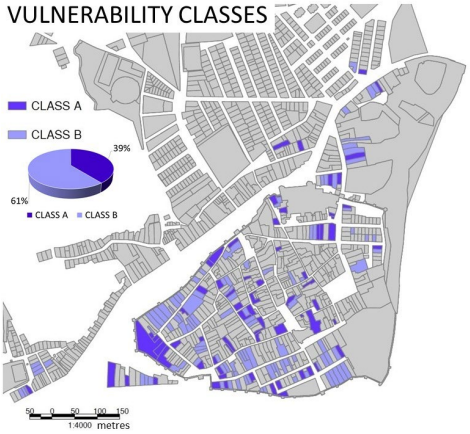

Fig. 9 – *Map of Vulnerability classes of each analysed building, according to EMS-98.*

Fig. 10 – *Map of seismic hazard of Spain (return period of 500 years), 2002* (IGN).

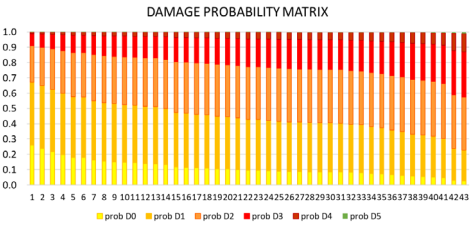

Fig. 11 – *Damage probability matrix (DPM).*

Heritage losses are determined by the likelihood of a building reaching each damage grade and the associated cost of repair or reconstruction. According to the HAZUS-4.2 SP3 Technical Manual (FEMA, 2020), the loss percentages for slight, moderate, extensive and complete damage state are 2%, 10%, 44.7% and 100% of the construction replacement cost, respectively.

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The costs for repairing or rehabilitating a residential single-family dwelling occupancy class (RES1) are calculated (FEMA, 2020) by multiplying the probability of each damage state by the corresponding loss percentages. These percentages account for structural, acceleration-sensitive non-structural, and drift-sensitive non-structural costs, all expressed as a percentage of the building's replacement costs. The resulting loss ratios for all damage states are then summed to determine the total cost.

Given the unique characteristics of rammed earth buildings and the challenges in establishing a market price for reconstructing this building typology, the authors have opted to map the mean damage ratio (MDR). This ratio represents the percentage of the damaged area relative to the total built area of a building requiring reconstruction. Consequently, the map in Fig.12 displays the MDR for each building, and the bar chart in Fig. 13, the MDR percentages and number of buildings in each interval.

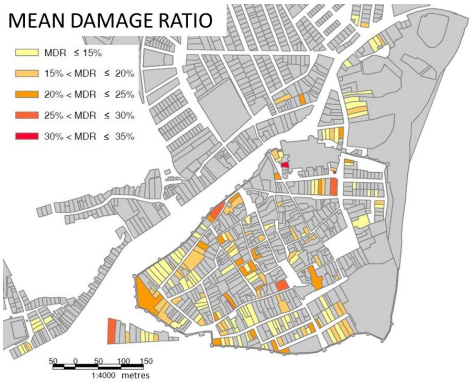

Fig. 12 – *Mean Damage Ratio (MDR) for each analysed building.*

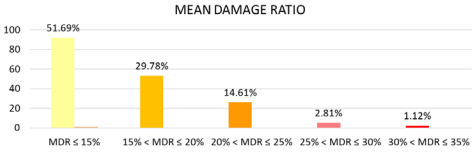

Fig. 13 – *MDR: percentages and number of buildings.*

According to the map and the bar chart, in the event of an earthquake of intensity VII, the ratio of damaged area will be less than 15% for 92 buildings (51.69%), for 53 buildings (29.78%), MDR will range between 15% and 20%, while for 26 buildings (14.61%) MDR will be between 20% and 25%. Additionally, for 5 buildings (2.81%) between 25% and 30% of the built area will be damaged and for 2 buildings (1.12%) the damaged built area will exceed the 30%.

7. Conclusions

This study focuses on analysing the seismic vulnerability of a sample of traditional earthen rammed earth single-family dwellings in Niebla, which would sustain significant damage in the event of an earthquake of intensity VII in the region.

The seismic vulnerability has been assessed using the L1-Risk-UE Vulnerability Index Method, adapted to account for the unique characteristics of earthen building types. The results reveal a high seismic vulnerability for the analysed rammed earth single-family residential buildings in Niebla, with 39% of the analysed dwellings being classified as A (EMS-98), with vulnerability indices bigger than 0.82.

Given the heritage value of the historic built ensemble, which was declared a historic-artistic site in 1982, the losses have been assessed based on the percentage of damaged built area. This approach was chosen because determining the economic value of structures with heritage significance is challenging, due to their unique and irreplaceable nature.

The research highlights the significant impact an earthquake could have on these buildings and emphasizes the need to develop strengthening solutions that are compatible with their heritage character. These measures are essential to reduce their seismic vulnerability and ensure their long-term conservation and preservation.

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In the authors' view, it is crucial to catalogue all earthen residential buildings at the earliest opportunity. This will enable a more comprehensive and in-depth study of their seismic vulnerability and expected behaviour during an earthquake, helping to establish intervention criteria and allocate resources effectively to prevent potential irreparable damage and subsequent heritage losses.

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Assessing the Performance of Earthen Sites Exposed to the Environment: The Wupatki Pueblo Case in Arizona, USA

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Abstract

This paper presents the inspection, diagnosis and monitoring activities conducted at the Wupatki Pueblo in Arizona, USA, to assess the conservation state and performance of this archaeological site, which has been exposed to increasingly harsh environmental conditions. On-site inspections, including visual damage surveys and non-destructive testing, revealed that the archaeological remains – masonry walls consisting of sandstone units laid with earth-based mortars – experience severe degradation phenomena, posing risks to their structural stability and long-term durability. These findings underscored the need for an in-depth study of the walls' hygrothermal behaviour to understand how environmental fluctuations in temperature and moisture affect the performance of the masonry. To avoid invasive testing on the archaeological remains, four test walls were built nearby the site, using representative materials and building system, namely earth-based mortar prepared from locally sourced soil and sandstone units from the Moenkopi formation obtained from a local quarry. During construction, temperature and moisture sensors were embedded into the mortar joints to enable continuous monitoring of the hygrothermal conditions. Data are being collected over a 2-year period and are expected to allow the characterisation of the masonry's response to local environmental conditions, which are concurrently monitored by an on-site weather station. Regular visual inspections are also being conducted to monitor surface degradation.

Keywords: *earthen site conservation; environmental degradation; hygrothermal performance; on-site diagnostic inspection; test wall monitoring*

1. Introduction

Earthen architecture represents one of the oldest and most widespread building traditions, with evidence of early human settlements dating back to 10,000 BC in Mesopotamia (Heathcote, 1995) and 5,000 BC at the mouth of the Nile River (Houben & Guillard, 2008). While typically associated with vernacular and rural construction, earthen architecture encompasses a wide range of techniques, forms and functions, from simple huts, granaries, and rural dwellings to complex urban centres such as Shibam in Yemen and Yazd in Iran (Minke, 2006). Today, earthen constructions remain widely employed, particularly in developing countries where its accessibility and cost-effectiveness make it a

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sustainable building option (Houben & Guillard, 2008; Jaquin et al., 2008; Silva et al., 2018). However, this invaluable earth-built heritage is increasingly at risk due to the vulnerability of earthen materials to environmental factors, which are nowadays unpredictably altered by climate change (Ashtari, 2020; Fatorić & Seekamp, 2017). Thermal fluctuations, for instance, induce expansion and shrinkage, leading to internal stresses and promoting decay due to freezing and salt crystallization. Additionally, changes in water content – in both liquid and vapor states - due to humidity cycles and extreme seasonal rainfall, cause the clay binder to swell and shrink, further contributing to material deterioration and salt weathering (Brimblecombe et al., 2008; Matero, 2015). Notable examples of climate-induced damage include the floods in Wadi Hadhramaut, Yemen, which devastated thousands of mud-brick buildings, and sand encroachment that threatens the historic mosques of Timbuktu (Al-Masawa et al., 2018; UNESCO, 2007). Similarly, in Peru, rainfall associated with El Niño has accelerated the degradation of Chan Chan's adobe structures. These cases underscore the pressing need for research and conservation strategies to mitigate climate-related risks and ensure the long-term preservation of earthen heritage. In this context, the present study aims to assess the conservation status and performance of the earthen site of the Wupatki Pueblo in Arizona, USA, which is exposed to severe environmental conditions, through a combination of inspection, diagnosis, and monitoring activities. This research is part of the broader "Integrated Site Conservation and Management Plan and Training for Wupatki National Monument, Arizona" project, supported by the J. Paul Getty Trust. The paper first gives the necessary context for the case study, detailing the site's conservation status. It then presents a comprehensive description of the experimental study conducted to monitor the hygrothermal behaviour of the site's walls. Finally, conclusions and anticipated future developments are outlined.

2. Site description and inspection

2.1. Overview of the Wupatki Pueblo

The Wupatki Pueblo, located in northern Arizona, represents the largest archaeological site within the Wupatki National Monument (WUPA), an extensive area of 143 km^2 where over 2,500 sites have been recorded. The Pueblo dates to the period between AD 1150 and 1250 and is attributed to the Sinagua culture, although the influence of other pre-Columbian populations is not excluded (Brennan & Downum, 2001). Situated at an elevation of 1480 m in the Wupatki Basin, the site is positioned on a narrow sandstone ridge and comprises two primary room blocks (the South and North Units), a Community Room and a Ballcourt (Fig. 1).

Fig. 1 – *View of the Wupatki Pueblo archaeological site facing west: the South Unit on the left, the North Unit and the Community Room on the right* (Authors, 2025).

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At its peak, it is estimated that the Pueblo counted around 100 rooms, of which 80 have been excavated to date, that were likely connected in a single aggregate. The structures were primarily built from Moenkopi sandstone units, bonded with earth-based mortars, and occasionally adorned with basalt pebble bands sourced from nearby volcanic formations. Over time, some sections of the pueblo were reconstructed using concrete and reinforcing bars, with the repointing of mortar joints employing cement and, in the most recent maintenance works, stabilised earth-based mortars. The masonry exhibits irregular patterns, attributed to the use of unevenly shaped stones and varying joint thicknesses. Evidence from collapsed sections suggests a double-leaf wall construction, with few through stones and no discernible foundations. Horizontal elements such as floors and roofs, originally made of wood, have not survived.

2.2. Visual damage assessment

On-site inspections, including visual damage surveys and NDTs such as sonic and ambient vibration tests, have identified structural instability and extensive material degradation, primarily caused by environmental exposure and weathering processes that followed the excavation of the site. Structural damage is evident in the partial or complete collapse of sections, with walls of varying heights functioning as independent elements due to weak interconnections and the absence of horizontal elements. In particular, inadequate connections between wall leaves, along with movements in the underlying boulders and foundations, have resulted in tilted walls. This instability is especially pronounced at corners and exposed cross-sections, where the irregular masonry morphology further compromises structural integrity. Cracks are present throughout the site, particularly at the mortar-stone interface, and are likely caused by various factors, such as weak connections between orthogonal walls or different sections of the same wall, structural buckling, and inadequate support (Fig. 2). Material deterioration is also evident, particularly at the bases of walls and supporting boulders, due to water runoff, snow accumulation, and salt crystallisation. These issues are exacerbated by inadequate drainage systems, which lead to the detrimental pooling of water (Fig. 2). Recent extreme rainfall events, attributed to climate change, have intensified the damage, further highlighting the vulnerability of the site. Signs of decay underscore the need for thorough condition assessments to inform maintenance strategies and mitigate the risks posed by future climate scenarios.

Fig. 2 – *Example of extensive damage: wall settlement, crack pattern, inadequate drainage system* (Authors, 2025).

3. Experimental study on test walls

3.1. Objectives and experimental setup

The experimental study aimed to assess the hygrothermal behaviour of the Wupatki Pueblo's masonry walls under local weather conditions. Four test walls, built to replicate the masonry at the site using sandstone units and earth-based mortars, were instrumented with temperature and moisture sensors to monitor hygrothermal parameters. A weather station was also installed to record environmental data (Fig. 3). This controlled setup ensured no impact on the archaeological site while enabling a detailed investigation of wall interactions with environmental factors.

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Fig. 3 – *Experimental setup: four test walls and the weather station on the right* (Authors, 2025).

The study has three main objectives: (i) characterizing the hygrothermal behaviour of the masonry, (ii) assessing material degradation and durability through visual inspection, and (iii) collecting data over two years to validate numerical models to simulate wall performance under different environmental conditions.

The experimental setup was completed in May 2024 in collaboration with National Park Service archaeologists and a crew of masons. Located 1.6 km from the Wupatki Pueblo, the construction site was chosen for its similar environmental conditions and discreet placement to avoid disrupting visitors. Test walls were built replicating materials, textures and orientations of the original masonry, with two different types of walls reflecting the heterogeneous mortar compositions found at the site:

- Type A used unstabilized earth-based mortar to replicate the original masonry.
- Type B combined unstabilized mortar in the core with stabilized mortar at the edges to simulate current repointing techniques.

Each type included two walls, one oriented north-south and other east-west to capture the effect of exposure according to the main directions of the walls at the site.

3.2. Wall design and construction

The construction of the test walls began with the excavation of shallow pits (1.7 x 0.8 m, 0.10 m depth), followed by the placement of compacted gravel aggregates to facilitate rainwater infiltration and prevent water accumulation at the base. A geotextile sheet was laid over the gravels, and a paver block base was then installed using cement mortar. A PVC waterproof membrane was applied to prevent rising damp.

Each wall was constructed with consistent dimensions across the test group, measuring 1.2 m in length, 0.4 m in thickness and 1.0 m in height (Fig. 4). The masonry was built using irregular sandstone units, with dimensions ranging from 4-6 cm in height, 15-35 cm in length, and 15-30 cm in thickness, replicating the stone sizes found at the Pueblo. As mentioned in section 3.1, the walls were built with two types of earth-based mortar: unstabilized and stabilized.

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Fig. 4 – *Test wall construction* (Authors, 2025).

The unstabilized mortar consisted of a mixture of sieved local soil (ASTM sieve ¼") and commercial sand (2:1 by volume), mixed with water. The stabilized mortar used for Type B walls followed the same soil-sand mixture, but incorporated an acrylic polymer bonding agent, Adacryl, added to the mixing water at a 4:1 volume ratio. Mortar joints varied in thickness, with horizontal joints ranging from 1 to 3 cm, replicating the traditional masonry joints found at the site. To prevent moisture ingress, the joints on the small sides of the walls were coated with stabilized mortar. Each wall was then capped with a roofing system consisting of plastic tiles, anchored to the masonry with screws, and installed with a sufficient slope to ensure proper water drainage.

3.3. Hygrothermal and visual monitoring

The hygrothermal monitoring system for the test walls was designed to collect data over a period of 2-3 years, providing insights into the temperature and moisture dynamics within the masonry. Each wall was equipped with a total of ten sensors purchased from the company OnSet, comprising five for temperature and five for moisture.

These sensors were strategically positioned at different heights - top (T), middle (M), and bottom (B) - as well as across various orientations - east (E), west (W), north (N), and south (S) - to comprehensively assess the hygrothermal performance across the wall cross-sections (Fig. 5).

To ensure accurate data collection without compromising the structural integrity of the walls, all sensors were embedded within the mortar joints during construction (Fig. 6). The sensors are connected to a data acquisition system powered by a solar panel and battery. The data acquisition units are mounted on tripods positioned adjacent to the walls to minimize interference (Fig. 7).

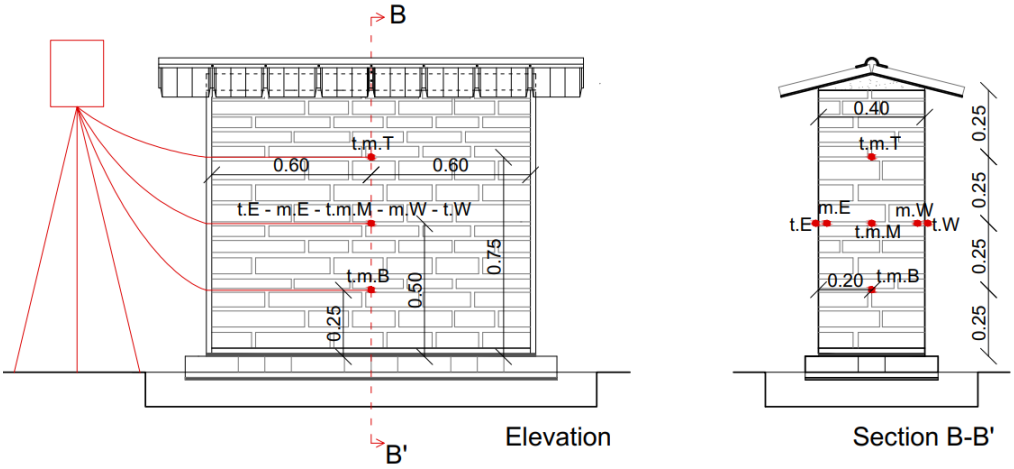

Fig. 5 – *Placement of the sensors* (Authors, 2025).

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Fig. 6 – *Temperature and moisture sensors embedded within the mortar joints* (Authors, 2025).

Measurements are recorded at five-minute intervals and stored in the system's memory. To prevent data loss and ensure continuous monitoring, data are downloaded every maximum three months.

At each data retrieval session, a visual assessment of wall conditions has been conducted. This assessment involves capturing both general and detailed photographs of each wall's surfaces and corners to document any material degradation over time.

Fig. 7 – *Example of test wall and monitoring system tripod* (Authors, 2025).

Particular attention is given to variations in deterioration patterns associated with different orientations and exposures. The visual documentation will serve as a complementary dataset, aiding in the interpretation of sensor measurements and enhancing the overall understanding of the long-term hygrothermal behaviour of the masonry.

3.4. Monitoring of environmental conditions

To monitor external environmental conditions, a weather station supplied by OnSet was installed on-site, positioned to avoid any interference from the surrounding walls and knolls (Fig. 8). The station is equipped with multiple sensors to measure key climatic parameters, including air temperature and relative humidity, wind speed and direction, barometric pressure, solar radiation, and rainfall. Data acquisition has been carried out at five-minute intervals, ensuring a high temporal resolution that captures short-term fluctuations in environmental conditions. The weather station operates in synchronization with the wall monitoring system, enabling a direct correlation between atmospheric variables and the temperature and moisture dynamics within the masonry.

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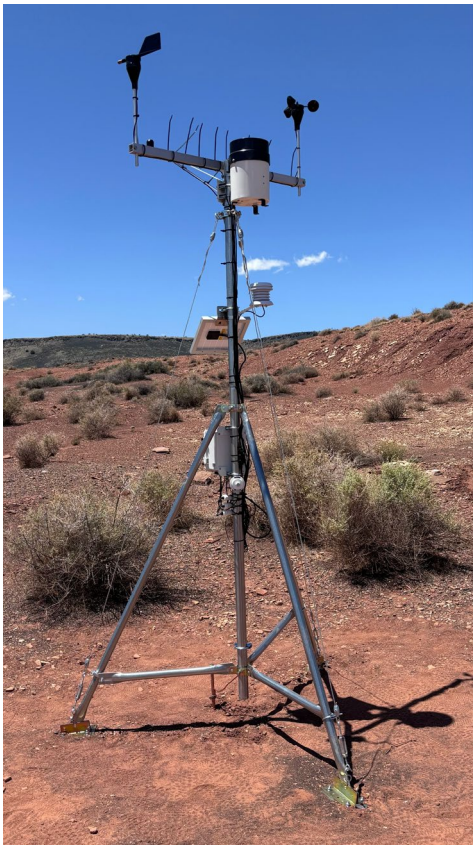

Fig. 8 – *Weather station tripod with sensors* (Authors, 2025).

4. Conclusions and future work

The preservation of earthen architectural heritage is a pressing challenge due to its inherent vulnerability to environmental factors, which are becoming increasingly unpredictable due to climate change. Understanding the hygrothermal behaviour of earthen building materials and structures is therefore crucial for developing effective conservation strategies and mitigating climate-related risks. In this regard, this paper presents the first steps of an experimental study aiming at investigating the hygrothermal performance of masonry walls at Wupatki Pueblo by building four test walls representative of the site, equipped with temperature and moisture sensors.

The collected data, recorded alongside environmental parameters, are expected to provide valuable insights into the walls' response to fluctuating climatic conditions over the next two years. Furthermore, the findings from this research will contribute to the validation of multi-physics numerical models, enabling the prediction of masonry performance under relevant climate change scenarios, including extreme weather events. By integrating empirical data with computational modelling, this approach has the potential to identify deterioration mechanisms and inform the development of targeted preventive conservation measures.

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Balancing Sustainable Conservation and Risk in Earthen Archaeological Structures: Insights from a Case Study

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Abstract

Given their lack of original protection, earthen structures in archaeological sites face extremely adverse conditions once they have been exposed to the elements. Their unique construction and age make them systems of great interest, difficult to conserve effectively, while current interventions entail complex conflicts and dichotomies in the field of sustainability, despite the wide spectrum of variables. As reducing maintenance for this type of architecture is inviable without compromising its appearance, in a context of social dissemination among other factors, it requires a balance that is often conditioned by the meteorological characteristics of the enclave, as well as by the topography or geometry of the site and exposed structures. This article aims to apply this approach, based on the case study of the archaeology of Coll del Moro in Gandesa (Tarragona, Spain), for combining different exposed adobe structures and a range of intervention systems in a single physical space over time, as well as geometries capable of increasing the risks of these being affected. This aims to elicit a qualitative reflection observing the results of the different solutions applied over time, and how these can compromise or reinforce the degree of sustainability for this type of architecture.

Keywords: *heritage; archaeology; traditional construction; sustainability; adobe; preservation; flood*

1. Introduction

Although earthen architecture is a fundamental system in the construction of dwellings of past societies, its survival has traditionally been endangered by the complexity of archaeological identification, documentation, and conservation. Since the late 20th century in particular, its increasingly comprehensive characterization (Knoll et al., 2019) has been accompanied by a growing willingness to identify damage (Gandreau et al., 2018), risks (Nakhaei Ashtari & Correia, 2022), and valorization (Matero, 2013). Due to a lack of professional consensus, valorization has given rise to numerous strategies which have not followed homogeneous principles or shared criteria.

In recent years, this heterogeneous approach has also been seen in the Iberian Peninsula. This has evolved from the destruction of earthen architecture – due to limited sensitivity and

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training – to restorations and reconstruction using all types of materials and techniques. This heterogeneity has strengthened a fragmented panorama in which decision-making is not always in keeping with sustainability and compatibility criteria, with substantial variations, even in single sites. In addition, the evolution of values associated with heritage has prompted consideration – not just physical conservation – in defence of the technique in past societies and its possible viability in contemporary society. Thus, reflections on the wide spectrum available from the theoretical viewpoint of conservation (Cooke, 2010) and sustainability enable the optimization of responses to the challenges of preservation, always taking into account the specific circumstances of individual contexts. In this regard, striking a balance between maintaining authenticity and mitigating the more serious risks is a particularly complex challenge. However, the analysis of these dynamics can help to define more efficient responses or to establish a system of priorities that incorporates all dimensions of the problem.

In Spain, numerous enclaves with this type of architecture can be visited and studied in their original context, although the heterogeneous interventions further widen the gap in solutions referenced earlier. In this respect, given the variety of actions on structures conserved in situ within a single location, one of the most interesting enclaves is the site of Coll del Moro in Gandesa, specifically the settlement area. Since the 20th century many important finds have been made there thanks to the work of numerous professionals (Jornet Niella et al., 2018, 2020, 2021; Pons et al., 2016; Rafel Fontanals et al., 1994b, 2018; Rafel Fontanals & Blasco Arasanz, 1994), an essential source of information for the study.

The aim of this article is to use a case study to offer some preliminary reflections on the response to different interventions for the conservation of earthen structures. These aim to offer protection from potential threats and degradation while also taking into consideration the approach followed in terms of their sustainability, aiming to establish a satisfactory balance in design scenarios which present dilemmas where forceful decisions must be made, choosing whether to opt for authenticity or durability.

2. Methodology

The starting point for the localization of a case study and the range of interventions considered ideal was decided following the bibliographical review and in situ data collection of up to 170 sites with earthen structures conserved in situ in Spain (Manzano-Fernández, Mileto, et al., 2024b). This database managed in GIS environments includes domestic, productive, and funerary architectural typologies, mainly dating from the protohistoric and Roman periods. To ensure greater representation, the prehistoric and medieval examples were also included.

Given the ideal situation of Coll del Moro, two technical visits were carried out for in situ data collection and monitoring in the months of April 2022 and 2023. Furthermore, related bibliographical information was collated in collaboration with the Arqueología Protohistórica of the Institut Català d'Arqueologia Clàssica-ICAC research group, directed by Dr. M. Carme Belarte and Jordi Diloli, who took part in the process of excavation, documentation, and dating of original structures.

The preliminary discussion on sustainability was conducted in line with the recent definitions of architectural heritage (Correia et al., 2014) and previous research (both completed and in process) by the authors (Manzano-Fernández, Vegas López-Manzanares, et al., 2024), with a view to testing its applicability to case studies of earthen archaeology. This approach considers not only material durability but also the socio-cultural implications of conservation strategies.

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Finally, information relating to the climatic context of the site was obtained from the Atlas Nacional de España, and cross-referenced with the geographical localization in GIS environments. This was complemented with precise data on rainfall and temperatures recorded by the weather station of Horta de Sant Joan (9946X), located in the municipality of the same name, 12.28 km from the site, at 41 m.a.s.l.

3. Results

Observation of the risk factors found in the enclave and the conservation strategies used for the individual earthen structures offers preliminary reflections of interest regarding response times and degree of compliance with sustainability criteria.

3.1 Risk factors

Currently, the main natural and social risk factors are represented by dangers of earthquake, flooding and rainfall, desertification, and human interaction. On a seismic level, the archaeological enclave is located in a territory of seismic intensity VI (classified as *slightly damaging* according to EMS-98) and acceleration ≤ 0.04 (which falls within the lower range) (IGN, 2019). In addition, the maximum elevation of structures is 70 cm, but tends to be around 30-40 cm, which, for regulatory purposes, could even be considered ground level, further minimizing the potential risk.

In terms of flooding, the site is not included within any floodable areas, even for periods of return of T=500 (IGN, 2019). However, the morphology of the remains presents areas with a potential for waterlogging given the lack of outlets or outflow points (Fig. 1), and the presence of paving levels below the access thresholds to the spaces, or due to the capacity of these elements to accumulate (Figs. 2 & 3), which is similar to cisterns or tanks. Therefore, this type of flood does not bring about violent erosion, but rather the continued dampening of weaker structures or the bases of the walls.

Throughout history this anthropic problem has been similar to intensive excavation through excavation squares.

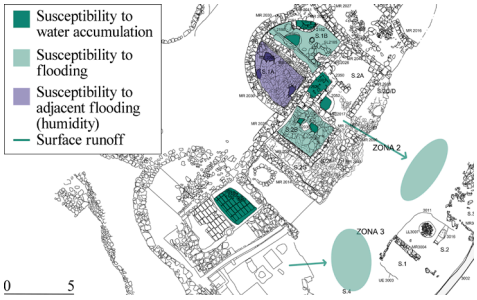

Fig. 1 – *Diagram showing areas susceptible to waterlogging* (Sergio Manzano, 2023; on a survey by Rafel Jornet et al. 2018).

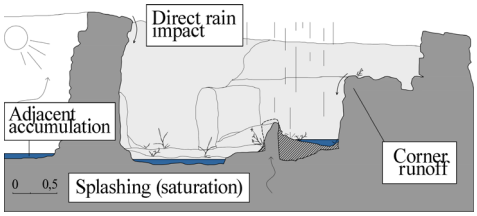

Fig. 2 – *Section of waterlogging mechanisms in sector S2A.*

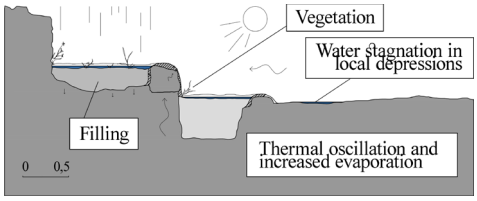

Fig. 3 – *Section of waterlogging mechanisms in sectiono S1B.*

In terms of rainfall, the site is not under excessive pressure, and presents annual average values at the lower end of the spectrum (400-500 mm), although daily maximum rainfall can be heavier (60 mm) (IGN, 2019).

In terms of desertization, the territory is located within a high-risk area (AA.VV., 2008), which is an indicator of potential droughts preceding torrential rain, and increases the loss of cohesion between particles insufficiently linked by low humidity levels.

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Finally, as it is in the process of musealization, the site presents social risks arising from the insufficient education of the wider public (Manzano-Fernández et al., 2024a). For this reason, the municipality organizes open days to disseminate themed events as well as the results of the excavations. However, the absence of human interactions reduced the risk of trampling, circulation, and anthropic degradation, as well as increasing the risk of damp due to nearby agricultural activity.

3.2. Sustainable balance: retaining authenticity, visibility, and durability

The work carried out to date by the different archaeological teams has revealed earthen architecture structures in sectors 7, 8, S1B, S2A, S2B and S2G. This makes it possible to reflect on the difficulties of establishing a balance between the suitable transmission of the findings and their resistance to the elements, depending on the different conservation strategies executed on each one:

3.2.1. Section 8 and defensive tower: backfilling

Elements such as the northwest bench, low bench and quadrangular deposit executed in sector 8, as well as the paving and hearth (Rafel Fontanals et al., 1994a, 2018), were consolidated by Carmen Prats and are currently backfilled (Fig. 4).

Fig. 4 – *Backfilled earthen structures in Sector 8.*

A similar situation can be seen in the defensive tower, where the structures were confined in formwork filled with earth until they were ultimately enhanced, through the use of partial backfilling focusing on specific elements.

This type of solution offers high protection from the natural risks described, preventing the direct impact of rainfall and drought. However, occasional deformations may occur at the corners deriving from the stress introduced by geotextiles and the weight of the upper infill.

As regards sustainability, this leads to a very positive adaptation in environmental terms given the minimal use of materials. However, this is not as positive in terms of cultural commitment, since it does not promote the transfer of construction techniques. Instead, these techniques and intangible values become invisible and the execution of local activities is limited. While the site organizes limited visit sessions, which may not be a permanent measure, this situation could on the whole be seen as balanced, but somewhat to the detriment of sociocultural sustainability.

3.2.2. Sectors S1B (1) and S2G: temporary covering, consolidation and exposure

The earthen structures discovered in the S1B apse sector were excavated in 2014-2017 (Jornet Niella et al., 2018), backfilled in 2015, and partly consolidated in 2017 (Bertral Arias, 2017) before reaching the geological and paving level. This resulted in different levels of exposure to degradation in the lower sections following excavation.

This consolidation was carried out prioritizing minimum intervention (Fig. 5), with local earth mortars and chromatic adaptation to spaces where the earth had been affected by fire and carbonized, re-adhering damaged parts (Bertral Arias, 2017). After being completely uncovered, low walls in adobe and unconsolidated benches presented a sloping appearance, with a far greater loss of volume than in the consolidated section.

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Fig. 5 – *Compatible consolidation of the upper section and partial destruction of the unconsolidated lower section.*

Between campaigns, these structures were temporarily covered, first with protective tarps in polyethylene (Fig. 6). This waterproof material can generate microclimates, maintain capillarity for long periods, cause earth to break apart, and introduce stress on the corners. In recent years, apart from the usual geotextiles, 150 g/m^2 polypropylene sheets with greater breathability have been used, but these have not eliminated capillarity or prevented occasional flooding in the space.

Fig. 6 – *Temporary polypropylene covering of earthen structures in S1B.*

A similar situation was observed, albeit with a lower level of damage, in the gaps in the render identified in sector S2G, consolidated in 2017 and covered temporarily.

Recently, these structures have remained exposed, protected by some stones placed in the top section, which can reduce the direct impact of rainfall. Thus, these structures are highly adaptable in terms of sustainability, as the transfer of the construction culture is carried out in full, remaining authentic while enabling visibilization. However, partial maintenance and consolidation have led to a partial loss of the structures. This irreversible loss, which cannot be restored, compromises the useful life of the remains.

In view of the above, the balance observed is considered quite satisfactory. This may be optimized with cyclical maintenance and repair work, combined with preventive systems which limit the scale of waterlogging in torrential episodes, and rapid responses preventing the partial destruction of the volumes after exposure.

3.2.3. Section S1B (2): relocation

An earthen element of unknown function was discovered to the north of the sector. Given its interest, it was excavated and moved to the laboratory of the University of Barcelona for further study (Fig. 7).

This type of intervention can completely protect the piece and can maintain it in optimum hygrothermal conditions, safe from the damage caused by the elements. In terms of sociocultural sustainability, adaptation plans are rated even lower than backfilling, as the pieces do not only become invisible to the general public and researchers, but are also completely disconnected from their original context. This impact could be lessened by returning the piece or relocating it in a museum once studies had been completed, although this option does not provide a fully satisfactory solution to the problem.

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Fig. 7 – *Process for moving an earthen structure in S1B* (Rafael Jornet et al., 2018).

3.2.4. Sectors S2A and S2B: encapsulation

The earthen structures of sectors S2A and S2B were also uncovered in 2014, backfilled in 2015, fully excavated in 2019 incorporating some adobe paving (Jornet Niella et al., 2021), and finally displayed under sacrifice layers for protection, also known as *encapsulation*. Given their geometry and use for decantation, those from sector S2A are highly susceptible to waterlogging.

The sacrifice layers were executed with earth-lime mortar, differing slightly from the traditional appearance. At present, the encapsulated remains display damage including the appearance of fissures, damp stains, and slight efflorescence, particularly in the elevations most exposed to sunlight (Fig. 8). However, this damage is noticeably less than that of the consolidated structures with minimum intervention. This enables a better response to occasional floods that can spread across the entire surface and could even be optimized with better sand-lime mixes. However, the architectural interpretation has been gravely compromised, displaying —both visually and to the touch— based on the characteristics typically found in earthen architecture, such as porosity and flexibility. This leads to a homogeneous system that under-represents the wide variation of techniques.

Fig. 8 – *Encapsulation of earthen structures in S2A.*

For all these reasons, a balance halfway between protection and visibility can be seen, where neither are obviously satisfied or compromised. This system is less sustainable in sociocultural and environmental terms than a compatible consolidation, although useful lifespan and socioeconomic sustainability are slightly improved.

4. Conclusion

Exposure over a period of 7 years of the earthen structures in Coll del Moro in Gandesa, with a total recorded rainfall of 3386.6 mm, 23 daily rain events above 30 mm, and 3 days of rain followed by frost (AEMET, 2023), offers very varied results. The influence of the conservation systems used in each case are considered in a variety of ways, prompting conclusions on the degrees of sustainability and response in terms of interest from the scientific community.

Table 1 – *Sustainable balance for the different conservation actions*.

	Protection	**Visibility**	**Authenticity**
Sec. 8	High	Low	High
S1B-1	Medium	High	High
S1B-2	High	Low	Medium
S2A	Medium	Medium	Medium

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Better performance, showing a degree of improvement, can be observed in consolidations that are compatible and require minimal intervention. However, some issues still require optimization, such as the consistent failure to control capillary damp on the part of the 150 g/m^2 polypropylene sheet used as a temporary covering, which could be improved with better application to allow for runoff; the need for immediate consolidation responses following the excavation through hygrothermal shock; and regular maintenance. In the future, the optimization of preventive conservation materials, techniques, and strategies combined with maintenance, can aid the mitigation of the issues detected, applying approaches offering a comprehensive response to all aspects of the problem.

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Between Respect and Innovation. Innovative Recovery and Extention of a Historic Rammed Earth Farmhouse in Novi Ligure, Italy

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Abstract

This paper presents the restoration and refurbishing project of a historic farmhouse located in the rural area of Novi Ligure (AL), Italy; it's the Italian reachest area of rammed earth heritage. The building, a rectangular structure (22 x 6 m) standing three stories high (9 m), has load-bearing rammed earth walls and pavilion vault brick floors. Initiated in 2012, the project aimed to renovate the residential areas, repurpose rustic sections for habitation and expand westward. The design process focused on respecting the original earthen building technology and structural behaviour, while prioritizing sustainability and energy efficiency. The new extension was built using cross-laminated timber (CLT) panels and insulated with wood fiber, featuring a green roof to enhance thermal performance at ground level. This addition was designed to align with the comfort and indoor health standards set by the historic rammed earth structure. The existing structure underwent targeted structural interventions based on an in-depth analysis of its original construction. These interventions honored traditional earthen construction techniques while integrating modern materials and technology. Thermal and hygrothermal strategies were also carefully adapted to the unique properties of the rammed earth, ensuring compatibility with its physical and performance characteristics. Innovative solutions included the use of CLT and steel for new floors, lime-based mortars and screeds, and a novel approach to reinforcement. For the first time, fiber-reinforced mesh with an organic lime matrix, secured by stainless steel helical bars, was applied in place of traditional structural bracing for the (new) openings and the chains reconnecting disjointed wall sections. Additionally, an experimental 18 cm layer of lime and glass-cell microsphere thermal plaster was applied externally, achieving an insulated yet "monolithic" appearance that enhances structural integrity. This project serves as a model for sustainable restoration, combining traditional earthen techniques with contemporary materials to meet modern performance (and economic) requirements.

Keywords: *rammed earth construction; historic restoration; structural reinforcement; sustainable architecture; innovative insulation; cross-laminated timber (CLT)*

1. Introduction

The conservation and adaptive reuse of earthen architecture pose complex challenges, requiring a balance between heritage protection and adaptation to contemporary performance. To ensure the survival of these buildings, it is necessary to keep them inhabited and habitable;

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in other words, it means integrating them into the normal economic cycle of the real estate market, without limiting them to mere examples of museum conservation (Bollini, 2013).

2. Objective

The article presents the renovation of a historic farmhouse in the countryside of Novi Ligure (Alessandria), in an area with a rich rammed earth heritage. The aim is to integrate sustainable solutions that respect the original material and its architectural integrity. The focus is on the correct technical management of the earth, with a rational approach, without excessive emotion or nostalgia.

The intervention demonstrates that traditional building techniques can be enhanced and improved through the use of contemporary materials and technologies, not necessarily earth-based, but fully compatible with it. This makes the renovation more accessible to both the contractor and the client, and more economically sustainable. (Bollini, 2013).

3. The project

The farmhouse is rectangular in plan and has three storeys. It is load-bearing in rammed earth (45-50 cm thick), except for the top barn elevation in fired brick. The floors between the storeys are brick pavilion vaults with acacia chains, while those on the ground floor rest directly on the ground.

Fig. 1 – *The farmhouse before the work* (Bollini, 2012).

The double-pitched roof of wood and tiles, with a non-pushing structural scheme, is unique to the whole building. There is an attic above the living area; the barns on the first floor are double-height and were originally only accessible from the outside. On the west front, a single-storey rammed-earth volume was used as a bathroom, with internal and external access.

The project began in 2012 and it will be partially completed internally. The client wishes to renovate the residential part, recover the barns and the attic as living space and extend it to the west, thus obtaining two new residential units. The project was developed through an in-depth analysis of the existing structure, combining architectural tradition and technological innovation. Respect for the structural logic of the rammed earth construction was a guiding principle, guaranteeing a calibrated intervention in keeping with the characteristics of the material.

4. Methodological approach and technological choices

For the part of the intervention on the existing, the design choices were based on three pivotal points:

- understand and accept the logic of structural behaviour and the balance achieved over time by each factory;
- limit structural interventions on earthen buildings to a minimum;
- in any legitimate aspiration to reuse, respect the constituent material and consistency of the buildings, integrating new resources without subtracting or wasting existing ones.

The interventions were targeted. Knowledge of the structure's origins made it possible to identify critical points and to carry out punctual interventions using modern earthen building materials and technologies.

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At the same time, the thermo-hygrometric approach took into account the peculiarities of the structure and the physical-performance characteristics of the earthen material.

The aim of the extension was to provide the same level of performance, comfort and healthy indoor environment as the earthen farmhouse

4.1. Structural scope

First, a detailed analysis of the existing structure was carried out. It was based on a detailed observation of the artefact and not on numerical models. The aim was to understand its construction logic and evolutionary phases.

Some corners on the first floor and in the attic, including the central hayloft built later at the back of the house, were not damped. Two chimneys had deteriorated, interrupting the masonry continuity of the transversal septa, and some vaults showed micro-settlements (due to the 2003 earthquake). The complete removal of the plaster revealed cracks and some wall areas with unfired and fired bricks. At the same time, chains appeared on the walls of the first floor, at the level of the attic, highlighted by the keys on the façade. From a project point of view, it was also necessary to open new windows in the barns and to create a connection to the extension on the ground floor. The roof also needed to be renovated and insulated.

4.1.1 Renovation of wooden roofing

The client required an increased eaves height and a different structure for the re-roofing. This changed the static model and transformed the roof into a pushing roof. The load is now carried by a horizontal component on the long walls. The impost height was increased using brick blocks filled with pure natural hydraulic lime mortar (NHL 3.5) rather than cement. A structural fibreglass mesh (1×1 cm mesh) embedded in lime mortar (NHL 5) was laid across the interface between the brick wall and the underlying earth wall (Fig. 2). The mesh overlaps both elements by 30 cm. A wooden load divider was laid on top of the brick wall and mechanically anchored to the underlying wall with screws and chemical socks. Transverse chains anchored to the sleeper were then installed to resist horizontal shear; all the timber elements are made of laminated fir.

Fig. 2 – *The fibreglass mash and the "stripe" on wall* (Bollini, 2015).

4.1.2 Restoration of wall continuity

A precise graphical representation of the joints showed that several chains would have to be positioned in both directions. This would have been a complex, costly and invasive operation, exacerbated by the chimneys (Fig. 3).

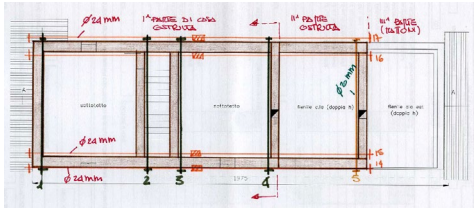

Fig. 3 – *The graphic representation of septa: attic level* (Bollini, 2014).

After research, a system inspired by the wedge-shaped wooden connectors found in the technical literature (Bollini, 2013) was identified. These are helical stainless-steel bars, 1 m long and with a total cross-section of approximately 1 cm, normally used for seismic consolidation of traditional masonry. The bars were inserted, by percussion and before pre-drilling, along all the edges to be reinforced, with a spacing of 75 cm and an inclination of

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45° (Fig. 4). Before proceeding, a pull-out test was carried out in the earthen wall to determine the tensile strength (Fig. 5). All the pre-existing chains (uncovered by the emptying of the vaults to consolidate them) were protected by wrapping them in corrugated tubes to ensure that they could slide freely; at the same time, the existing key plates were replaced with elements of greater surface area. The chimneys were restored with a "cuci-scuci" of fired bricks, also reinforced over the entire height with a band of fibreglass mesh (in this case about 1 m wide), also filled with NHL 5 lime mortar.

4.1.3. Openings

On the ground floor, an important opening was created between the farmhouse and the future living area of the extension (Fig. 6).

Fig. 4 – *The insertion of the helical bars* (Bollini, 2015).

Fig. 5 – *Pull-off test* (Bollini, 2014).

The wall concerned, has a net length of 5 m (6 m gross on the outside) and the impost of the pavilion vault of the intermediate floor slab starts at a height of 1.91 m. Although the initial design envisaged the relocation of the old access door to the former bathroom, the client insisted on a wide opening to give continuity between the entrance and the new living area. The opening created has a gross opening of 2.60 m, a height of 2 m and is 33 cm from the inner edge of the room (about 93 cm from the outer edge). Undoubtedly a bold choice. To achieve this, a framework of four steel frames (HEA 140 profile) was welded side by side; the pillars of the two outer frames are connected to the corners of the house by chains (one at mid-height and one at floor level), thus restoring the wall's tensile strength. Along the inner part of the lintel, a steel plate has been welded to form the impost of the vault.

Fig. 6 – *The ground floor opening to the living room* (Bollini, 2016).

On the northern façade, new windows were made, also surrounded, with a mixed system of wooden lintel and reinforced balusters, 'wrapped' with the same fibreglass mesh as in the previous interventions, lined with NHL 5. The outer and inner edges of the mesh were welded with a steel plate. The outer and inner edges of the mesh were joined together with stainless steel helical bars to form a single body without the need to insert other elements (by splitting the wall).

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4.1.4. Vaults consolidation

Interventions were limited to the necessary areas and carried out with precision. The method chosen was to reinforce the extrados of the vaults using fibreglass mesh embedded in lime mortar, applied like a 'bandage' to reconnect displaced sections. Once consolidated, the vaults were refilled with loose expanded clay beads, with only the top layer stabilised with a light lime slurry to facilitate subsequent functional layers. Work on the vaults was carried out only where deemed necessary and in a timely manner. The technique used was once again that of fibreglass mesh mixed with lime, which was used in the extrados of the vault in the form of 'scotch' to reconnect parts that had moved. The vaults were then filled again, but this time with loose expanded clay in beads, with only the surface part fixed with a lime mortar to facilitate the laying of the subsequent functional layers.

4.1.5. New floor slabs

The renovation of the two barns required the construction of new intermediate floors and a new staircase (for the distribution of the second unit). The two volumes presented a number of critical issues: very little clearance between the floors; unusable masonry in the eastern barn, where the raised part is made of single-headed fired brick. It was decided to construct the floor structure with 12 cm thick CLT (cross-laminated timber) panels. In the central barn, which is entirely in-ground, the panels are supported by L-shaped profiles running around the perimeter (Fig. 7). The profiles are connected to metal plates on the opposite side. In the second barn, on the other hand, we didn't want to rely on the existing masonry, so we built an internal steel frame made up of box sections going up and L-sections going across. It's independent of the masonry, except for a bracing along the short sides. This is done with threaded rods welded to the steel section. CLT panels were laid on top (Fig. 8). The frame has a concrete conglomerate foundation; as an alternative to a slab, which would have been the simplest solution in terms of execution, 4 plinths and their connecting beams were built, with the aim of maintaining the hygrometric equilibrium of the slab against the ground and leaving as much of the surface as possible to be left free of concrete. The plinths themselves were separated from the stone foundation of the farmhouse by mineralised wood panels (Fig. 9).

The reconstruction of the intermediate floor (floor) of the room to the left of the staircase deserves a special description. This was also a situation where the available height for the new functional layers was minimal, if not insufficient). In this case, the expanded clay backfill did not cover the keystone of the vault; a structural fibreglass mesh (5 x 5 cm mesh) was placed on the keystone, and a lime screed (also NHL 5) was poured on top, with a thickness ranging from 4.5 cm on the wall to 0.4 cm on the keystone (Figs. 10 & 11).

Fig. 7 – *CLT slab on L-profiles anchored to the wall* (Bollini, 2018).

Fig. 8 – *Freestanding steel frame with CLT panels* (Bollini, 2018).

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Fig. 9 – *Foundation of the steel frame* (Bollini, 2019*).*

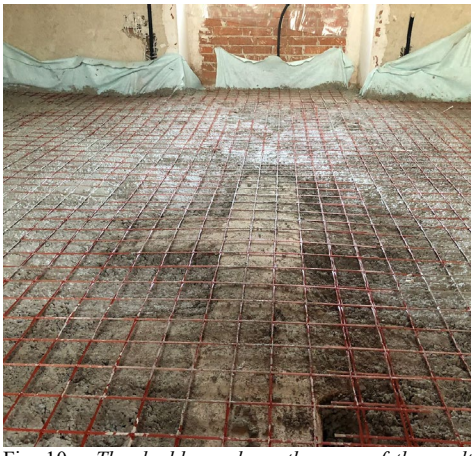

Fig. 10 – *The double mesh on the cusp of the vault* (Bollini, 2018).

Fig. 11 – *The lime screed* (Bollini, 2019).

4.2. Thermo-hygrometric environment

The thermo-hygrometric aspect was addressed in relation to indoor comfort and the healthiness of the structures, as well as the control of rising damp. In the latter case, the focus was on the management of the space between the foundation of the walls in the ground, the floor against the ground and the external paving.

For comfort, the focus was on the overall envelope (opaque and transparent). Particular attention was paid to the perimeter earth walls. From a thermal point of view, such buildings operate on the basis of mass and thermal inertia. Therefore, although a calculation of the transmittance gives a very poor figure, the actual behaviour is different precisely because of the internal thermal capacity and admittance (Bollini, 2013). In this sense, during the discussions with the municipal administration, an exemption was obtained from the obligation to insulate the volumes for the change of use. However, the client subsequently wished to insulate the walls. In response to this request, it was proposed to evaluate a minimum thickness capable of maximising the thermal capacity of the wall, maintaining its warm core and optimising its inertial behaviour. However, the possibility of benefiting from tax incentives for energy efficiency drove the choice to comply with legal requirements.

4.2.1 Foundation node

The ground floor slab had to be completely rebuilt to separate it from the ground, insulate it, allow the passage of services and prepare it for the installation of radiant heating. All of this had to be done without too much digging, both for cost reasons and, above all, to avoid exposing too much of the stone base (and foundation) of the perimeter walls. As the original floor was laid directly on top of an earthen foundation and there was no paving outside, the aim was to maintain this hygrometric balance while ensuring a functional floor and paving around

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the house, as required by the client. Inside, a non-woven fabric was laid under a layer of loose, water-repellent expanded clay. This layer acts as a moisture barrier (like gravel) and also provides thermal insulation. On top of this is a second layer of non-woven fabric to keep the expanded clay clean. On top of this is a structural lime screed (not cement) in which a further 1x1cm fibreglass mesh is embedded (Fig. 12).

This stratigraphy maintains a hygrometric behaviour at the base of the masonry that is extremely consistent with the previous one, which would not have been the case with more usual cement systems (U 0.24 W/mqK). Similarly, the external paving was dry laid on a layered bed of gravel, pebbles and sand.

4.2.2 Thermal envelope: earthen walls

The insulation of the earthen walls was carried out with the experimental application of an 18 cm thick thermal plaster of NHL 3.5 lime and cellular glass microspheres (U 0.33 W/mqK, attenuation factor 0.018). The thermal plaster was applied in three layers, with two glass fibre mats (5x5 cm) for reinforcement, and then smoothed with a lime finish (Fig. 13).

The choice was motivated by the following considerations:

- the traditional coating would have required a major preparation of the substrate; it would have made the thermal resolution of the primary node of the fixtures more complex (and delicate); it implied a more articulated stratigraphy of materials and the need to check the tightness of the dowels;
- the specific thermal plaster is perfectly coherent with the earth (being lime) and maintains the monolithicity of the wall structure, with all the advantages that this brings, guaranteeing performance over time and reducing the risk of hygrometric criticalities due to incorrect installation;
- the application of the thermal plaster with the interposed nets, constituted an additional perimeteric (and modest structural) bundling of the walls.

Fig. 12 – *The lime and fibreglass mesh floor slab* (Bollini, 2017).

Fig. 13 – *The three coats of the thermal plaster* (Bollini, 2016).

4.2.3 Thermal envelope: roof and windows

The other elements of the envelope - roof and windows - have been designed to provide comfort in line with the performance of the earth wall structure. In particular, the roof has been insulated with 20 cm of 160 kg/m³ wood fibre in order to achieve a summer performance equivalent to that of the earth wall (U 0.19 W/mqK, insulation factor 0.22).

The window and door frames, made of wood with double-glazing and low-emissivity glass, are installed with false frames on all four sides and equipped with tapes for airtightness, supplemented by a micro-ventilation system to

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counteract any concentrations of humidity in the indoor environment (U_w 1.7 W/mqK). The thresholds are made of frost-proof brick. In the French windows, an autoclaved honeycomb concrete block was laid underneath to insulate them. In the windows, on the other hand, the fired bricks rest directly on the thermal plaster. In order to protect the thermal plaster from possible water infiltration (due to the porosity of the bricks and the joints), a lime-based waterproofing product was spread over the brick laying surface.

4.3. Enlargement

The extension is made of CLT panels, insulated with wood fibre cladding, and has a flat roof with a green roof for the ground floor. The aim was to minimise the size of the structure while maximising its thermal performance, in a coherent dialogue with the ground floor building, both in terms of thermo-hygrometric performance and the materials used (Table 1). The introduction of the green roof is in line with this approach.

Table 1- *Thermal values (referring to 2015).*

Element	U W/mqK	Attenuation
Ext. walls	0.21	0.049
Ground floor	0.18	/
Sloping roof	0.19	0.22
Flat roof	0.20	0.020
Windows	1.7	/

5. Conclusions

This intervention combines the protection of the architectural heritage with contemporary living. It shows that it's possible to intervene in historic earthen buildings without compromising their integrity, through strategies of consolidation and improvement. Traditional and contemporary technologies have been used to achieve a result that meets the principles of conservation and sustainability. The case study shows how raw earth buildings can be effectively upgraded without invasive or incompatible solutions. It demonstrates the possibility of improving their structural and thermo-hygrometric performance through coherent materials and targeted design strategies. From a structural point of view, the choices made ensured the safety of the building without altering its static balance. At the same time, the thermo-hygrometric choices increased comfort, demonstrating that it's possible to adapt an earthen building in terms of energy without compromising its overall hygroscopic performance. The project raises a broader reflection on the need to develop replicable intervention models for the rehabilitation of earthen heritage. The recovery of these buildings must be part of a wider process of valorisation and reintegration into the contemporary housing and economic fabric. In this sense, the possibility of making earthen buildings an active part of the property market, without reducing them to museum testimonies or isolated cases of restoration, is one of the main challenges for their future. This intervention demonstrates that knowledge of earth materials and properties leads to effective, sustainable design. The combination of historical research, technology and material compatibility can underpin future restoration, conservation and revitalisation of heritage.

Fig. 14 – *The outcome* (Bollini, 2016).

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Compatibility between Sustainability and Conservation in Earthen Architecture: Initial Analysis of Restoration Interventions and Contemporary Applications in Spain

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Abstract

The rehabilitation of traditional earthen architecture in Spain currently faces the challenge of reconciling heritage values with sustainability objectives such as energy efficiency, emission reduction, and cost-effectiveness, increasingly applied across the construction sector. Earthen architecture represents significant cultural heritage, offering an opportunity to promote traditional bioclimatic strategies and circular economy practices adapted to the demands posed by climate change. Within the context of the "Earth4Future" research project, which aims to evaluate the rehabilitation of traditional buildings and contemporary earthen construction, this study focuses on identifying intervention dynamics documented in 70 traditional buildings and contemporary applications in 15 newly constructed buildings. A statistical analysis has been conducted on the types of interventions, the compatibility of materials and techniques used, and the primary motivations driving these interventions. The analysis of the contemporary applications examines the type of technique employed in relation to traditional methods and the mechanisms applied for quality control, energy improvement, or cost reduction. The paper ultimately aims to identify patterns of good practices, evaluate the synergies between tradition and innovation, and lay the groundwork for sustainable intervention guidelines.

Keywords: *traditional techniques; intervention strategies; earthen construction; sustainable design*

1. Introduction

Earthen construction is found in a large part of the Spanish territory, and a considerable part of the population continues to live in these buildings (Correia et al., 2011; Houben & Guillaud, 1994; Maldonado & Vela Cossío, 2011; Mileto et al., 2017). Its conservation as

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heritage is undeniable, considering its intrinsic value and the risk of loss which threatens all of Spanish traditional architecture (IPCE, 2014).

However, this conservation should also take into account the current context of climate change and the need for energy efficiency, reduction of emissions, and economic profitability (United Nations Environment Programme, 2023; Von Der Leyen, 2019). The constructive use of earth also presents a series of environmental advantages which have encouraged its application in contemporary architecture, mostly at bioclimatic, economic, and energy level.

In this context, the project "*Earth 4 Future: Sustainable reuse of earthen architecture and its lessons for contemporary architecture*" (PID2022-139154OB-I00) seeks to provide a global approach to the use of earth in interventions in both traditional and contemporary buildings. It is thus proposed to study aspects such as compatibility of interventions with heritage value, energy efficiency, life cycle, and construction costs.

2. Objectives and methodology

This text focuses on the study of the compatibility of these interventions with the heritage value of this type of architecture, by analysing dynamics relating to intervention in 70 traditional buildings and to application in 15 modern buildings throughout Spain (Fig. 1).

The cases of interventions in traditional buildings have been identified in research projects carried out previously (Mileto et al., 2017, 2022), while the modern buildings have been selected following an extensive bibliographical review of publications.

Two fiche models with general data on buildings (geographical, climate, and architectural data) and specific information on the form of intervention in existing elements and on the form of construction in new buildings have been proposed for this study (Fig. 2). This has allowed the statistical analysis of different aspects, enabling conclusions to be drawn on the compatibility and application of these techniques.

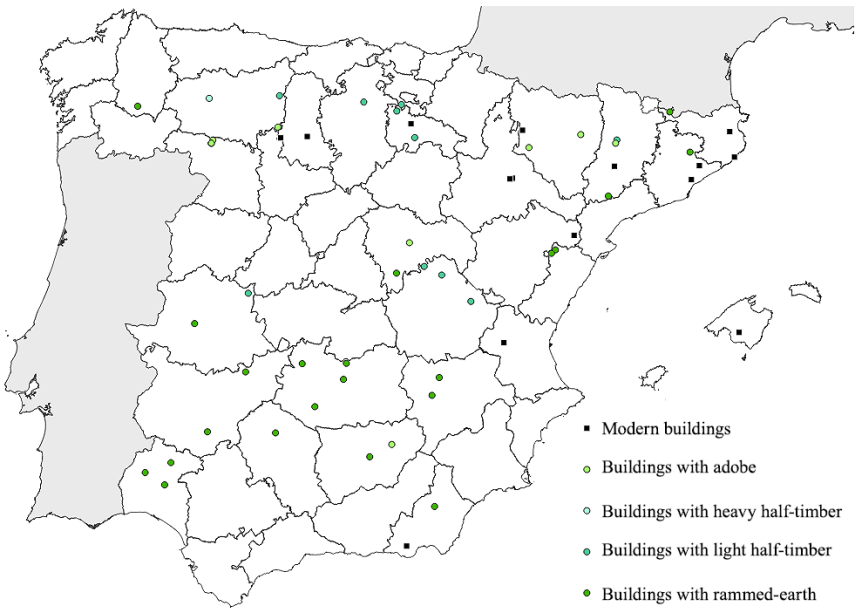

Fig. 1 – *Distribution of case studies* (Hueto-Escobar, 2025).

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The study of the interventions has focused on the analysis of different aspects in 385 constructive elements such as walls, openings, roofs, and renders. However, interventions in plinths, floors and ceilings, partition walls and paving have also been documented, while the process of obtaining valid conclusions on these elements has been conditioned by difficult access and lack of visibility.

The study has focused on an initial reflection, distinguishing between planned interventions seeking to propose multiple cohesive actions and spontaneous interventions with no prior criteria established. Equally, the degree of compatibility of techniques and materials has been analysed to establish whether they differ from the original ones.

Moreover, the general objective of the intervention was analysed based on the work's initial criterion, result, or motivation and the type of intervention based on the physical action carried out. Within the objectives, distinctions have been made between aesthetic updates, aimed at adapting to current standards and tastes; recurring maintenance or tasks, to prevent or anticipate occasional and limited repairs in response to the appearance of lesions; restorations taking into consideration the heritage value of the element; rehabilitations seeking to improve the features of the element or to include new functions; expansions which entail a volumetric increase of the buildings; and intentional demolitions of part of the building.

Finally, when assessing the type of intervention, factors considered include the consolidation of existing elements; reintegration of missing parts using similar solutions; reconstruction of elements with similar ones; replacement of elements with different ones; and demolition adding other elements which did not exist previously.

In terms of the contemporary forms of application of these techniques, an analysis has been made of the material, volumetric, compositional, and aesthetic relationship of these buildings with regard to local tradition. This has helped ascertain whether they replicate local tradition or import traditions from other areas; whether they reinterpret local tradition or tradition from other areas; or whether they opt for a modern solution.

Equally, an analysis was carried out to identify the constructive elements in which earth was most frequently used and the particular techniques applied.

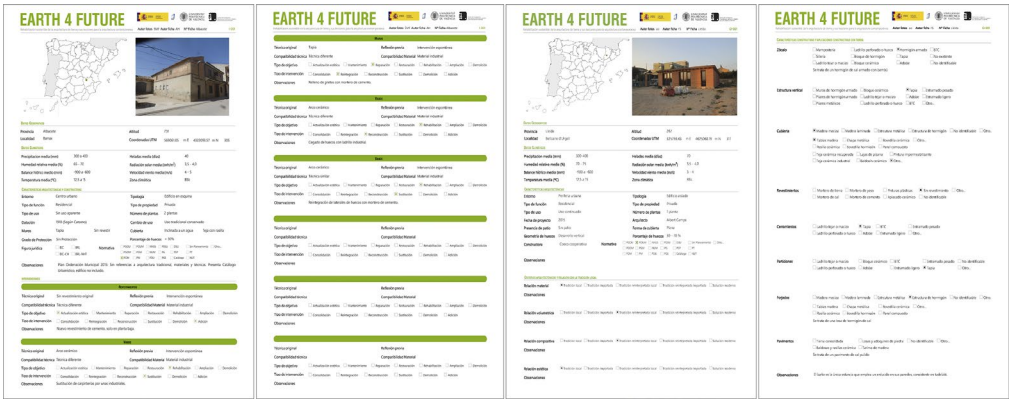

Fig. 2 – *Study fiches for interventions in traditional buildings and application in contemporary buildings.*

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3. Earthen intervention dynamics

In general (Table 1), the interventions identified answer to a spontaneous dynamic in 63.6% of cases and to prior planning in 36.4% of cases. When examining the degree of compatibility with pre-existing techniques and materials, there is a predominant use of different techniques in 61.8% of cases and industrial materials in 82.1% of cases. In fact, the use of similar traditional materials falls to 14.8%, and different traditional materials are used in 3.1% of cases. Among the general objectives driving these interventions (Table 2), it is worth noting repairs (36.9%) and rehabilitations (33.2%). In contrast, there is a significant drop in more respectful interventions such as maintenance (6.0%) and restorations (8.8%). As regards the types of intervention (Table 3), there is a predominance of substitutions (34.3%), reintegrations (24.9%), and additions of elements (26.8%). However, there is a considerable reduction in more respectful actions such as consolidations (2.9%) and reconstructions (11.2%).

Load-bearing walls are the constructive element (33.5%, Table 1) displaying the most frequent interventions. Among the different traditional

Table 1 – *General analysis of prior planning, technical compatibility and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Walls	129 33.5%	102 79.1%	27 20.9%	93 72.1%	36 27.9%	13 10.1%	4 3.1%	112 86.8%
Openings	96 24.9%	71 74.0%	25 26.0%	75 78.1%	21 21.9%	12 12.5%	1 2.1%	82 85.4%
Roofs	77 20.0%	27 35.1%	50 64.9%	31 40.3%	46 59.7%	17 22.1%	1 1.3%	59 76.6%
Claddings	54 14.0%	26 48.1%	28 51.9%	24 44.4%	30 55.6%	10 18.5%	2 3.7%	42 77.8%
Plinth	21 5.5%	17 81.0%	4 19.0%	12 57.1%	9 42.9%	3 14.3%	2 9.5%	16 76.2%
Slabs	5 1.3%	2 40.0%	3 60.0%	3 60.0%	2 40.0%	1 20.0%	0 0.0%	4 80.0%
Partitions	2 0.5%	0 0.0%	2 100%	0 0.0%	2 100%	1 50.0%	0 0.0%	1 50.0%
Pavings	1 0.3%	0 0.0%	1 100%	0 0.0%	1 100%	1 100%	0 0.0%	0 0.0%
Total	385 100%	245 63.6%	140 36.4%	238 61.8%	147 38.2%	57 14.8%	12 3.1%	316 82.1%

Table 2 – *Analysis of the general objectives of the interventions documented.*

	Total	Walls	Openings	Roofs	Claddings	Plinths	Slabs	Partitions	Floors
Update	39 10.1%	2 1.6%	3 3.1%	0 0.0%	33 61.1%	1 4.8%	0 0.0%	0 0.0%	0 0.0%
Maintenance	23 6.0%	1 0.8%	3 3.1%	16 20.8%	3 5.6%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Repair	142 36.9%	61 47.3%	24 25.0%	22 28.6%	16 29.6%	17 81.0%	2 40.0%	0 0.0%	0 0.0%
Restoration	34 8.8%	7 5.4%	2 2.1%	15 19.5%	6 11.1%	3 14.3%	0 0.0%	0 0.0%	1 100%
Rehabilitation	128 33.2%	38 29.5%	67 69.8%	21 27.3%	0 0.0%	0 0.0%	0 0.0%	2 100%	0 0.0%
Extension	30 7.8%	21 16.3%	2 2.1%	4 5.2%	0 0.0%	0 0.0%	3 60.0%	0 0.0%	0 0.0%
Demolition	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Total	385 100%	129 33.5%	96 24.9%	77 20.0%	54 14.0%	21 5.5%	5 1.3%	2 0.5%	1 0.3%

Table 3 – *Analysis of types of interventions documented.*

	Total	Walls	Openings	Roofs	Claddings	Plinths	Slabs	Partitions	Floors
Consolidation	11 2.9%	5 3.9%	0 0.0%	1 1.3%	1 1.9%	3 14.3%	0 0.0%	0 0.0%	1 100%
Reintegration	96 24.9%	44 34.1%	16 16.7%	11 14.3%	7 13.0%	17 81.0%	1 20.0%	0 0.0%	0 0.0%
Reconstruction	43 11.2%	7 5.4%	5 5.2%	18 23.4%	10 18.5%	0 0.0%	1 20.0%	1 50.0%	1 100%
Replacement	132 34.3%	32 24.8%	52 54.2%	24 31.2%	19 35.2%	1 4.8%	3 60.0%	1 50.0%	0 0.0%
Demolition	14 3.6%	4 3.1%	9 9.4%	1 1.3%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Addition	103 26.8%	44 34.1%	18 18.8%	23 29.9%	17 31.5%	0 0.0%	1 20.0%	0 0.0%	0 0.0%
Total	385 100%	129 33.5%	96 24.9%	77 20.0%	54 14.0%	21 5.5%	5 1.3%	2 0.5%	1 0.3%

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Table 4 – *Detailed analysis of interventions on walls: planning and technical and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Rammed earth	66 51.2%	56 84.8%	10 15.2%	54 81.8%	12 18.2%	5 7.6%	1 1.5%	60 90.9%
Adobe	32 24.8%	22 68.8%	10 31.3%	18 56.3%	14 43.8%	5 15.6%	3 9.4%	24 75.0%
Heavy half-timber	19 14.7%	14 73.7%	5 26.3%	13 68.4%	6 31.6%	1 5.3%	0 0.0%	18 94.7%
Light half-timber	1 0.8%	1 100%	0 0.0%	0 0.0%	1 100%	0 0.0%	0 0.0%	1 100%
Masonry	7 5.4%	5 71.4%	2 28.6%	5 71.4%	2 28.6%	2 28.6%	0 0.0%	5 71.4%
Brick	1 0.8%	1 100%	0 0.0%	1 100%	0 0.0%	0 0.0%	0 0.0%	1 100%
Replaced	1 0.8%	1 100%	0 0.0%	1 100%	0 0.0%	0 0.0%	0 0.0%	1 100%
Unidentified	2 1.6%	2 100%	0 0.0%	1 50.0%	1 50.0%	0 0.0%	0 0.0%	2 100%
Total	129 100%	102 79.1%	27 20.9%	238 61.8%	147 38.2%	57 14.8%	12 3.1%	316 82.1%

Table 5 – *Detailed analysis of interventions on openings: planning and technical and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Squared timber	30 31.3%	24 80.0%	6 20.0%	18 60.0%	12 40.0%	8 26.7%	1 3.3%	21 70.0%
Rounded log lintel	3 3.1%	22 66.7%	2 33.3%	0 0.0%	3 100%	2 66.7%	0 0.0%	1 33.3%
Stone lintel	5 5.2%	4 80.0%	5 20.0%	4 80.0%	1 20.0%	1 20.0%	0 0.0%	4 80.0%
Ceramic arch	8 8.3%	6 75.0%	2 25.0%	7 87.5%	1 12.5%	0 0.0%	0 0.0%	8 100%
Replaced	17 17.7%	9 52.9%	8 47.1%	17 100%	0 0.0%	0 0.0%	0 0.0%	17 100%
Unidentified	33 34.4%	26 78.8%	7 21.2%	29 87.9%	4 12.1%	1 3.0%	1 3.0%	31 94.0%
Total	96 100%	71 74.0%	25 26.0%	75 78.1%	21 21.9%	12 12.5%	2 2.1%	82 85.4%

Table 6 – *Detailed analysis of interventions on roofs: planning and technical and material compatiblity.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Roof tile & timber	35 45.5%	16 45.7%	19 54.3%	15 42.9%	20 57.1%	9 25.7%	0 0.0%	26 74.3%
Roof tile & thin tile	14 18.2%	6 42.9%	8 57.1%	5 35.7%	9 64.3%	2 14.3%	0 0.0%	12 85.7%
Roof tile & reed	1 1.3%	0 0.0%	1 100%	0 0.0%	1 100%	1 100%	0 0.0%	0 0.0%
Roof tile & moulding	1 1.3%	0 0.0%	1 100%	0 0.0%	1 100%	0 0.0%	0 0.0%	1 100%
Plant & reed	3 3.9%	0 0.0%	3 100%	0 0.0%	3 100%	2 66.7%	1 33.3%	0 0.0%
Replaced	18 23.4%	5 27.8%	13 72.2%	9 50.0%	9 50.0%	2 11.1%	0 0.0%	16 88.9%
Unidentified	5 6.5%	0 0.0%	5 100%	2 40.0%	3 60.0%	1 20.0%	0 0.0%	4 80.0%
Total	96 100%	27 35.1	50 64.9	31 40.3	46 59.7%	17 22.1%	1 1.3%	59 76.6%

Table 7 – *Detailed analysis of interventions on renders: planning and technical and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Lime mortar	20 37.0%	6 30.0%	14 70.0%	4 20.0%	16 80.0%	6 30.0%	1 5.0%	13 65.0%
Earth mortar	6 11.1%	6 100%	0 0.0%	4 66.7%	2 33.3%	0 0.0%	0 0.0%	6 100%
Gypsum mortar	1 1.9%	1 100%	0 0.0%	0 0.0%	1 100%	0 0.0%	0 0.0%	1 100%
No render	15 27.8%	8 53.3%	7 46.7%	12 80.0%	3 20.0%	1 6.7%	1 6.70	13 86.7%
Replaced	9 16.7%	4 44.4%	5 55.6%	2 22.2%	7 77.8%	2 22.2%	0 0.0%	7 77.8%
Unidentified	3 5.6%	1 33.3%	2 66.7%	2 66.7%	1 33.3%	1 33.3%	0 0.0%	2 66.7%
Total	54 100%	26 48.1%	28 51.9%	24 44.4%	30 55.6%	10 18.5%	2 3.7%	42 77.8%

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techniques which can be used to build these walls (Table 4), rammed earth is the technique with most frequent interventions (51.2%), followed by adobe (24.8%) and heavyweight half-timbered walls (14.7%). In general, spontaneous interventions predominate although planned interventions are slightly more frequent in adobe walls and considerably less so in rammed earth walls (Fig. 3). In terms of technical and material compatibility there is a predominance of different techniques and industrial materials. However, adobe and half-timbered walls often undergo interventions with similar techniques incorporating industrial materials such as industrial brick.

Openings are the second most frequent element (24.9%, Table 1) requiring intervention, probably to improve energy efficiency. Although it is often impossible to identify the type of lintel, there is a high percentage of interventions in squared lintels (31.3%, Table 5). As in the rest of constructive elements, there is a clear predominance of spontaneous interventions, with different techniques and industrial materials. In this regard, the replacement of joinery with PVC or aluminium doors and windows, as well as the expansion of openings in entrances to buildings (Fig. 4) and the installation of unsuitable elements such as blinds and railings are of particular note.

Fig. 3 – *Rammed earth wall intervened with industrial brick* (Vegas & Mileto, 2016).

Fig. 4 – *Adobe wall where the entrance has been enlarged* (Vegas & Mileto, 2016).

Roofs (20.0%, Table 1) are in third place in terms of frequency of intervention. Among the traditional techniques with interventions (Table 6) it is particularly worth noting roofs with roof tiles and timber (45.5%) and roofs with roof tiles and thin ceramic tiles (18.2%). However, it is also worth highlighting the high number of cases where the roof has been completely replaced (23.4%). In this case, there is a relatively higher frequency of planned interventions using similar techniques. Likewise, although the percentage of industrial materials is also higher, the frequency with which similar traditional materials is used is significantly higher than for the rest of the elements. Among the interventions documented those that stand out most are complete and partial reconstructions using similar techniques but using cement mortar, as well as structural replacements with concrete and metal elements. However, it is also worth emphasizing the high number of interventions which include insulation material and gutters.

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Table 8 – *Analysis of compatibility with local tradition at a material, volumetric, aesthetic, and comoposition level.*

	Material	Volume	Aesthetic	Composition
Local tradition	5 33.3%	6 20.0%	4 26.7%	5 33.3%
Local reinterpreted tradition	8 53.3%	6 53.3%	5 33.3%	5 33.3%
Imported tradition	2 13.3%	1 6.7%	0 0%	0 0.0%
Imported reinterpreted tradition	0 0.0%	8 6.7%	2 13.3%	1 6.7%
Modern solution	0 0.0%	4 13.3%	4 26.7%	4 26.7%

Claddings (14.0%, Table 1) occupy the fourth position in terms of the frequency of intervention. Among these (Table 7) it is worth highlighting interventions in lime mortar renders (37.0%) and earth mortar renders (11.1%). As seen with the roofs, the frequency with which interventions are planned and similar techniques are used is relatively greater. However, there is a great predominance of the use of industrial materials such as cement mortar and plastic paints. These generally require the partial or complete replacement of existing render or the application of new render with the materials mentioned.

4. Earthen contemporary construction

Although the bibliographical review has covered the whole of Spain, it should first be noted that many of the examples identified are concentrated in the northeast of the country, particularly in Catalonia where 5 of the 15 cases documented are found. Equally, although the oldest project dates back to 2001, most were completed between 2010 and 2023. In terms of the compatibility of these new materials and local constructive tradition (Table 8), this is seen slightly more frequently in the aspects analysed which involve a degree of reinterpretation of local tradition or a direct replication of local tradition. However, in terms of the aesthetic and composition of openings the percentage of cases displaying modern language is relatively higher.

The use of earth in construction in contemporary residential buildings focuses on load-bearing walls, enclosures and partitions. Although in load-bearing walls there is a predominant use of rammed earth (7 cases), it is worth highlighting the greater use of compressed earth blocks or CEBs (6 cases) over that of adobes (2 cases) or heavyweight half-timber (2 cases). Both the CEBs and the rammed earth walls used show a degree of industrialization, given the use of cement in the case of the former and the use of pre-manufactured rammed earth blocks in the latter.

Equally, in enclosures with no structural function, rammed earth (5 cases) and CEBs (6 cases) have mostly been reported, although other examples can be found with heavyweight half-timber (2 cases) and adobe (1 case). In the case of partitions the use of CEBs (5 cases) is also frequently encountered, although there are also some documented examples of heavyweight half-timber (2 cases). However, the presence of other industrial techniques such as brick (2 cases) should also be noted.

While the use of industrial reinforced concrete (2 cases) and ceramic blocks (1 case) can be seen in some buildings for the execution of plinths and foundations, there is some concern for structural and material compatibility as reinforced lime concrete (5 cases) is used with different reinforcements solutions such as steel rods or bamboo.

In roof and floor structures it is common to use solid timber in correlation with traditional solutions, while vaults are also observed in a few cases.

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5. Conclusions

The analysis conducted, based on 385 interventions documented in 70 historic residential buildings built with earth, shows a general tendency towards spontaneous interventions and the use of industrial materials, reflecting the risk to the conservation of this type of heritage. It is clearly revealed that load-bearing walls are the elements displaying the most interventions, followed by openings, roofs, and renders. A significant use of industrial materials is found in all cases, particularly when earthen elements are replaced with brick, concrete, or PVC, affecting technical and material compatibility with original structures.

Although the number of interventions which resort to similar traditional methods is limited, the use of these techniques in contemporary residential projects shows that these solutions are viable and to some degree compliant with current requirements. The analysis carried out on 15 contemporary buildings in Spain has highlighted the use as load-bearing walls, enclosures, and partitions. In this respect, the solutions documented show a degree of industrialization which offers better control of the properties of the material and a reduction in financial costs.

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Conservation Strategies of Earthen Architecture at the Acropolis of Kaminaljuyu, Guatemala

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Abstract
The pre-Hispanic site of Kaminaljuyu in Guatemala is a heritage complex of inestimable value, notable for its cultural significance, extensive size, and singular use of varied earthen construction techniques. However, urban development has compromised much of the site's original integrity, leaving only a few intact structures. Among these are the "La Palangana" and "La Acrópolis" complexes, built during the Early Classic period, which are now preserved within the Kaminaljuyu Archaeological Park. Research conducted throughout the 20th century by the Institute of Anthropology and History of Guatemala and Pennsylvania State University uncovered and exposed portions of the site, providing much insight into the past but creating some problems for the conservation and interpretation of the ancient remains. To solve these problems, and to anticipate other problems arising from recent excavations, preventive conservation actions have been carried out over the past two years to stabilise the exposed remains and give a better understanding of their historicity to the visiting public. To do so, recycled materials from the monument itself were used, applied with compatible construction methods in which the integrated components were lightened by adding pumice material in different granulometry. In this way, reversible integrations were achieved, with a low environmental impact and easy to carry out by the personnel working on the site.

Keywords: *consolidation; reversibility; compatible materials; stabilized soil; visual continuity*

1. Introduction

Systematic studies of earthen architecture — articularly those evaluating the processes required for its conservation— are relatively recent compared to research on other building materials. This accounts for the limited understanding of some ancient construction systems (Pastor, 2017) and, more notably, the diverse range of solutions applied to preserve these structures (Rodríguez & Jiménez, 2022), which have produced widely varying results. Consequently, many interventions have required follow-up efforts due to a lack of understanding about the compatibility of materials with earthen substrates (García & Gómez, 2023).

In the case presented here, Kaminaljuyu is an archaeological site located in the Maya highlands in the central valley where Guatemala City is currently located (Arroyo, Conde & Sarazúa, 2016). The Acropolis is the most well-known architectural group within the archaeological park. It was initially excavated by Gustavo Espinoza in the 1960s. However, Espinoza did not publish his notes, and the available

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information is fragmented, primarily preserved through Charles Cheek's doctoral dissertation at the University of Pennsylvania (1977), which includes transcriptions of conversations with Espinoza (Arroyo, 2024). A reassessment of the excavation was later published by Houston and colleagues (2003), who proposed four construction phases. In 2004, a field report from a Universidad del Valle de Guatemala project partially documented the existing excavations and mapped the tunnels (Ivic & Alvarado, 2004).

Since the development of the Kaminaljuyu Park Management Plan in 2008, significant progress has been made in assessing the condition of the site's facilities and structures, as well as documenting prior interventions (Arroyo et al., 2011). The first basic conservation efforts for the earthen architecture were undertaken at the Acropolis and included community engagement activities. In 2012, public interest in the Maya past surged due to the celebrations of the 13th B'ak'tun, a significant calendrical event that drew an exceptional number of visitors to the site (Arroyo, 2013).

At that time, the Acropolis received the most attention, especially after the renovation of the archaeological shelter originally built to protect the exposed remains uncovered by Espinoza. In 2019, additional efforts were carried out at the Palangana, where the installation of a new protective shelter enabled a comprehensive conservation intervention plan, as described below.

Before the work at the Acropolis, the first half of the 20th century saw several archaeological projects at Kaminaljuyu that exposed important examples of earthen architecture. The most representative of these was the excavation conducted by Kidder, Jennings, and Shook (1946) in Mounds A and B. These structures were under imminent threat from the construction of a major road that ultimately destroyed them. However, this circumstance allowed the researchers to document multiple construction episodes layer by layer, revealing some of the earliest talud-tablero buildings from the Early Classic period. These structures contained the most significant royal tombs from that era, indicating Kaminaljuyu's connections not only with central Mexico but also with the central Petén region and possibly with Copán or another site in eastern Guatemala (Wright et al., 2010). Unfortunately, none of these buildings were preserved; only the detailed and remarkable publication remains as testimony to the construction materials and techniques used.

Subsequent work by Shook and Kidder (1952) focused on the excavation of seven construction phases of the site's tallest mound, E-III-3, which dates to the Late Preclassic period. This funerary mound revealed two royal tombs from that era. Protecting the legacy of earthen architecture is a challenge because of the many risks posed by visitors and anthropic factors that impact their long-term conservation (Manzano-Fernández et al., 2024).

The site has a long history of occupation with cycles of rises and declines, starting around 800 BC and continuing without abandonment until AD 1200. As a result of urban growth, at least 200 pre-Hispanic buildings of outstanding dimensions have been destroyed, leaving only 40 of them today (Álvarez & Arroyo, 2018).

The archaeological park preserves a considerable number of structures in a good state of conservation because they are under the mounds that have not been excavated, and two of its groups are exposed to the public: the Acropolis and the Palangana. Here, there are sequences of ancient buildings starting in the Late Preclassic, around 50 BC, with the ones visible today dating to the Early Classic period (250-600 AD). Both complexes have had recent conservation actions, but this paper will focus on the most recent works carried out in the Acropolis. The Palangana results were recently published (Guerrero et al., 2025).

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Among the most outstanding components of Kaminaljuyu's buildings are its construction systems, which were made from the use of local earth used as mortar to join blocks of the native soil known regionally as “talpetate”, as well as pieces of pumice stone, adobes and in a massive way through the “cob” system.

The Kaminaljuyu Acropolis is situated at the highest point of the site, with a construction sequence spanning approximately 1,000 years (Cheek, 1977). It features the finest examples of the Teotihuacan talud-tablero style architecture found in the Guatemalan highlands to date. This space served as elite residences and a venue for royal visits.

Most of the Acropolis was excavated in the 1960s by Gustavo Espinoza, leaving the buildings exposed without further intervention other than some controversial reconstructions made with cement on the façade of Structure G. In 2012, following processes of redesigning walkways and the shelter that protects this section (Fig. 1), basic conservation work was carried out under the direction of Daniel Juárez (Arroyo and Juárez 2014).

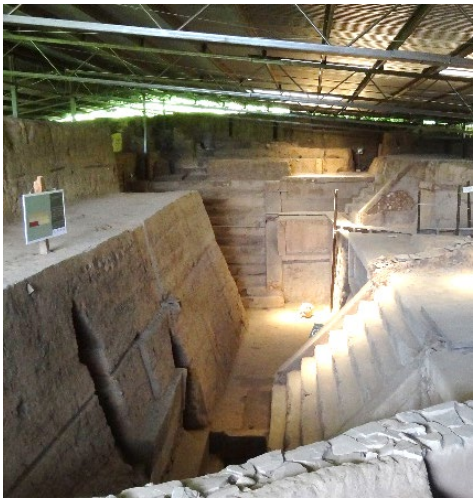

Fig. 1 – *Perspective of the acropolis in which various stages of its original construction can be seen, covered by a metal roof.* (Arroyo, 2024).

2. The Lower Acropolis

In 2011, a large platform located north of the Acropolis complex was discovered, referred to as Structure “T”. This was found in the Lower Acropolis sector but was not extensively excavated until it could be protected in the long term. In 2019, this building was uncovered, revealing that it was partially collapsed. The large platform with a *talud-tablero* façade was exposed, and a section of the central staircase which conducted to a plaza.

A section of 21 meters of this platform with 2.5 meters in height was exposed, learning that it dated to the Esperanza phase from the Early Classic. This platform that overlaps at least two substructures was impacted by the activities of the Late Classic period inhabitants who cut sections of the building, including a drainage that disarticulated the central stairway.

In 2024, the excavation was expanded, and another large platform was found to the east and underneath the façade of Structure “T” with a stairway. A balustrade was built over the eastern side of the platform, with at least three windows. The dating of this building corresponds to the Early Classic period. Unfortunately, it suffered several modifications in the Late Classic period, impacting some sections and blocking up the windows, one of which had even been partially destroyed (Crasborn, 2000).

While the search for the corner of this substructure was being carried out, an important discovery was made of a structure located to the southeast of Structure “T”, which has been named Structure AA and is composed of a large platform of approximately 21 meters long by 1.80 meters high, with a *talud-tablero* façade and a central stairway. This building is topped by a room with walls of earth and pumice stone on the northwest corner. It has a central doorway aligned to the axis of the stairway, but the width of this space has not yet been determined because more excavations are needed.

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Another element of notable singularity is a stairway attached to the northeast corner of the building, which seems to go up to the roof of the space or a second floor. This could have been of perishable material, but no traces have been found. However, there is no other explanation for the presence of this stairway, which also shows at least one previous construction stage in its interior (Fig. 2).

Fig. 2 – *Excavation process in which the first steps of the staircase can be seen in the foreground.* (Arroyo, 2025).

3. Present damage and sustainable conservation criteria

The preventive conservation interventions developed in the excavations were based on which areas could be opened to the public. Once the complex was documented with both manual and 3D scanning, the series of preventive conservation or reburial activities described in this text were designed, including the construction of a metal roof with a structure like the rest of the Acropolis.

Given that the ancient buildings remained buried by natural and artificial accumulations, the components' state of preservation was excellent. They have maintained stable humidity and temperature conditions for over a thousand years. Even the possible effects of the constant earthquakes that the region experiences did not affect the archaeological remains, thanks to the surprising constructive quality achieved by their original builders.

However, some conditions had specific effects on the remains, coming from three agents: two of natural origin and the third one being anthropogenic. Since the site was abandoned over a thousand years ago, its entire surface was progressively covered with vegetation, developing ecosystems that took advantage of the slopes and hydrography. Among the most radical impacts are those derived from the presence of tree roots that at some points reached 6 or 8 meters deep, softening or breaking some structural components.

But one of the major complications that arise during the excavation of the site, both for its archaeological understanding, as well as for its conservation and possible exhibition to the public, is derived from the series of adaptations that the last inhabitants of the site carried out for social, political, and religious reasons. As has happened in most of the urban structures of the world, it was decided to change the pre-existing spaces and buildings to build on top of them. In this superimposition of layers, the inhabitants made cuts and structural adjustments that partially or fully transformed the pre-existing components. The dimensions of the foundations were progressively increased in height and extension. Even some of the original orientations of the structures were modified so that it is not easy to distinguish the structural relationships, uses, and dates of the excavated components (Fig. 3).

As the raw material used throughout the almost two millennia of occupation of the site is very similar, careful monitoring of every centimeter that is explored is required because it is impossible to recognize the difference between the core of a wall, a platform, an *alfarda*, the fill between mounds, or simple natural rubble. Although sometimes there are fills made with components such as "talpetate" masonry as well as pumice stones, the predominant earthen matrix is the same, which generates multiple challenges in the archaeological work and the understanding of the site.

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Fig. 3 – *Drone view of the excavated complex before being partially re-buried.* (Ajú, 2024)

For these reasons, once a permanent shelter was designed to cover a section of the excavated areas, the intervention criteria used for the areas to protect are based on the premises of sustainable conservation (Guerrero, 2015), which focuses on minimal disruption, stabilization of the mechanical behavior of the structures, volumetric restitution of components for better understanding, the reversibility or at least the re-treatability of the interventions, the use of non-toxic materials with low environmental impact that are also compatible with the monument, the use of traditional techniques easily appropriated by local artisans (Toledo & Barrera-Bassols, 2008), and the reburial of areas that will not be exposed to the public. In addition to the display of past elements, it is essential to understand their functional relationship, construction process, and stages of development over time. This implies making decisions that are often difficult when having to "sacrifice" the presence of certain structures corresponding to more recent stages to understand that underneath (Guerrero & Avalos, 2022).

4. Specific Applied Strategies

To intervene in the area, backfilling and complements were carried out using original raw materials but transformed into different construction procedures. In this way, the proper interaction of the components was guaranteed, but it was evident that they were recent additions. An attempt was made to provide visual continuity to the missing remains so that, from a distance, their volume could be understood without being misleading because of the creation of "fake historic" or restoration interventions that reconstruct the original elements, replacing the ancient work.

Based on preliminary results of the fragment analysis of archaeological coatings that was carried out at the National Science Laboratory for the Research and Conservation of Cultural Heritage from the Universidad Nacional Autónoma de Mexico, it is known that the local soil has an important presence of montmorillonite and kaolinite that give the construction components a high consistency.

After several material characterization tests, to obtain soil mixtures with adequate cohesiveness and adherence, the soil was combined with equivalent volumes of coarse pumice sand.

This strategy obeys the interest of generating lighter integration components, less sensitive to changes in volume due to water effects, recognizable at short distances, and easy to remove (Guerrero, 2021). The presence of coarse sand also allows the development of components with greater porosity that favor evapotranspiration, preventing colonization by algae or fungi and the possible migration of soluble salts (Fig. 4).

Fig. 4 – *Reintegration of one of the balustrade lintels.* (Arroyo, 2025).

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With this material from the excavation debris crushed, mixed with pumice sand, hydrated, and kneaded in a plastic state, it was possible to develop very resistant construction components.

The strategies employed for each area to intervene depend on the volume of material required. Thus, when the damaged areas were of small dimensions and were present in superficial areas, the raw material was previously sieved to obtain plastic mixtures capable of penetrating thin fissures.

If the presence of cavities in the interior was detected, nozzles made with 2 to 3mm hoses placed 10 to 15cm apart were introduced in parallel, through which a concentrated clay grout was injected.

This type of intervention, like the other work carried out with earth on pre-existing structures, is based on the shaping of superimposed layers. When working with earth and placing thick volumes, there are different drying speeds between the external and internal layers, in addition to causing cracking that can damage the historic substrates. For this reason, all integration measures are carried out by wetting the preliminary layers and always applying thin ones left to dry, wet again, and following with additional layers.

Thus, when grout was poured or injected into fissures, it was necessary to let it dry and repeat the injection as many times as required until no more material penetrated, and it was certain that a series of layers would be formed inside

In the case of volumetric restitutions or the filling of larger missing parts, the mixture of earth and pumice sand added in equal volumes was integrated into a plastic state, but with the minimum possible humidity, to speed up the drying of the successive layers and to avoid cracking due to shrinkage. This is the construction logic of "cob", which has been used on the site since ancient times.

A key resource for its application was pumice stone fragments previously carved and finished in point shape, which were inserted as the volumetric restitution progressed. These components help to fix the new mixtures to the substrate, and as they are integrated by percussion with wooden tools, the soil in a plastic state is densified but without excessively increasing its weight because it contains a high proportion of pumice (Fig. 5).

Fig. 5 – *Volumetric recovery of a cornice broken in the Classic period.* (Guerrero, 2025).

Before the material was fully dried, it was moistened, and the next layer was placed to be filled with pumice stone fragments and compacted in the same way; the procedure was repeated until the required profile was recovered (Guerrero & Uviña, 2020).

At the points where test excavations were carried out that did not yield information appropriate for the understanding of the site or had put the stability of the neighbouring areas at risk, two types of reburial measures were taken. The first consisted of backfilling the archaeological excavations with successive layers of pumice material with decreasing granulometry. In the deeper areas, on top of a layer of pumice sand, pumice blocks were placed using the "dry stone" technique, placing pumice gravel 1 to 2 cm in diameter that was moistened and compacted.

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On top of it was placed a layer of a maximum of 5 cm of the mixture of "cob" spheres used in all the interventions, compacted as best as possible, and, finally, a layer of pumice sand slightly moistened and compacted. When the backfill was set, the surface layer that characterizes the architecture of the site was applied, which for decades has been called "piedrín", containing clayey soil, pumice sand, as well as black or reddish volcanic sand. This coating also settles in thin layers with low humidity because it needs to be compacted to achieve its densification and smoothing (Fig. 6).

Fig. 6 – Integration of the first step cut out for an exploratory cove. (Arroyo, 2024).

The second reburial strategy was applied in large areas where most of the volume was filled with pumice gravel contained in recycled sacks used in the agri-food industry (Fig. 7). The filled sacks were arranged following the logic of the masonry, taking care of their proper overlapping and compacting them manually. Once most of the missing material was filled, the exposed face was covered with clayey soil mortar that has a good adherence to the fibers of the sacks.

Fig. 7 – *Reburial using bags filled with pumice gravel.* (Benito, 2024).

5. Conclusions

The incorporation of sustainability in conservation interventions for archaeological heritage is a relatively recent process that needs to be evaluated according to medium-term results. The socio-cultural, economic, and ecological conditions in a significant number of countries where a considerable concentration of earthen architecture sites is located make it necessary to think about the need to optimize the available resources and generate the smallest possible ecological footprint. The permanence of local building traditions is the best evidence of sustainability, so it is crucial to study and enhance their value.

The activities carried out from 2022 to 2025 in the Acropolis of Kaminaljuyu, Guatemala, are an example of the possibility of carrying out processes in which it has been possible to consolidate and restore the volumetry of components that were damaged or modified during the periodic processes of superposition of stages that characterize the construction in Mesoamerica in a very economical way. In addition to achieving structural stabilization through sacrificial layers that guarantee its durability, it is possible to offer the visitor a more complete and legible perspective of the original conformation of its architectural composition.

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Diverse Approaches from a Participatory Perspective: The Experience of Nuestra Señora de la Purísima Church in Tabladitas (Jujuy, Argentina, Argentina)

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Abstract

The documentation, diagnosis, and intervention of historic earthen architecture require diverse strategies to understand the phenomena affecting it, its historical trajectory, and the social meanings superimposed over time. Recently, incorporating local communities into these processes through participatory methodologies has gained increasing relevance. However, the field of participatory conservation remains under discussion regarding its scope and the role of professional knowledge. This paper proposes that participation is not a methodology per se but a broad perspective that frames various methods. The experience between 2019 and 2022 with the Community of Tabladitas in conserving its nineteenth-century earthen church offers a fertile context for this analysis. At the community's request, a multi-faceted strategy based on a participatory approach was developed. This included (1) collaborative fieldwork in dialogue with historical documentation studies, (2) material characterisation in the laboratory, and (3) structural analysis through computational models based on the Finite Element Method. This strategy produced a consensual intervention project resulting from long-term collaboration. This paper addresses the strategy deployed, its various actions, and the implications of the participatory approach, considering the contradictions encountered during the project. Additionally, it will present and discuss concrete results from the dialogue between different actors, contributing to discussions in participatory conservation.

Keywords: *multivocality; Andean area; earthen heritage; field work; participatory approaches*

1. Introduction

The most recent debates in heritage conservation have been marked by decolonial perspectives that question valuation and management criteria. From this viewpoint, heritage is an unfinished process where multiple voices intervene, expressing diverse ontologies (Alonso Gonzalez, 2015). Understanding the multivocality of heritage requires recognising the existence of these different ontologies within their power networks (Tomasi & Barada, 2021). This necessitates reconciling perspectives in tension.

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This interdisciplinary work in northwestern Argentina provides a starting point to consider conservation through the dialogue between knowledge and meanings. In 2019, the Laboratorio de Arquitecturas Andinas y Construcción con Tierra (LAAyCT | CONICET-UNJU) was invited by the community of Tabladitas, in the highlands of Jujuy, to collaborate in restoring their chapel, the Church of Nuestra Señora de la Purísima (Fig. 1). This request arose from the severe structural and construction issues the temple faced.

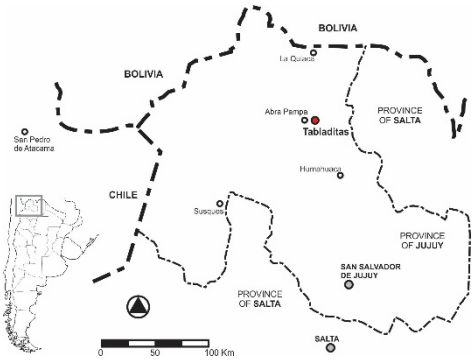

Fig. 1 – *Location of Tabladitas in the province of Jujuy, Argentina.* (Authors, 2025).

The role of local communities in earthen heritage management and conservation processes is shaped by the history of these techniques and the role of community architecture in building and rebuilding social ties (Barada et al., 2023). Institutional intervention in their management presents challenges. The question is: how to conceive and operationalise the intervention of different actors in participatory conservation processes: is it a singular methodological strategy or an integral perspective from which methodologies are designed? Moreover, how are institutional and disciplinary roles defined in these contexts? In essence, what does it mean to approach participation as a core axis rather than a collateral methodology?

A process based on this participatory approach has begun in this context and is still in development. The church, built in the 19th century, is central to the social and cultural life of Tabladitas, with a significance that transcends the religious, emphasising the need for an intervention that includes these multiple voices. However, this building has no formal protection declarations, giving the process particular characteristics.

This text will outline the methodological process that guided this experience. The strategies used for architectural and constructive characterisation, diagnosis, and project planning will be analysed. It will be shown that multivocality (Rodríguez Gallego & Nin, 2016) not only implied the coexistence of ontologies but also their active recognition in decision-making.

2. Strategies for characterisation

Both oral traditions and the historical records of the Tabladitas chapel suggest it was built around 1820. At that time, the community consisted of ‘five or six families grouped around the chapel, and two or three at a distance’. Although constructed during the Republican era, its design aligns with the aesthetic and morphological repertoire used in colonial times for chapels in the so-called "pueblos de indios" (Gisbert & Mesa, 1985). This includes a single longitudinal nave, an adjacent tower, and an open atrium (Fig. 2). There is an open chapel at the entrance, a lateral sacristy, and a gabled roof.

Fig. 2 – *Historical image of the Chapel* (Alameda, 1935).

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The structure is made of adobe, with lateral walls supporting a roof of cactus wood tied with leather straps. The roof is finished with "guayado", a technique involving bundles of straw soaked in viscous mud, typical of the high Andean regions of northern Argentina, Chile, and southern Bolivia (Tomasi, 2013). Inside, the nave features ornamental clay reliefs and numerous mural paintings, created around the 1950s (Fig. 3).

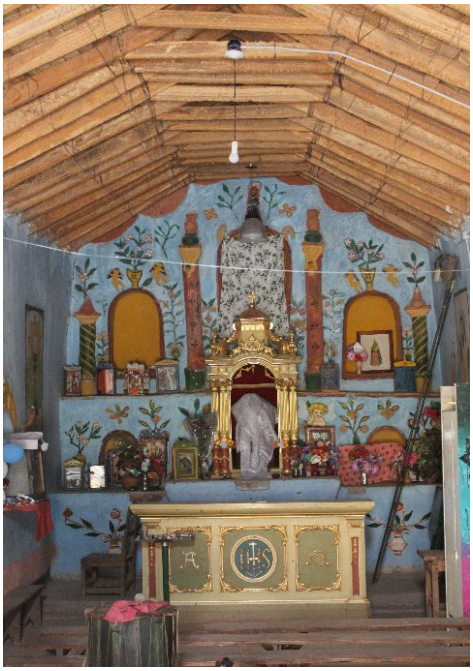

Fig. 3 – *Image of the altarpiece of the church* (Authors, 2022).

Studying the constructive characteristics also required understanding the details of techniques, procedures, and maintenance practices over time, in relation to their social history. To achieve this, 16 workshops and meetings were held in the field, aligned at different times with community assemblies and with the participation of the LAAyCT's technical team (Fig. 4). This involvement extended to other collective ritual instances, exploring the universe of meanings that connect objects and people in social life dynamics (Miller, 2005).

Fig. 4 – *One of the workshops in the atrium of the church* (Authors, 2023).

Each of these instances varied. Some assemblies discussed issues beyond the church's restoration, leaving space for the technical team meeting. Others focused directly on work in the chapel. In this context, exchanges and discussions occurred. These spaces allowed for understanding the relevance of certain technical operations and their evolution over time, contributing to the diagnosis.

The historical description, combining oral traditions with graphic and written archives, revealed significant modifications to the current tower of the chapel, including a partial reconstruction in 1994. This involved extending the height by adding a third section and replacing the dome-shaped top with a pyramid-shaped one. Additionally, the tower was attached to the northwest wall of the nave. The tower and the enclosure, which currently serves as the sacristy, provide the only lateral bracing on the northwest wall, while three buttresses were added to the southeast wall. This analysis led to various exchanges with the community about historical structural problems, current concerns, and possible solutions.

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The roof of the nave presented challenges in its characterisation. Workshops recorded and activated collective memories of a particular ceiling technique, a mesh of continuous leather strapping, which remained unmodified over time (Fig. 5). Meanwhile, the "guayado" maintenance was ongoing. Memories revealed that lower layers were not removed in each renovation, thus increasing "guayado" thickness over time, allowing load estimation on the building.

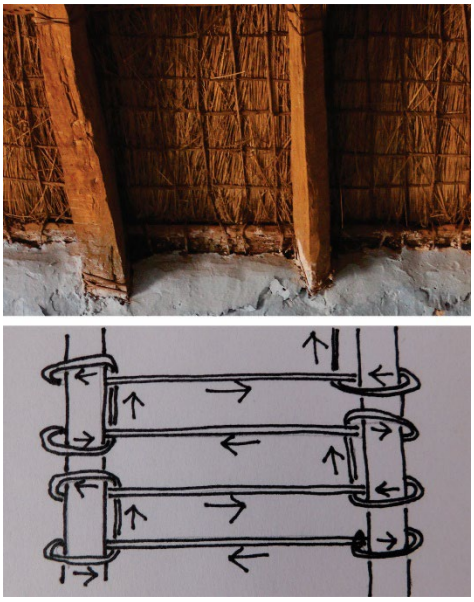

Fig. 5 – *Leather meshing of the ceiling and diagram made with the community* (Authors, 2022).

The collective study involved soils, key to the long-term sustainability of earthen structures, considering both plaster and "guayado". The participatory approach aimed to identify the most suitable soils for each procedure based on builders' subjective experiences, complemented by laboratory studies. Commonly used soil for plaster and adobe is sandy, while "guayado" soil, locally known as "lama" or "lame," is very fine and "gredoso" [clayey], cracking significantly during drying. Therefore, it is used solely in this technique to bind fibres providing structure. The fine soil character suits the viscous consistency required for work. Laboratory studies confirmed these characteristics through wet granulometric analysis and sedimentometry, following local standards and specialised literature (Houben & Guillaud, 1994; Neves et al., 2009).[1]

The granulometric distribution of the soil for plastering is balanced, with a predominance of fine sands (40%) and silts (20%), and a lower presence of clays (9%), aligning with builders' descriptions. Similarly, the "guayado" soil showed a very fine texture (98% passing the #200 sieve), with high silts (80%) and clays (18%), matching local characterisations.

Combining laboratory data with local knowledge from workshops and assemblies provided insights into the building's history, local techniques, and material usage. Community accounts established which elements to conserve and which to replace, while a detailed structural analysis identified the building's main problems.

3. Strategies for structural diagnosis

The structural problems of the church, recognised by the community, prompted the call to the LAAyCT. The main damage consisted of a horizontal crack running nearly the entire length of the southeast wall on the inside of the nave, two courses above its base. This was accompanied by vertical cracks at wall junctions and near a niche (Fig. 6). Due to their extent and severity, these cracks were seen as distinct from those caused by the roof's punctual support.

[1] For the "guayado" soil, the Atterberg Limits were also determined to qualitatively assess its behaviour in different states of consistency (Houben and Guillaud, 1994). The Liquid Limit (LL) was 43.4%, and the Plastic Limit (PL) was 29.29%, resulting in a Plasticity Index (PI) of 14.21% and an Activity Coefficient (AC) of 0.78 for the clays. This indicates a moderately active, cohesive, and expansive soil.

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Fig. 6 – *Cracking map on the inside of the south-east wall* (Authors, 2023).

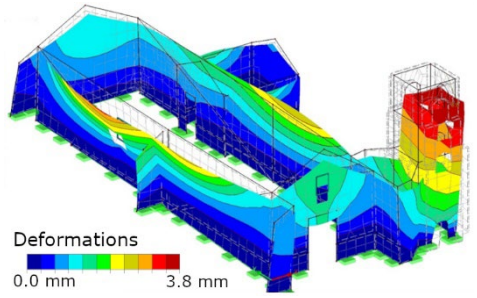

Fig. 7 – *FEM model of the Tabladitas chapel for the structural analysis of the lateral thrust of its roof* (Authors, 2023).

The placement of crack monitors confirmed active pathologies, advancing at a rate of 1 mm per year. Besides the collaborative survey and inspection, community participation was crucial in the structural diagnosis, providing testimonies on the sequence and rhythm of the chapel's damage perception.

A series of computational structural analyses were conducted using a commercial implementation of the Finite Element Method (FEM). Initially, the mechanical characteristics of the materials were estimated using literature on reinforcement in historic earthen buildings (Lourenço & Pereira, 2018). Simplifying considerations were made regarding the FEM formulation and its working regime to reach preliminary conclusions on the hypotheses and testimonies collected.

Consequently, five structural models were created, considering different construction evolution states, including variations in modification order, and reporting stress states compatible with the damage and the structure's history (Fig. 7).

The structural diagnosis revealed that the nave was damaged by an exceptional lateral thrust from the roof onto the top of its walls. This was caused by a misadjustment of the purlins at their highest point, which acted as an articulation of a roof section heavier than the original. This finding is consistent with the roof damage, observed with the community's help, due to repeated rethatching without removing the previous material. Local builders confirmed rethatching occurred in 1970 and 2010.

Despite its counter-stressed inclination, the southeast wall had little capacity to support the roof's weight. It proved incompatible with a new “guayado” renovation due to the weight of the community members on the roof during the task. The structure's seismic vulnerability was also evident, indicating poor performance under lateral accelerations. Additionally, the northwest wall was affected by the articulation mechanism at the roof ridge. It was clear that reinforcement work (and previous shoring) on the southeast wall required similar reinforcement for its counterpart.

The chapel tower, with cracks in its walls and openings, was found to be structurally and constructively incompetent. Studies showed a lack of integrity in its heavy top, built with bricks and cement, along with marked seismic weakness according to computational modelling (Fig. 8).

During the workshops, the community questioned the nature and authenticity of the tower's top and discussed reconstruction methods that would preserve the structural and constructive quality of the building.

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Fig. 8 – *Photograph of the tower and some of its pathologies* (Authors, 2022).

Throughout each diagnostic stage of the various structural and architectural elements, the entire community actively participated alongside the technical team, evaluating possible solutions based on previous knowledge, structural analysis, and available resources. This approach effectively integrated local building culture knowledge and had a direct impact on strengthening community ties.

4. Strategies for the project

The remediation of pathologies did not come as an entirely separate stage from the diagnosis. Ideas and proposals emerged from the observations in the workshops, framed within the plurality of voices. These ideas were then articulated in specific meetings for drafting an initial proposal. The project's starting point, based on the community's request, was to maintain the historical building techniques present in the chapel, while also incorporating external resolutions that would allow its consolidation.

The chapel's lack of formal protection declarations broadened the range of possible choices. Remediation of pathologies is not an entirely objective field but involves technical choices within a broad spectrum of possibilities, with the community at the centre of the decision-making process.

The comprehensive proposal involved decisions on different scales, from recovering the roof structure and mud plasters to deeper interventions for structural consolidation. The latter are the most relevant for this paper, regarding the type of decisions taken. This consolidation focused on two main issues: the southeast wall suffering from overturning, and the integral recovery of the tower, due to its intrinsic damage and the impact on the northwest wall of the nave. In both cases, the resolutions adopted implied profound interventions, conceptually aligned with the types of actions historically carried out on the chapel within the dynamic definition of its authenticity.

In the case of the southeast wall, the mural paintings inside the chapel prevented the implementation of consolidation methods, such as cord-wrapped reinforcement [drizado] according to Peruvian standards,[2] which have been applied in other cases in the region. Considering this, the community's proposal to incorporate new buttresses to contain the horizontal forces generated by the roof structure's thrust on both the southeast and northwest walls was structurally verified. Notably, the existing buttresses were incorporated in the 1950s but lacked the desired connection to the nave. Additionally, the project included timber braces at the joints and a wooden collar beam at the top of the walls. These measures aimed to improve the walls' connection to the roof structure and limit the punctual stresses of the trusses (Fig. 9).

[2] Norma E.080. Diseño y construcción con tierra reforzada. Lima: Ministerio de Vivienda, Construcción y Saneamiento. Ministerio de Vivienda, Construcción y Saneamiento, 2017.

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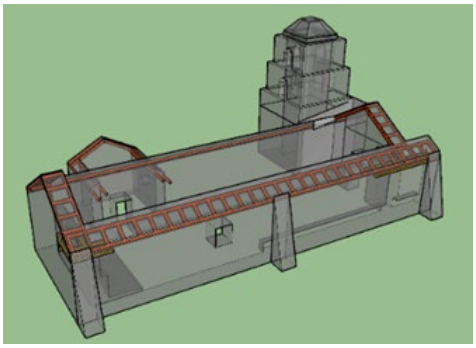

Fig. 9 – *Axonometric model of the church, with the proposal for the wooden collar beam and reinforcement timber braces* (Authors, 2023).

The diagnosis revealed the need for an integral reconstruction of the upper sections of the tower, opening a relevant field of discussion. Community perspectives considered reconstructing the tower in its current form from the 1990s, recovering the tower as seen in historical photos, and even constructing a different tower. The latter was chosen, based on a proposal from one of the oldest community members, who referenced the tower of the Rosario de Coyahuaima church in the Puna area. This tower features a “guaya” roof, with straw and mud (Fig. 10).

Fig. 10 – *Church of Rosario de Coyahuaima with its "guaya" tower* (Authors, 2013).

Undoubtedly, a modification of this scale opens a conceptual debate about the property's authenticity. This proposal focused on the community's perspective and the continuity of its bond with the chapel. This bond has implied continuous change of the tower over time, through collective action, highlighting the complexity of understanding authenticity as raised by the Nara Charter.

5. Conclusions

The intervention in the Tabladitas Church places community participation at the centre of earthen heritage conservation.

Fig. 11 – *Process of constructing the buttresses by the community* (Authors, 2023).

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Through this approach, the community not only contributed to the characterisation and diagnosis but were also key actors in decision-making regarding the interventions.

The Laboratorio de Arquitecturas Andinas y Construcción con Tierra (LAAyCT) team acted as facilitators and mediators, based on local knowledge and the community's connection with the chapel. This dialogue between scientific knowledge and local practices allowed for solutions that addressed both technical demands and the chapel's social and cultural significance for the community.

Historically, the church has been a reference point for the social, religious, and cultural life of Tabladitas. Its existence has been marked by transformations and adaptations in response to functional needs and changes in social dynamics, as seen with the tower. Thus, the role of the community is central in managing its own heritage.

Although a process of fund mobilisation was initiated for the integral execution of the project, it has not seen effective responses due to national political changes. However, the community itself constructed the buttresses, in dialogue with the technical team and the project as a whole (Fig. 11). This process has shown that community participation must be an integral and continuous approach, permeating the entire intervention process and transforming the relationship between professionals and the community into a joint construction effort.

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Energy Retrofitting Solutions for Traditional Half-Timbered Walls with earth infill in Spain: Challenges and Technical Recommendations

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Abstract
Adapting traditional buildings to current habitability and thermal comfort standards is essential to ensuring that they continue to be used as residential spaces. However, this adaptation requires careful consideration, reconciling energy efficiency improvements with their constructive characteristics and associated heritage values. In this regard, traditional buildings constructed with half-timbered walls display specific characteristics which considerably influence interventions related to energy retrofitting. These include the presence of constructive discontinuities between the timber frame and infill, as well as the existence of overhangs, porticoes, and galleries which complicate the installation of external insulation. To contribute to technical knowledge and promote compatible energy retrofitting, a systematic analysis using structured study fiches was conducted on 758 half-timbered walls with earth infill documented in Spain. It first provides an overview of the construction features that impact energy retrofitting actions and the related dynamics observed in some intervened buildings. Subsequently, it offers a series of reflections on the compatibility of these dynamics with the conservation of heritage values and some technical recommendations for the installation of thermal insulation depending on geometric, material, and other constructive characteristics, improving the thermal transmittance of certain types of infill in cases where substitution is justified, and reducing thermal bridges at the interface between the timber frame and the infill. This research aims to contribute to the development of technical knowledge about a traditional constructive technique at risk, offering solutions for its conservation while respecting and adapting to contemporary requirements.

Keywords: *traditional architecture; respectful interventions; compatible energy improvement; insulation*

1. Introduction

The adaptation of traditional buildings to the current standards and demands for thermal comfort is crucial to ensuring their continued use and facilitating their maintenance.

However, given the great heritage value of these constructions, with original techniques and materials which form part of their architectural and cultural identity, the need to improve energy efficiency in them should be addressed with great

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care. In this regard, energy retrofitting strategies must attempt to balance improved thermal performance and the conservation of traditional constructive characteristics, avoiding interventions which may jeopardize their authenticity or cause irreversible alterations.

This is even more important in the case of privately owned dwellings, where decisions regarding conservation and energy efficiency depend largely on the needs, preferences, and spending power of the owners. In many cases, interventions carried out do not reflect suitable technical expertise, and this can at times lead to an alteration of the original architectural elements, the introduction of inefficient solutions, and even pathologies brought about by incompatibility between traditional materials and modern systems.

Spain still houses an extensive and diverse vernacular heritage in which traditional constructive techniques vary greatly depending on climatic conditions, the materials available, and local constructive traditions. Among these techniques, half-timbered walls with earth infill combine a timber frame, mainly serving a structural purpose, and a wide selection of materials used for infill, enclosure, and render.

Most of these walls are found in the northwest of the Iberian Peninsula, in areas with an annual mean temperature of 10-12.5 °C and relative humidity of 65-75 % (Hueto-Escobar et al., 2022). In some areas where these techniques are found annual mean temperatures can drop to 7.5ºC while relative humidity can reach 80%.

In these environmental conditions, improving the hygrothermal behaviour of this type of building is a possible strategy to ensure or at least facilitate conservation. Adapting buildings to the current habitability and comfort standards encourages owners to continue living there rather than replacing these with contemporary housing (Jarosz, 2014).

2. Objectives and methodology

Therefore, this text aims to analyse the compatibility of energy retrofitting interventions in order to establish basic recommendations in keeping with the heritage values of this type of wall. The starting point for this is a broader study which documented 1218 half-timbered walls with different infills throughout Spain (Hueto Escobar, 2023). Given that thermal behaviour is largely conditioned by the materials used, the case studies were filtered, providing a final selection of only 758 case studies using earth infill.

Case study analysis was carried out using study fiches. These were structured as follows: a first part relating to the building, the second characterizing the half-timbered wall with earth infill and its constructive elements, and a third and final part recording the state of conservation and transformation dynamics. Based on the constructive characterization, the conditioning factors encountered when improving thermal insulation in buildings with half-timbered walls with earth infill were examined, while the final section provides qualitative conclusions on the interventions conducted by owners to improve energy efficiency. The combination of both aspects has led to the establishment of technical recommendations, based on restoration publications and manuals from countries including France, Germany, and England (Eßmann, 2021; McCaig & Ridout, 2012; Pasquet, 1986; Pickles, 2011). These recommendations seek to propose basic premises for the compatible improvement of energy efficiency and the conservation of heritage values.

3. Conditioning factors in construction

The energy behaviour of these types of walls is highly conditioned by their limited thickness (McCaig & Ridout, 2012), as well as by the wide range of materials that can be used as infill in the spaces defined by the frame.

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However, their constructive configuration intrinsically entails several conditioning factors which require prior consideration in order to combine the improvement of energy efficiency and the conservation of heritage values.

Although the initial premise is that insulation can increase efficiency when installed on the exterior wall (McCaig & Ridout, 2012), preventing the formation of thermal bridges and taking advantage of the thermal inertia of the wall, this is not always possible or suitable for this type of installation. In terms of typologies, it is possible to distinguish continuous walls which follow a single vertical plane from discontinuous walls which can incorporate changes of plane, resulting in the formation of overhangs, porticoes, and galleries. In this last case, although the construction inside is also interrupted by floors and ceilings, the exterior installation can be particularly complicated as different elements such as the joists of the overhangs, or the structure and railings of the galleries can be found (Fig. 1). Furthermore, from the outset the placement of the renders protecting the half-timbered walls with earth infill can allow distinctions to be made between continuous mortar render and discontinuous render on pieces.

Fig. 1 – *Half-timbered wall with earth infill, with overhangs and galleries hindering the direct placement of insulation on the exterior, in Sotoserrano (Salamanca)* (Hueto-Escobar, 2019).

Fig. 2 – *Half-timbered wall with earth infill where the thickness of the render suggests the incorporation of some form of render on the exterior, in Areiltza-Olatzar (Vizcaya)* (Hueto-Escobar, 2021).

In turn, these continuous mortar renders can also be divided between render covering the whole wall and render covering only the infill, leaving the timber exposed. In this last case, adding external insulation and then rendering in mortar cannot be in keeping with the aesthetic value in areas where the timber frame was usually left exposed (Fig. 2). However, this system can be used in cases which were left fully rendered.

Therefore, in addition to choosing a compatible material, ensuring the correct size in order to prevent internal condensation, it is necessary to bear in mind how the insulation is placed in order to guarantee compatibility and coherence with the heritage values of this type of wall.

4. Energy retrofitting dynamics

The main energy retrofitting dynamic identified is the interior doubling of walls, which can also cover needs for structural reinforcement in the building. Taking advantage of these double walls, internal air cavities may have been created or insulation material included.

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Fig. 3 – *Half-timbered wall with earth infill showing interior doubling in the window area, in Calatañazor (Soria)* (Hueto-Escobar, 2019).

The main indicator of this dynamic is the excessive thickness of window jambs, which also suggests that the original material may have been changed (Fig. 3). Although mere visual inspection cannot provide conclusive evidence, given how often industrial materials are used in interventions in these types of buildings, industrial brick may have been used to double the walls.

Another energy retrofitting dynamic documented is packing using different materials on the cracks formed between the frame and the infill. The constructive configuration of this type of wall, using materials with different thermal dilation coefficients in a structure which is not fully consolidated, encourages the formation of these cracks (Hueto-Escobar et al., 2024). However, they are vital to the thermal behaviour of walls as they generate thermal bridges (McCaig & Ridout, 2012) and points of entry for damp, giving rise to problems with xylophages and rot (Cappellazzi et al., 2020).

Although these cracks are generally filled in or at least rendered externally with cement mortar, in some cases they have been filled in with injected polyurethane foam (Fig. 4). Both materials are incompatible with traditional infill due to their higher rigidity and impermeability, which can increase cracking and hinder wall breathability.

The projection of polyurethane foam is another energy retrofitting dynamic which has been specifically identified in cases involving party walls (Fig. 5) left exposed to the elements following the demolition of an adjoining building. This thermal and acoustic insulation material is directly injected in liquid state, and expands in contact with the air, forming a relatively rigid layer. However, when exposed to ultraviolet solar radiation it undergoes a process of accelerated degradation which not only causes a loss of mechanical properties but alters its colour, significantly reducing thermal and acoustic effectiveness. In order to lengthen the useful lifespan of this material some form of protective render should be added, but this may not allow the visual appearance of half-timbered walls with earth infill to be conserved where timber was traditionally left exposed

Fig. 4 - *Half-timbered wall with cracks filled with expanded polyurethane foam in Colmenar de Montemayor (Salamanca)* (Hueto-Escobar, 2019).

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Fig. 5 – Half-timbered party wall insulated with expanded polyurethane foam in Gormaz (Soria) (Hueto-Escobar, 2021)

5. Technical recommendations

The material, thickness, and installation of thermal insulation must be selected and carried out correctly in order to prevent internal condensation which may prompt pathologies (Eßmann, 2021). This situation is potentially extremely serious not only because of the vulnerability of the materials to damp, but also because of the difficulty to detect and assess them when they are covered by insulation.

A poor choice or incorrect installation of insulation may increase the absorption of damp in the structure, speeding up deterioration processes such as timber rot and the development of microorganisms (Jarosz, 2014). In order to prevent these problems, it is essential to carry out a prior hygrothermal study to predict the spread of water vapour and the behaviour of the enclosure after the intervention.

These studies should consider the drying capacity of the walls, which is influenced by their orientation and specific conditions. Therefore, the design and thickness may vary between different façades.

The use of air cavities is discouraged due to the potential risk of condensation caused by unsuitable design and dimensions (Eßmann, 2021). Consequently, the use of natural materials such as lambswool, hemp fibre, linen fibre, and cellulose fibre is highly recommended. In addition to improving insulation, these natural materials can contribute to the controlled liberation of damp, reducing the risk of excessive accumulation in enclosures (Jarosz, 2014). However, it is essential to establish an optimum thickness so that improved thermal insulation and reduced condensation risk can be balanced.

The application of interior thermal insulation without a correct vapour control barrier can cause the area of condensation to move towards the timber structure, increasing the risk of biological and mechanical deterioration (WTA, 2022). It is therefore advisable to avoid excessively waterproof plates, favouring barriers susceptible to vapour, and a variety of diffusion membranes encouraging the evaporation of internal damp when necessary (Jarosz, 2014). Equally, the use of materials such as cement mortar render and waterproof plastic paint is not advised as it prevents correct breathability in the building.

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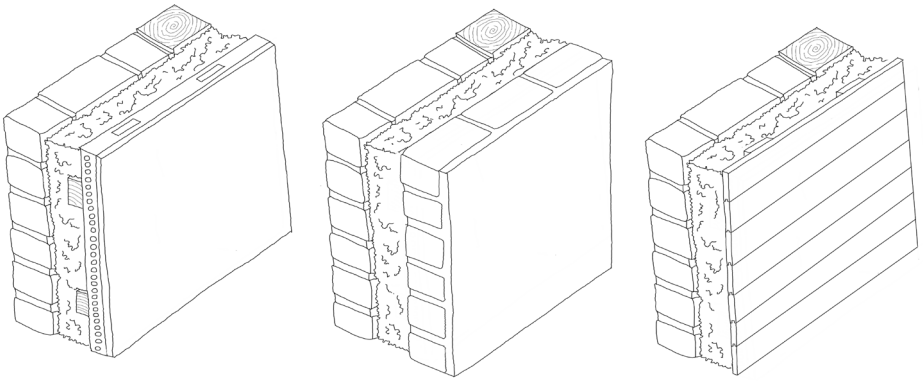

Fig. 6 – *Interior installation of thermal insulation behind reed panels, brick wall and boards* (Hueto-Escobar, 2023).

In the case of walls with continuous mortar render, exterior insulation can be added providing there are no changes of plane to complicate the installation. Some finish variants therefore offer the possibility of improving a building's thermal insulation taking advantage of its constructive layout. This is the case of half-timbered walls covered with cladding, where insulation material can be added in the space between the frame and the wood cladding (Brindel-Beth & Moeuf, 1993). If these have to be installed inside the building there are many constructive solutions based on adding insulation behind a wall (Fig. 6), which can be made of bricks, lightweight clay brick, wooden boards, reed panels, etc.

Another possible option for the retrofitting or improvement of thermal behaviour can be used in situations where the infill or enclosure of the framework requires replacement. Providing the traditional solution used in the wall to conserve its heritage value is respected, the same type of element can be executed, while adding compatible components to help improve thermal behaviour. For example, in the restoration of half-timbered walls with lath-and-daub the earth mix can be improved by adding hemp fibres and lime, reducing the final weight of the infill, displaying sufficient flexibility and aiding the hygrothermal behaviour of the building (Pickles, 2011). In the case of adobe, numerous plant fibres can be included, also improving mechanical resistance (Alioui et al., 2024). Another option, albeit with greater impact on the constructive value of the building, is the complete replacement of infill with insulation panels (Pickles, 2011).

In terms of the fissures formed between the frame and the infill, it is advisable to fill these with compatible materials which do not encourage the accumulation of internal damp and which allow speedy transmission of vapour (Fig. 7). In this case it is possible to use a traditional solution such as lime mortar, previously introducing plant or animal fibre cords (McCaig & Ridout, 2012). However, this constructive point must be reviewed periodically and the relevant maintenance actions carried out. By way of reference, German technical recommendations establish that the timber of the exposed half-timbered walls with earth infill and joints must be inspected annually (WTA, 2022).

Finally, it is important to remember the fundamental role played by windows in the thermal behaviour of traditional buildings (Radivojević et al., 2014). In this regard it is possible to simply replace glazing by dismantling the battens and rebate before installing new glass panes with better properties and re-installing the batten (Fig. 8).

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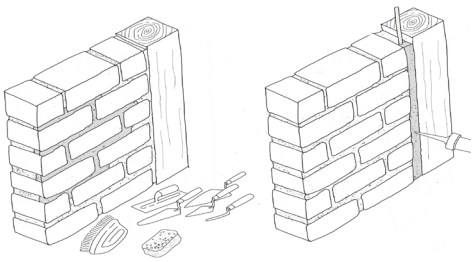

Fig. 7 – *Filling of perimeter fissures with natural fibres and traditional mortar* (Hueto-Escobar, 2023).

In cases where the rebate cannot be cut sufficiently new battens can be installed, even projecting from the joinery, and low emissivity laminated glazing, pyrolytic glazing, or glazing with extra-thin chambers can be used if the budget allows. Equally, if the properties of the windows allow, perimeter weather strips in rubber or neoprene can be incorporated, increasing insulation and preventing the formation of thermal bridges at these points.

Another possible strategy which enables the complete conservation of historic joinery is the addition of new windows on the inside, mainly in cases where the timber frame is thick enough or when the wall has been doubled on the inside.

6. Conclusions

The energy retrofitting of half-timbered walls with earth infill in traditional constructions is a complex process requiring a balance between thermal insulation improvement and the conservation of heritage values. It also requires painstaking design, calculation, and execution in order to prevent negative effects on the material conservation of walls.

In this respect, the documentation and analysis of 758 case studies has firstly enabled the identification of some of the constructive conditioning factors encountered when improving thermal behaviour, especially in relation to wall typologies with overhangs, galleries, and traditional exteriors. Equally, energy retrofitting dynamics show that in many cases owners have favoured solutions with unsuitable technical criteria, such as the use of polyurethane foam or filling in cracks with cement mortar. These interventions may cause issues such as damp accumulation and deterioration of the timber structure.

Ensuring compatibility between traditional materials and insulation materials is crucial to ensuring effective interventions that do not cause damage. Therefore, the use of natural materials such as lambswool or hemp, linen or cellulose fibres is advisable. Equally, the reduction of the risk of internal condensation is encouraged, also avoiding the creation of air chambers and the use of excessively waterproof plates. The installation form chosen must consider the existing constructive conditioning factors, installed on the inside in cases where there is a change of plane or where timber must be left exposed to respect the traditional appearance. At the same time, some variants clad with wooden boards offer the

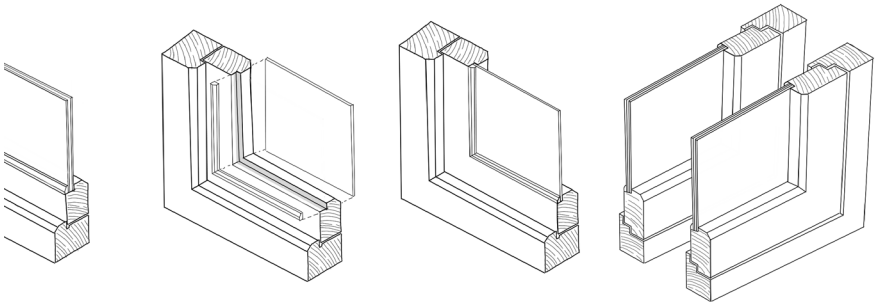

Fig. 8 – *Improvement of insulation with adding new glazing and with glazing replacement* (Hueto-Escobar, 2023).

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opportunity to incorporate insulation materials on the exterior. Finally, improvement of thermal behaviour must also consider windows, and this can be optimized by replacing glazing, incorporating weather strips and even installing a second interior window when this is viable.

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Experimental Investigation of the Mechanical Behaviour of an Earth Material from an Afghan Architectural Heritage

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Abstract

The paper is dedicated to the results of an experimental campaign to characterise the earthen material coming from the archaeological Buddhist site of Mes Aynak, Afghanistan, to undertake future conservation actions. The analysis focused on the study of the earth of an adobe taken from the 007 site of the Mes Aynak archaeological area, reporting the results of determining the grain size distribution test through a dry sieving analysis and a complete mechanical test analysis. The results were commented on and compared with those obtained from the same analyses carried out on Earth samples from an Italian site with a tradition of earth construction.

Keywords: *earth material; adobe; conservation actions; sieving analysis; mechanical characterisation*

1. Introduction

The Earth's vernacular architecture represents a unique heritage worldwide. Techniques and processes born and developed according to the context's conditions and availability reflect a country's cultural identity and a strong link between man, nature and architecture. Traces and evidence of buildings in raw earth material are found today all over the world: it is more than 50% of the world's population, of which about 20% of the cultural heritage is on the UNESCO World Heritage List (Houben & Guillaud, 1994; Miccoli et al., 2015). The success of the material is linked to the two forms of use that have always coexisted: the spontaneous, rural, and modest form, and the emergence of an elitist use that exploits its full potential both in technique and formal expressions (Fratini et al., 2011; Galdieri, 1982). In recent years, the consequences of various factors related to human intervention, urban pressure, globalisation, climate change, and global conflicts have highlighted the fragility and vulnerability of this artistic and cultural heritage and the growing awareness of its urgent protection.

Earth technology, as well as representing a cultural heritage of vernacular architecture of inestimable value, is widespread worldwide and

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well linked to sustainability principles towards which architecture should move (Minke, 2006; Pacheco-Torgal & Jalali, 2012). In this context, the raw earth material is a sustainable resource that does not require chemical or polluting processes, avoiding the production of waste harmful to the environment. At the end of its life cycle, raw earth is completely recyclable, paraphrasing (Galdieri, 1982). Despite reduced mechanical capacity compared to other building materials (Minke, 2001; Misseri & Rovero, 2022), raw earth walls, in addition to improving the thermal efficiency of buildings thanks to hygroscopic properties and thermal inertia, could produce satisfactory mechanical characteristics, allowing solid and durable masonry, if suitably combine with other materials (Illampas et al., 2014; Miccoli et al., 2014).

However, despite renewed interest in this material in the green building sector and the several advantages of the material itself, the high heterogeneity, which depends on several parameters influencing physical and chemical characteristics at the microstructural level, should be considered. Only a few studies have investigated the material, and they provide most of the available data on its mechanical properties Moreover, despite several countries having adopted standards for earth construction (ASTM, 2010; New Mexico, 2009; NTE, 2000; Silveira et al., 2012), these often lack unified tables and data and tend to group all earth typologies into one category, not considering the high variability of the material.

Only a deep knowledge of earthen material could guide the choice for compatible and efficient consolidation interventions in historical built heritage and promote the same use in architecture. To these aims, a better understanding of mechanical behaviour is deemed necessary.

An experimental campaign was implemented on the earth material taken in situ from the archaeological Buddhist site of Mes Aynak in Kabul. The archaeological Buddhist site of Mes Aynak, characterised by interesting and fragile stone stupas, has a rich heritage of adobe walls which constituted Buddhist monks' dwellings and monasteries (Benard & Sugarman, 2013; Klimburg-Salter, 2018; Paluch, 2014). This suggestive and unique heritage is in one of the largest copper mines, and the risk for the archaeological site is further worsened by a state of abandonment to which it has been subjected.

To examine the mechanical properties of earthen material with a view to future consolidation actions, an extensive experimental campaign was conducted on earth from a historical adobe of the archaeological site and on earth from an Italian site with a tradition of earth construction.

The experimental campaign reported in Section 2 encompasses grain size analysis by dry sieving test, conducted for both earth materials separately, preparation of the two different mixes and packaging of specimens respectively, mechanical characterisation, through uniaxial compression tests and three-point bending tests.

A comparison between the data obtained is reported in Section 3, where the main results from the experimental campaign are discussed. General conclusions are drawn at the end of the work.

2. Materials and methods

2.1. The historical Adobe

An original adobe was removed from the Mes Aynak Site 007. The Adobe sample was taken from a monastery with a rectangular plan, featuring a central courtyard surrounded by rectangular, domed, and vaulted rooms. The walls are built using adobe blocks measuring 38 × 38 × 9 cm³, in combination with cob. (Fig. 1).

The block was irregular and parallelepiped in shape, with dimensions of ~ 390 mm long, 250 mm wide and 105 mm high and weighing 15 kg (Fig. 2).

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Fig. 1 – 007 Mes Aynak archaeological area (Authors).

Fig. 2 – Adobe block taken from 007 Mes Aynak archaeological area (Authors).

Numerous micro-cracks and more substantial fractures affected the sample, indicating considerable fragility. The adobe was manually crushed with a wooden hammer to produce material for specimen preparation in the laboratory, minimising pulverisation to preserve coarse particles. This phase revealed the presence of fibres of different kinds, carefully taken and analysed under the microscope, as well as other elements such as feathers, incoherent stones, and nodules in incoherent stones. To make a comparison, the earth from Terranova Bracciolini, Arezzo, an Italian site characterised by earthen architecture, was considered in the experimental campaign.

2.2. Grain size distribution test by dry sieving analysis

The first differences between the two selected earth materials were immediately visible to the naked eye: the earth material from the Mes Aynak site was grey and more friable, compared to the earth material from Terranova Bracciolini, Arezzo, Italy, which was ochre and more compact.

Following ASTM D422 (ASTM, 2003), sieves ranging from 0.85 mm (No. 20) to 0.075 mm (No. 200) were used. They were arranged in descending order of mesh size and agitated for 10 to 15 minutes to achieve effective particle separation. All the retainers were weighed, and percentages were calculated.

Further assessment of the quality of the earth materials was carried out by calculating the Coefficients of Uniformity $Cu= D_{60}/D_{10}$ and the Coefficient of Curvature $Cc=(D_{30})^2/D_{10}x\ D_{60}$, for each analysed earth. In these formulas, D_{60} represent the particle diameter at 60% passing, D_{30} the particle diameter at 30% passing and D_{10} the particle diameter at 10% passing.

2.3. Specimens' preparation

The two earths selected for the specimens' packaging were dried in an oven at 110°C to constant weight as prescribed (ASTM, 2003). The weight change was recorded at a time interval of 1 h between each weighing with an accuracy scale of 0.01 g.

The weight was considered stable after about 7 hours. In a prior experimental study conducted in the laboratory with earth from the Mes Aynak site, the two types of dried earth were mixed with a water content of 25%.

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For the packaging of the specimens, two different types of formworks were used: wooden formworks, which allowed for the production of cubic specimens, in several four for each of the two mixes, dimensions of 50 x 50 x 50 mm^3, and steel formworks, properly coated to facilitate, after the drying of the mixes the de-moulding, which allowed for the production of prismatic specimens, in number of three for each of the two mixes, dimensions of 40 x 40 x 160 mm^3.

The demoulding was carried out after 24 hours, while the samples were left to dry naturally for 7 days.

2.4. Laboratory tests for mechanical characterisation

The earth samples, from the two different mixes, were subjected to laboratory tests for mechanical characterisation. Compressive strength, Young's elastic modulus, and Poisson's coefficient were determined through uniaxial compression tests (Fig. 3a; Fig. 3b) and the bending tensile strength was determined through a three-point bending test (Fig. 3c).

All the tests were carried out after 7 days of natural air drying. To accommodate for surface unevenness and to allow a uniform distribution of the load during the tests, the upper and lower faces of all specimens were lightly smoothed by abrasion using an electric sander.

To set the tests, the results of compression tests reported in the literature (Illampas et al., 2014), varying between 0.6 MPa and 8.3 MPa, with the most common values being between 0.8 MPa and 3.5 MPa, were considered. The lowest strength limits set in the national directive documents range from 1.2 MPa (NZ4298, 1998) to 2.1 MPa (NTE, 2000). All the tests were carried out using a ZWICK-ROELL Allround Z100 test machine, equipped with a 100 kN strain gauge load cell. The load cell is located over the transverse table and is used to measure both tensile and compressive forces directly. The displacement data were recorded through a Linear Variable Differential Transformer (LVDT) incorporated into the testing apparatus.

2.4.1. Uniaxial compression test

A total of four cubic specimens (50 × 50 × 50 mm^3) were tested under uniaxial compression for each of the two mixtures. The tests were conducted in displacement control. According to EN 1015-11 (EN 1015-11, 1999), to establish the rate for the test, values for a mortar class $M_{2,5}$ (f_m= 2.5 MPa) were considered. A rate of 100 N/s was imposed. The stress-strain diagrams obtained from each test were interpreted. The stress values were obtained by dividing the maximum load values recorded by the surface area of the specimen (A=2500 mm^2), while the strain was calculated from the maximum displacement.

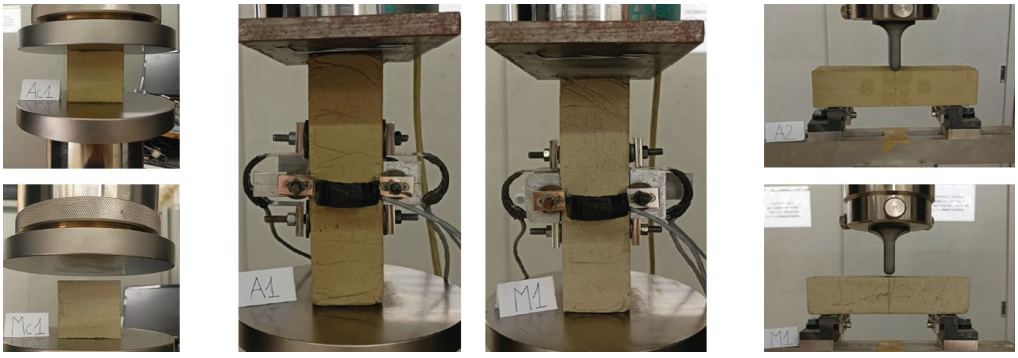

Fig. 3 – *Test setups: a) uniaxial compression test for the determination of compressive strength; b) uniaxial compression test for the determination of Young's modulus and Poisson's coefficient in compression; c) three-point bending for the determination of tensile strength* (Authors).

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2.4.2. Determination of Young's elastic modulus and Poisson's coefficient

Uniaxial compression testing was conducted on three prismatic specimens (40 × 40 × 160 mm³) for each of the two mixes to determine Young's modulus and Poisson's ratio. In particular, for the three pre-loading cycles from 0.5 MPa to 0.95 MPa (corresponding to 1/3 of the compressive strength carried out previously) for specimens made using the earth taken from Terranova Bracciolini and cycles from 0.5 MPa to 1.3 MPa (corresponding to 1/3 of the compressive strength carried out previously) for specimens made using the earth taken from Mes Aynak, were set as stress bounds at 0.1 MPa/s. Two Cantilever Displacement Transducers (CE-DT) were placed on the upper loading plate, separated from the test press head by a steel sphere. To measure strains in the central part of the specimen, two 50 mm Omega extensometers were installed and removed before the tests were completed.

2.4.3. Three-point bending test

Three-point bending tests were carried out on prismatic specimens (40 × 40 × 160 mm³), with three specimens for each of the two mixes. A load application rate of 40 N/s was selected, with the load applied at the midpoint between two supports placed 100 mm apart. The specimens were instrumented with two Cantilever Displacement Transducers (CE-DT) at the loading point.

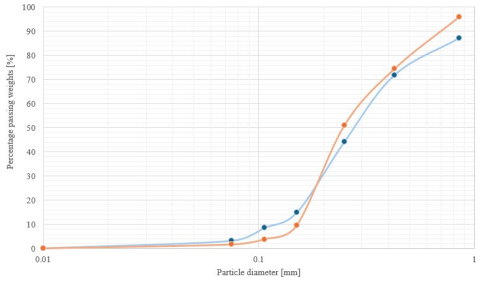

Fig. 4 – *Superposed granulometric curves of percentage passing weight derived by dry sieving analysis, Terranova Bracciolini in blue, Mes Aynak in orange* (Authors).

3. Results

The superposed granulometric curves obtained from the grain size distribution by dry sieving analysis, shown in Fig. 4, provide a visual perception of the two different earth compositions and a more direct comparison between the two examined earths.

According to the Unified Soil Classification System (USCS), ASTM 2487 standard (ASTM, 2017), was used to classify the earth materials analysed: gravel for the class between 76.2 mm and 4.75 mm, sand for the class between 4.75 mm and 0.075 mm, silt and clay for diameters below 0.075 mm. As indicated in the table, both earth materials are classified as sands for almost all the samples: the sample of Mes Aynak shows a cumulative percentage of 98.39% of particles falling in the sand class and 1.61% of silt and clay; the sample of Terranova Bracciolini instead has 96,86% sand and 3.14% silt and clay. Clay has a key role in the earth as a building material. This fraction exerts binding effects, determinants for the performance of cohesion and stability (Achenza et al., 2008). It should be considered in mind that the percentage values obtained for particles <0.075 mm by the dry procedure are not very reliable because small particles may remain attached to large ones and thus not be among the passing particles. For this reason, wet sieving should be integrated.

From the observation of the grain size distribution curve (Fig. 4), it can be noted that both curves exhibit sections with greater and lesser slopes, although not too pronounced. This indicates that the gradation in both cases is not optimal, despite a slightly more regular trend being observed for the sample of the Terranova Bracciolini. The results for the primary parameters used to characterise the gradation of earth material particles are consistent with the trends indicated by the curves. The values of the Coefficient of uniformity and curvature obtained for both the analysed earths are Cu= 2.10 and Cc= 0.835, for the earth of Terranova Bracciolini,

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and Cu= 2.99 and Cc= 0.996 for the earth of Mes Aynak. The range values of Cu > 6 and 1 ≤ Cc ≤ 3 indicate a good gradation for sand. The analysis results reveal homogeneous soils with imperfect gradation, although the Terranova Bracciolini sample exhibits a somewhat more regular trend.

The main results obtained from the uniaxial compression test are summarised in Table 1, while Fig. 5 shows all the experimental stress-strain curves superposed.

For the specimens made from the earth of Mes Aynak, higher compressive strength and stiffness are recorded compared to those of the Terranova Bracciolini. Tests showed an average value of compressive strength of 2.89 MPa for Terranuova Bracciolini specimens and 4.10 MPa for Mes Aynak specimens. Both sets of tests exhibited limited dispersion, with CV under 15% (4% for Terranova Bracciolini specimens and 10% for Mes Aynak specimens), declaring good robustness of the averages despite the limited number of specimens available.

Table 1 – *Results of the uniaxial compression test on the specimens for the determination of compressive strength and ductility* (Authors).

Terranova Bracciolini	**σc [MPa]**	**E [Mpa]**	**μc**	**μcd**
Av. value	2.89	206	1.13	2.88
CV [%]	4	9	9	15
Mes Aynak	**σc [MPa]**	**E [Mpa]**	**μc**	**μcd**
Av. value	4.10	284	1.16	2.72
CV [%]	10	16	4	21

The results obtained are consistent with the compression strength ranges reported in the literature, between 1 and 3 MPa (Achenza et al, 2008; Illampas et al., 2014). Regarding the value of the elasticity modulus, the results provided an average of 206 MPa and 284 MPa for the Terranova Bracciolini and Mes Aynak specimens, respectively. Both kinematic ductility (pre-peak non-linear capacity) and available kinematic ductility (displacement capacity after peak), of 1.13 and 2.88 for Terranova Bracciolini specimens and 1.16 and 2.72 for Mes Aynak specimens, respectively, are different but quite close.

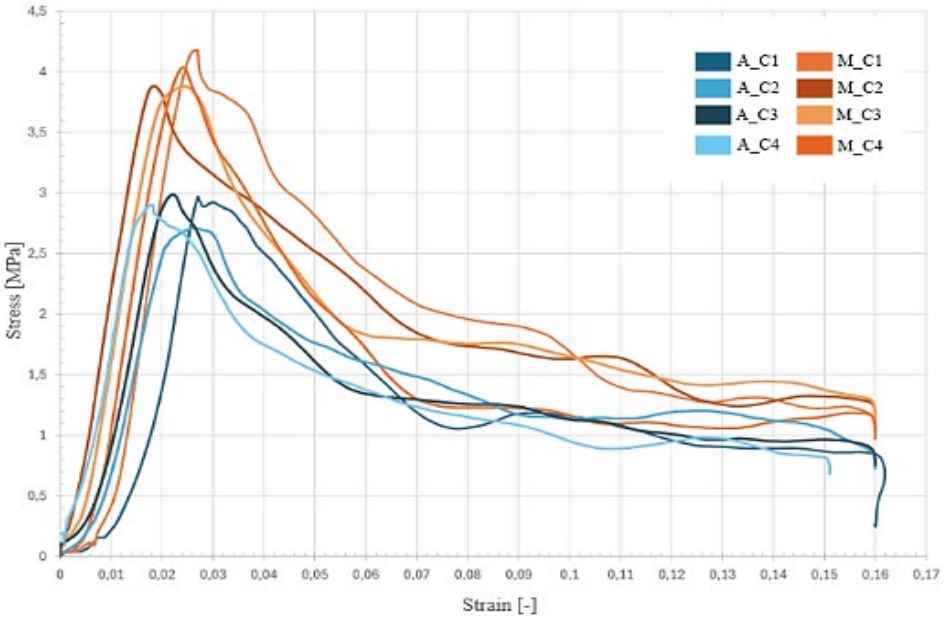

Fig. 5 – *Stress-strain diagrams with superposed curves derived by uniaxial compression test* (Authors).

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At failure, the specimens showed almost the same crushing layout. The crack pattern manifestly expresses a classical distribution of compressive stress with a homogeneous vertical flow in the central part of each specimen, inducing a cone-shaped failure. The main values of Young's elastic modulus and Poisson's coefficient obtained are summarised in Table 2.

Table 2 – *Results of the uniaxial compression test on the specimens for the determination of Young's elastic modulus and Poisson's coefficient* (Authors).

Terranova Bracciolini	**E[MPa]**	**G [MPa]**	**ν**
Av.value	3144	1467	0.073
CV [%]	34	34	45
Mes Aynak	**E[MPa]**	**G [MPa]**	**ν**
Av. value	3709	1504	0.270
CV [%]	4	18	78

The results show a lower deformability according to the strength of the specimens of Mes Aynak, with an average value of 3709 MPa compared to an average value of 3144 MPa for the specimens of Terranova Bracciolini. However, the high values of the coefficient of variation obtained, especially about Poisson's coefficient, especially in the case of Mes Aynak specimens (78%), indicate scattered data related to the difficulty in the precision of transversal measurements of small entities. It is also noted that the problem in glueing measuring instruments in a material such as earth that easily loses cohesion.

Regarding the results obtained from the three-point bending test, as expected, the tensile strength obtained was slightly less than half that of the compressive strength previously recorded. For both, the values of the coefficient of variation lower than 15% (6% for Terranova Bracciolini specimens and 12% for Mes Aynak specimens) verify the validity of the tests, although there is a greater dispersion of results in the case of samples from Mes Aynak, which have withstood higher loads, average value of 1.74 MPa, than those of the Terranova Bracciolini, average value of 1.30 MPa, recording a higher tensile strength.

4. Conclusion

This paper presents the results of an experimental campaign exploited to evaluate the most relevant mechanical properties of earth materials taken in situ from two different sites: one sample from the archaeological Buddhist site of Mes Aynak, in Kabul, and one sample from Terranova Bracciolini, Arezzo, Italy.

The dry sieving analysis shows that both earth materials can be classified as sands, with the Mes Aynak sample consisting of 98.39% sand and 1.61% silt and clay, while the Terranova Bracciolini sample contains 96.86% sand and 3.14% silt and clay.

The Coefficient of Uniformity and Curvature of the grain size curves suggest that the earth material is poorly graded, characterised by a limited particle size range and an excessively steep grading curve.

Uniaxial compression tests are used to determine compressive strength, Young's modulus, and Poisson's ratio, while bending strength is evaluated through three-point bending tests.

According to the mechanical tests, the earth specimens from Mes Aynak showed superior mechanical characteristics compared to those from the Terranova Bracciolini.

This difference would be due to various factors, which in addition to the size and nature of the particles that make up the earth, are dependent on several variables due to the heterogeneity of the material, which make it difficult to develop standardised and universally applicable procedures, thus explaining the absence of specific regulations for the use of raw earth.

This experimental campaign is a preliminary study for future in-depth investigations, for planning more conscious and compatible consolidation and restoration actions.

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Lessons Learnt from Adaptive Reuse of Earthen Heritage in Desert Oases in Hot Arid Climates

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Abstract
Earth is the most widely used construction material, especially in desert oases, due to its ominous presence, thermal insulation, soundproofing capacities, and cultural appropriateness. The adaptive reuse of earthen heritage is an emerging trend in the desert oases that aims to preserve the historical values of the heritage sites and revitalize it to suit contemporary needs. While there is an increasing awareness of the significance of heritage adaptive reuse and the renewed attention for earthen architecture, the focus on the reuse of earthen heritage is not sufficiently explored yet in literature. This study provides a comparative analysis of successful adaptive reuse projects in desert oases across Egypt and other similar contexts worldwide such as: AlUla Town and Al-Turaif District in Saudi Arabia, Ksar Ait Ben Haddou in Morocco and Old Sanaa in Yemen. By analyzing many approaches of earthen heritage conservation in these climatic conditions, the research emphasizes common problems and solutions that can be applied to an international context such as the involvement of the community in the process and the provision of new economic activities for the locals. The findings provide useful strategies for stakeholders, architects, researchers, owners and planners, to guide them in the adaptive reuse projects using earthen construction materials.

Keywords: *adaptive reuse; earthen heritage; heritage conservation; economic revitalization; sustainable architecture*

1. Introduction

Earth has been one of the most sustainable and widely used construction materials, particularly in hot-arid climates and desert oases, due to capabilities of thermal and sound insulations, and cultural significance (Minke, 2006). It is considered a practical and efficient housing solution due to its versatility, simplicity and ease (Steen et al., 2003; Minke, 2006; Bourgeois et al., 1989). An oasis can be defined as a human settlement that started in a harsh desert environment and regenerates itself based on available resources to create a self-sustaining lifestyle protected from surrounding harsh conditions (Laureano, 1985). Oases are not only the result of natural conditions, but the interaction between humans and their natural

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context and the transfer of their knowledge from generation to another (Laureano, 2002). The oases found in the Saharah and Arabian Desert and around Near East, Mediterranean islands and peninsulas, vary in type: wadi (riverbed), erg (sand dune) and sebkha (salt flat) (Laureano, 1985).

Morgan argues that the efficiency of earthen building technology in desert climates is due to its capacity of heat-retaining, making houses warm in winter and cool in summer, protection against weather harsh conditions, absorption of humidity, and resistance to insects and fire (Morgan, 2008; Khalili, 1996; Bourgeois et al., 1989). Locals of desert oases' can reuse earth blocks in buildings or with soil for vegetation. In earthen villages, construction costs are generally lower due to the availability of local materials and skilled laborers. The building know-how in desert oases is based on the combination between knowledge, traditions and adaptation to existing conditions. Thus, locals' involvement is necessary to make decisions according to their social and economic needs and environmental conditions (Dabaieh, 2013).

However, the increasing dependency on the industrialized materials in contemporary architecture without consideration of cultural identities and authentic values of vernacular heritage has caused a growing risk of disappearance of earthen building technology. The abandonment of earthen architecture was encouraged by the social rejection of traditional lifestyle, desire for modern aesthetics and gradual loss of traditional building knowledge (Moriset et al., 2021). The reasons of deterioration of earthen settlements can be categorized into natural causes (e.g. rainwater, variations in temperature and humidity, strong wind, tornadoes, floods, etc..) and human causes (e.g. lack of social awareness, absence of sense of belonging, unavailability of financial funds for development and maintenance, unsuitable activities or interventions, increase of sewage networks use that causes rise of underground water, absence of regulations and coordinated integrated plan) (Elhamy & Ibrahim, 2022). In addition, technical factors, such as the lack of understanding of building technology, lack of skilled labors and lack of well-researched standards or solutions have further contributed to its deterioration (Bridgwood & Lennie, 2013).

In the last 20 years, many international organizations, programs and projects were created by the earthen conservation community for the preservation and raising awareness of earthen heritage. However, there are still factors that hinder the development of the conservation field such as the lack of global conservation theory and lack of understanding of the true value of earthen heritage (Carlos et al., 2022). In response to these challenges and the rise in demolishment and new developments after war, adaptive reuse emerged during the second half of the 20th century as an effective strategy for preserving abandoned historical buildings (Cantacuzino, 1975). Adaptive reuse can be defined as the process that changes an unused place to a new place that can be used for a different function (DEH, 2004). By introducing new functions that respect historical and authentic values of heritage, adaptive reuse ensures the sustainability of the heritage building while contributing to socio-economic development of the settlement. When heritage buildings are often given new commercial functions (hotels, shopping centers, residential buildings), they generate new job opportunities for the local community and attract more users and tourism, contributing to the building's financial and cultural development (Niemczewska, 2020).

While there is a growing awareness of the significance of adaptive reuse in heritage conservation, its effect on the preservation of vernacular earthen heritage remains underexplored. The study aims to fill this research gap by conducting a comparative

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Fig. 1 – *Aerial view of earthen heritage in AlUla* (afalula.com).

analysis of selected successful adaptive reuse projects in desert oases across hot-arid climates. By analyzing different adaptive reuse approaches, identifying common challenges and solutions of these case studies, the research provides efficient strategies for stakeholders to promote adaptive reuse as a sustainable approach to preserving earthen heritage.

2. Methodology

The research qualitative approach is based on comparative case studies analysis to examine adaptive reuse projects in many desert oases in hot arid-climates. This comparative approach was used to provide an understanding of the contribution of adaptive reuse to preservation of cultural identity and socio-economic revitalization in similar geographic and socio-economic contexts. The case studies were selected based on the following criteria:

1. Having a cultural and historical significance.
2. Located in a desert oasis.
3. Including a vernacular earthen heritage (adobe bricks, rammed earth, etc..).
4. Undergone an adaptive reuse project by local or international institution.

The selected case studies are AlUla Town and Al-Turaif District in Saudi Arabia, Ksar Ait Ben Haddou in Morocco, and Old Sanaa in Yemen. The data were collected based on review of literature and conservation reports.

3. Case studies analysis

3.1. Alula town, Saudi Arabia

3.1.1. General Information

Saudi Arabia, being the center point of Islam religion, has always been a meeting point for civilizations who left their heritage among history. AlUla oasis, located in Madinah Province in the northwest of Saudi Arabia, has been a crossing point on the trade route connecting Arabian Peninsula, Mediterranean countries, and Asia (UNESCO, 2024). It has been ruled by Ancient North Arabian Kingdoms (Dedan then Lihyan) and the Roman Empire which made it a 200,000 years witness of history, cultural heritage and human relationship with natural environment. The traces of these empires were then used by Muslims to build AlUla Old Town in the 13th century. AlUla is home to a combination of diverse landscapes such as yellow sand panoramas, sandstone canyons and cliffs, and natural arches.

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3.1.2. Adaptive Reuse Project

AlUla project is a part of Vision 2030 developed by Saudi Arabia to showcase its significant history and develop its economy. It is a result of the French-Saudi collaboration that founded The French Agency for AlUla Development in 2018. The main objective of the project was to create an open air living museum in the North-West of the country that consists of archeological, cultural and touristic attractions. The project included many sustainable development approaches: Natural heritage preservation by hindering human impact on the natural environment, cultural heritage restoration by implementing management plans, and resources management by installing infrastructure sustainable systems (AFALULA, 2019). At the same time, UNESCO and RCU joined forces in 2021 to create local community and youth development programs for AlUla community. They aimed to introduce concepts of sustainable living and empower local communities to leave their impact in the field of community-driven heritage conservation (UNESCO, 2024).

3.2. Al-Turaif District, Saudi Arabia

3.2.1. General Information

Al-Turaif District in Ad-Dir'iyah, located in Wadi Hanifah in the northwest of Riyadh, was the first capital in Saudi Arabia. Ad-Dir'iyah is a wadi-based oasis, composed of areas of settlement and agriculture, which was founded in 1446 (SCTA, 2009). The oasis was founded in the 15th century but its significant role in the political and religious fields has increased in the 18th and 19th century (El Ghabban et al., 2010). It is a representation of Najdi earthen architecture (Elhamy & Ibrahim, 2022).

3.2.2. Adaptive Reuse Project

From 1965 to 1980, a large number of heritage buildings in Saudi Arabia have been abandoned, replaced or removed. The settlement of at-Turaif fell in ruins because of time passing, lack of maintenance, lack of planned studies, and unsuitable interventions. One of the main causes of this deterioration is the phenomenon of sudden heavy rains that can flood the sites for many days and cause the erosion of mud brick walls. The control of floods has been taken into consideration in the planning of Wadi Hanifah, by redesigning roads infrastructure and planning of monitoring mechanisms. Another reason of deterioration is the degradation of the environmental resources and natural ecosystems caused by the growth of Riyadh from 1970-1990.

An integrated conservation and development project was set up by the governmental institution: "The Supreme Authority for Riyadh City Development". The development plan aimed to raise awareness of the locals in the field of vernacular heritage conservation and encourage their participation in the conservation project by creating training programs for laborers. In parallel, the project implemented the reuse of vernacular heritage and its revitalization as hotels and museums with respect to its original identity and heritage qualities (Elhamy & Ibrahim, 2022). The conservation of the abandoned 18th century ruins also included the implementation of a development program that aims to rejuvenate the site as a Living Heritage Museum, celebrating its history and values. The conservation strategy of the site was designed by Anthony Crosby for ADA[1]. The main principle is to consider the whole district as one museum, where the buildings are the artifacts to be shown.

[1] CROSBY,A.,April 2007, Conservation Assessment and Treatment Recommendations for Atturaif, study prepared for Lord Cultural Resources / ADA.

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Therefore, the restoration and adaptive reuse decision should follow the overall vision of the MUSEUM in addition to the international guiding principles of UNESCO. The revitalization project included the creation of a small reception center to host the visitors of the Living Heritage Museum. The site was cautiously prepared to host a large number of visitors while preserving the authenticity of the heritage.

Fig. 2 – *Aerial view of earthen heritage At-Turaif district in Ad-Dir'yah* (Constructionweeksaudi.com).

3.3. Ksar Ait Ben Haddou, Morocco

3.3.1. General Information

Ait-Ben-Haddou is the most famous ksars in Ouarzazate Province in south Morocco. It is one of the trading points on the commercial route between Sudan to Marrakech. Southern side of Morocco is characterized by harsh pre-desert climate that obligated the tribes to live in groups in areas around water and create oases (Rodriguez-Navarro & Gil-Piqueras, 2018). Dated from the 17th century, the ksar represents an exemplary of pre-Saharan earthen architecture in Southern Morocco. It is composed of a compact group of houses, inhabited by one tribe, gated by defensive walls and reinforced with slender towers and a baffle gate (Nijst et al., 1973; SCTA, 2009). It is one of the unique Ksars that have maintained their authenticity and architectural identity represented in their earthen architecture which makes it fascinating for the visitors (Elhamy & Ibrahim, 2022).

3.3.2. Adaptive Reuse Project

Similarly, the abandonment of the inhabitants result in the lack of regular maintenance of earthen buildings which eventually leads to the acceleration of their deterioration (Rodriguez-Navarro & Gil-Piqueras, 2018). Due to change in their needs and lifestyle, the locals have moved to the other side of the valley, choosing to live in concrete blocks in search for better accessibility and building services (SCTA, 2009). For this reason, the Moroccan Ministry of Housing carried out actions to improve the quality of life in the ksar so the locals can inhabit it again by repairing and reinforcing existing architecture (Rodriguez-Navarro & Gil-Piqueras, 2018). In 2007, the Center for the Conservation and Rehabilitation of the Architectural Heritage of Atlas and Sub-Atlas Zones (CERKAS) implemented a five-year management plan that respects the integrity and authenticity of the site and ensures the involvement of all stakeholders in the decision making (Elhamy & Ibrahim, 2022). Finally, in 2020, The "Ait Ben Haddou – Ksar Museum project" was created by We Speak Citizen NGO. The locals created three cooperatives that present three types of activities to promote this fascinating living heritage: a tourism cooperative, an agricultural cooperative and a cinema cooperative (Visit Aït Ben Haddou; 2022).

Fig. 3 – Close up view of earthen heritage in Ksar Ait Ben Haddou, Morocco (Yvon Fruneau).

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3.4. Old Sanaa', Yemen

3.4.1. General Information

Old Sana'a is not only a unique city in Yemen but also for Arab Muslim Architecture around the world (Conservation of Old Sana'a, 1995). It is composed of a narrow network of traditional buildings and a strong presence of social bonding. The city is divided into a commercial and residential area, composed of 61 quarters, and each quarter is composed of: housing unit, mosque, open space, water fountain, fruits and vegetables garden and hot bath (Haidara & Talib, 2013). The houses are clay traditional towers that rise more than 5 floors and are designed in a vertical axis (Lewcock, 1986).

3.4.2. Adaptive Reuse Project

After many years of foreign influences, the city opened its doors to the modern world in the 1970s. This phenomenon accompanied by the oil-driven economic boom and the rapid population growth has caused major changes in the lifestyle of the locals (Conservation of Old Sana'a, 1995). The socio-economic changes have led the locals to start reusing the unused spaces of their houses or change its entire use. To create a new source of income, the houses' inhabitants rent the ground floors of the towers for shops whose functions are chosen by the owner (Haidara & Talib, 2013). There are two types of projects: the governmental projects that are done in collaboration with international organizations which depend on the expertise of local and international professionals, and the local private projects which the owner funds, chooses function and degree of intervention. The adaptive reuse can include only the ground floor of the tower or the entire building.

The conservation efforts and adaptive reuse movement started by the creation of the General Organization for the Preservation of Old Saa'a in 1984 by the local government, in collaboration with UNESCO and UNDP. In 1987, it changed its name to the General Organisation for the Preservation of the Historic Cities of Yemen (GOPHCY) and started to include all Yemeni cities. The organization encouraged the promotion of Yemeni handcrafts by the reuse of Caravanserai (Samsara) Al-Mansorah into crafts shop, Al-Mutahar house into Women technical center and Bayt al Umari as guest house (Petzet & Koenigs, 1995). However, the movement has continued as a series of uncoordinated adaptive reuse projects executed by the locals (UNESCO, 2008). The locals were encouraged to restore and renovate their houses under the guidance of GOPHCY to revitalize the town, safeguard its economy and promote its culture.

Fig. 4 – *Close up view of earthen heritage in Old Sana'a, Yemen* (Jean-Jacques Gelbart).

4. Findings and discussion

This section presents the research key findings from the comparative case studies analysis, showing common challenges, adaptive reuse strategies and lessons learned in the field of preservation of earthen heritage in desert oases.

4.1. Common challenges of adaptive reuse

- Environmental deterioration: Earthen buildings remain vulnerable to harsh climatic conditions of oases (heavy rains, temperature changes, wind erosions, etc..).
- Abandonment and loss of traditional knowledge: Earthen heritage faces the threat of social abandonment (due to change in needs and lifestyles) which causes neglect and retrogression of traditional knowledge.

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- Regulations and global strategies barriers: Adaptive reuse and conservation projects require strong policies and stable funding resources to increase their success.

4.2. Strategies for successful adaptive reuse

- Importance of community involvement: Local participation in conservation efforts has proven to be very important in ensuring the suitability of the interventions.
- Heritage tourism and socio-economic Development: Adaptive reuse has a great capacity to revitalize heritage sites by transforming them into cultural and economic hubs to encourage locals and visitors to maintain them.
- Integration of enhanced infrastructure with traditional materials: Several case studies have demonstrated that combining traditional building methods with modern infrastructure is necessary to satisfy the locals' changing needs.

5. Conclusions and recommendations

Adaptive reuse has emerged as a vital strategy for preserving earthen heritage in desert oases, combining between heritage conservation and socio-economic development. Al-Ula, Al-Turaif, Ksar Ait Ben Haddou and Old Sanaa are considered as successful adaptive reuse projects. However, their common challenges such as climate vulnerability, social abandonment, and lack of policies still threaten the sustainability of these conservation projects. The analyzed case studies highlight the importance of integrating traditional materials with new services, community involvement, income-generating activities and official regulations to ensure long-term conservation. Despite the limitations of the methodology such as inability of performing on-site observation, the findings offer important insights for future heritage adaptive reuse policies. The comparative case study analysis approach provided a synthesis of the role of adaptive reuse in ensuring the sustainability of earthen heritage. By preserving the authenticity of precious heritage while addressing contemporary locals' needs, adaptive reuse can safeguard earthen heritage for current and future generations while contributing to cultural and socio-economic development of earthen settlements.

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Memories: Perspective of Intervention for the Safeguarding of Vernacular Earth Architecture

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Abstract
This research comprehensively addresses the multiple challenges and needs in the conservation and restoration of earthen buildings, proposing solutions based on an exhaustive and comparative analysis of practices and regulations at a global level. The integration of global intervention criteria, the identification of regulatory gaps, the exploration of restoration theories, and the classification and evaluation of construction methods, will contribute significantly to the advancement of the conservation of this valuable heritage. The use of database analysis, observation, and literature review ensures a thorough understanding of the topic. The elaboration of this work will be supported under the current experience and the reflection on it from a perspective, where the actions of protection of the historical and architectural value of vernacular architecture with earth are the first area. The search for the safeguarding process is a primary action prior to a proposal or plan, so mitigating and contending the deterioration of our heritage can be reached to a deeper extent.

Keywords: *earthen construction; conservation; cultural heritage; restoration; seismic risk; vernacular architecture*

1. Introduction

Vernacular architecture reflects the adaptation of human settlements to their natural and cultural environment, using locally available materials and traditional knowledge transmitted across generations. Among these, earthen architecture stands out as one of the most widespread and resilient construction methods worldwide. However, despite its historical and cultural significance, earthen-built heritage faces increasing threats due to environmental factors, natural disasters, and a lack of regulatory contexts that ensure its conservation.

This research explores the challenges and opportunities in the safeguarding, conservation, and restoration of earthen vernacular architecture, focusing on the development of intervention criteria, the identification of regulatory gaps, and the evaluation of construction methods.

A case study in La Jalca Grande, Peru actual situation about traditional construction is analyzed, where the impact of the 2021 earthquake (7.5 Mw) on earthen structures highlights the urgency of developing effective emergency response and conservation strategies.

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The study is structured as follows: Section 2 provides an overview of the global distribution and classification of earthen-built heritage, emphasizing its vulnerability to seismic risks.

Section 3 presents a review of the international regulatory frameworks and conservation theories applicable to earthen architecture. Section 4 introduces a methodology for the evaluation and intervention in earthen buildings, tested through a field study in La Jalca Grande.

Finally, Section 5 discusses the results and conclusions, proposing recommendations for the advancement of conservation strategies in vernacular earthen architecture.

2. Distribution and Characterization of Earthen Architecture

The UNESCO World Heritage List includes several earthen-built monuments and sites, which are well-documented, except for certain African regions where data remains scarce.

The institutions responsible for managing these monuments often emphasize the need for stronger policies to ensure their protection. A significant percentage of earthen-built heritage is located in seismically active regions, making them particularly vulnerable to natural disasters.

This highlights the urgent need for technological improvements and resilient adaptations to mitigate future risks.

The identification of earthen heritage sites in high seismic activity areas is crucial for developing prevention strategies and emergency response plans.

By mapping these sites, it is possible to anticipate potential structural weaknesses and establish conservation guidelines tailored to their environmental conditions.

Earthen structures hold historical, architectural, and cultural value, yet their anonymity and lack of documentation increase the risk of their silent disappearance. Furthermore, traditional construction techniques are often neglected, leading to a reductionist view that focuses solely on their technical contributions while disregarding their cultural and social significance.

Preserving earthen architecture requires integrating traditional construction practices into contemporary conservation efforts. Understanding their structural behavior in seismic contexts can enhance preventive measures and promote adaptive reuse, ensuring that interventions respect their original material and construction techniques.

The structural integrity of earthen buildings depends on multiple factors, including soil composition, compaction, drainage, and seismic adaptation. These elements influence the durability and resilience of vernacular earthen architecture.

- *Soil Composition:* The proportion of clay, silt, and sand determines the stability of earthen structures. Clay provides cohesion, but excessive amounts can cause shrinkage and expansion, leading to structural cracks.
- *Compaction:* Proper compaction techniques increase load-bearing capacity, minimizing differential settlements that can compromise structural stability.
- *Drainage:* Effective drainage systems prevent water infiltration, which can weaken the walls and foundations of earthen buildings.
- *Seismic Adaptation:* In seismically active areas, reinforcement strategies such as timber bracing, anchoring systems, and seismic bands can improve the resilience of earthen constructions.

Understanding these factors is essential for developing tailored conservation strategies that address the specific challenges of earthen-built heritage in different regions.

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3. Conservation and Restoration Approaches

3.1. Applicable Regulatory Frameworks

The increasing recognition of earthen architecture as a valuable cultural heritage has led to the development of various national and international regulations aimed at standardizing its conservation and restoration. However, the lack of global consensus has resulted in fragmented guidelines, often focusing only on specific construction techniques or materials rather than a comprehensive regulatory framework. Several international organizations, including ICOMOS and UNESCO, have established principles for earthen heritage conservation, emphasizing minimal intervention, reversibility, and the use of traditional materials. However, discrepancies between regional building codes and the lack of mandatory enforcement mechanisms often hinder their practical application.

Existing regulations highlight the importance of stabilizing earthen materials through natural or synthetic additives such as lime, gypsum, or Portland cement. Nevertheless, excessive use of stabilizers can alter the authenticity and mechanical properties of traditional earthen structures, raising ethical concerns regarding the balance between preservation and structural reinforcement.

A comparative analysis of international standards reveals significant variations in testing methods, material selection, and intervention criteria. While some regulations, such as the Spanish and French standards, advocate for a comprehensive approach, others focus exclusively on specific construction methods, such as compressed earth blocks (CEB) or adobe. These inconsistencies underscore the need for a harmonized framework that integrates scientific research, empirical knowledge, and local construction traditions.

3.2. Restoration and Conservation Theories Applied to Earthen Architecture

Theoretical frameworks in architectural conservation have evolved significantly, incorporating interdisciplinary perspectives that bridge historical authenticity, structural safety, and sustainability.

According to Brandi (1977), restoration should aim to recover the original unity of a monument without falsifying its history. This principle is particularly relevant in earthen architecture, where interventions must respect the material's inherent properties and cultural significance. Several key conservation theories apply to earthen-built heritage:

- *Preservation:* Focuses on maintaining structural integrity and preventing further deterioration through preventive conservation measures (González-Varas, 2005).
- *Consolidation:* Involves reinforcing weakened structures by reintegrating original materials whenever possible. In earthen architecture, this often entails reintroducing compatible soil mixtures to restore structural cohesion.
- *Reconstruction:* Used in cases of partial or total collapse, provided there is adequate documentation to ensure historical accuracy (Correia, 2004).

The UNESCO 1972 Convention and the ICOMOS Charter on Earthen Architecture (2008) highlight the importance of community involvement in the conservation process. Local artisans and builders possess specialized knowledge essential for the effective restoration of vernacular earthen structures. Their participation ensures that interventions align with traditional construction techniques, maintaining cultural continuity and material authenticity.

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4. Methodology

The methodological approach of this research is designed to enhance the identification, classification, evaluation, and intervention in earthen-built heritage, particularly in emergency contexts.

The study follows a multiscale strategy, integrating global standards, empirical observations, and case study analysis to develop a framework applicable to diverse contexts of vernacular earthen architecture.

4.1. Research Approach

The research is based on a comparative analysis of international standards for earthen architecture conservation, combined with fieldwork observations and historical documentation. The methodology includes:

- *Mapping and Classification of earthen heritage worldwide*, focusing on regions with high seismic vulnerability using UNESCO's criteria for World Heritage Sites.
- *Comparative Analysis of Regulations*, evaluating the compatibility, limitations, and applicability of existing frameworks.
- *Theoretical Review of Restoration Approaches*, analyzing the relationship between structural interventions, material authenticity, and cultural significance.
- *Case Study Application*, focusing on La Jalca Grande, Peru, as an example of post-disaster intervention and emergency response strategies.

Fig. 1 – *La Jalca Grande vernacular architecture* (Weston, 2024) .

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4.2. Case Study: La Jalca Grande, Peru

La Jalca Grande, Located in the Amazonas region of Perú, is a historical town that preserves a significant concentration of vernacular architecture built in adobe and rammed earth. The center of La Jalca reflects colonial and indigenous influences, with earthen constructions adapted to the mountainous terrain and humid climate. On November 28, 2021, a 7.5-magnitude earthquake struck the region, causing severe structural damage to several heritage buildings, particularly the San Roque Temple, which partially collapsed. The surroundings houses, also built with traditional earthen techniques experienced wides spread cracking, wall detachment, and total loss of roofs. The earthquake revealed not only the seismic vulnerability of these structures, but also the lack of preventive maintenance and institutional support.

Documentation during field visits allowed the identification of typologies, construction methods, and patterns of damage. This provided a foundation for understanding both the architectural value and the fragility of the heritage at risk.

4.3. Development of Assessment and Intervention Tools

Based on the fieldwork and damage analysis, a sequential methodology was developed to guide a emergency response and long-term conservation planning for vernacular earthen architecture. This methodology includes:

- Rapid diagnostic forms for documenting building typologies, materials, and damage patterns.
- Risk prioritization matrices to identify in imminent danger of collapse.

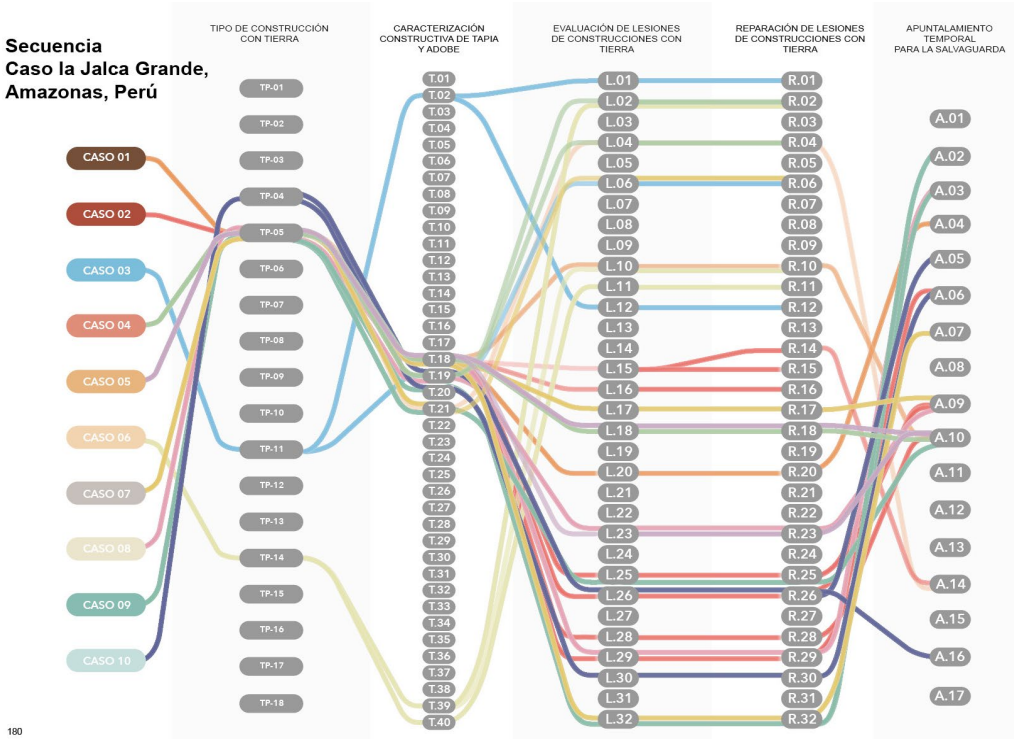

Fig. 2 – *Secuence of cases in La Jalca Grande* (Weston, 2024)

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- Technical guide lines for temporary stabilitation measures.
- Criteria for selecting traditional reinforcement strategies, such as timber tie-beams or stone foundations.

This methodology sequence emphasizes the need to engage local builders and community members, who possess practical knowledge of traditional techniques and can play an essential role in sustainable post-disaster recovery. Traning workshops were proposed to enhance technical capacity in structural assessment, emergency shoring, and compatible material use.

5. Discussion and conclusions

5.1. Challenges in the Conservation of Earthen Architecture

The preservation and restoration of vernacular earthen architecture face multiple challenges, primarily related to regulatory gaps, material degradation, and vulnerability to natural disasters. The fragmentation of international conservation standards creates inconsistencies in intervention criteria, making it difficult to establish a unified approach for safeguarding earthen heritage.

One of the main limitations is the incompatibility between traditional construction techniques and modern regulatory frameworks. Many building codes prioritize reinforced concrete and industrial materials, neglecting earthen construction despite its structural adaptability and environmental benefits. Additionally, insufficient funding and lack of technical training further restrict the implementation of conservation projects.

The case study of La Jalca Grande illustrates the complexities of post-disaster intervention in earthen heritage. The 2021 earthquake exposed the structural weaknesses of adobe and rammed earth buildings, while also revealing the limitations of emergency response mechanisms. Delays in damage assessment and intervention exacerbated the deterioration, emphasizing the need for preemptive safeguarding strategies.

5.2. Recommendations for Advancing Conservation Strategies

Based on the research findings, several key recommendations are proposed to enhance the preservation and resilience of vernacular earthen architecture:

1. Development of a Unified Regulatory Framework
   - Establish an international conservation standard for earthen construction, integrating scientific research and empirical knowledge.
   - Promote the harmonization of national regulations with global conservation principles.
2. Integration of Seismic Resilience in Conservation Policies
   - Implement seismic risk mapping for earthen heritage sites to prioritize vulnerable regions.
   - Develop reinforcement techniques that respect traditional materials and construction methods.
3. Strengthening of Emergency Response Mechanisms
   - Create standardized assessment protocols for rapid post-disaster intervention.
   - Provide training programs for local communities and conservation professionals to improve response capacity.
4. Promotion of Sustainable Conservation Practices
   - Encourage the use of local materials and traditional techniques in restoration projects.

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- Foster community participation to ensure the long-term maintenance and cultural continuity of earthen heritage.

5.3. Future Research Directions

While this study provides a methodological framework for the conservation of vernacular earthen architecture, further research is needed to refine and expand its application. Future studies should focus on:

- Comparative analyses of successful conservation models worldwide to identify best practices.
- Technological advancements in earthen material stabilization, exploring natural additives that enhance structural durability without compromising historical authenticity.
- Socioeconomic impacts of heritage conservation, examining the role of community-led initiatives in the sustainability of restoration projects.

By addressing these aspects, future research can contribute to a more comprehensive and effective approach to the preservation of earthen-built heritage, ensuring its resilience and cultural significance for future generations.

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Organic Stabilizers of Plant Origin in Archaeological Structures: Influence of Cactus Mucilage in the Making of Sacrificial Mortars

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Abstract

Today we have a wide variety of raw earth stabilizers, both of natural origin (animal, mineral or plant) and artificial. Thanks to them it is possible to provide greater stability to the earth that needs it, through physical, mechanical or chemical mechanisms. However, selecting the most suitable stabilizer for each type of earth remains a challenge, due to the variability in the nature of the substrate and its adaptation to climatic conditions. For this reason, it is essential to carry out previous studies and tests, both in the laboratory and in situ, that allow us to understand and optimize its properties. This research focuses on the use of plant-based stabilizers and their influence on the properties of raw earth. In particular, the effects of different mucilages from the plant species Opuntia spp., Austrocylindropuntia subulata (Mühlpfrdt. Backbg) and Opuntia huajuapensis (Bravo) are analyzed through experimental studies. The research includes, on the one hand, the laboratory evaluation of the adhesion capacity of these compounds on three types of supports: brick, raw earth and stone; and, on the other, field experimentation, where these substances have been integrated into mortars and coatings. The results of this study will contribute to the understanding of their potential as natural stabilizers in raw earth construction.

Keywords: *natural mortars; biopolymer adhesion; earth stabilization; raw earth*

1. Introduction

Raw earth constructions are structures especially exposed to severe deterioration because the materials they are composed of are easily degradable in nature. That is why, since ancient times, materials have been incorporated with the aim of stabilizing the earthy material.

Within the wide range of possible stabilizers for raw earth, the *Cactaceae* family has had a role of interest in the American continent (Alanís and Velazco, 2008).

Fortunately, many of these plant stabilizers have survived to our time, not only through archaeological evidence, but also through collective memory. This fact has demonstrated, among other characteristics, the sustainability and retratability that characterizes many of these natural materials.

However, the methodology and proportions of some of them may present a series of problems, mainly due to the lack of records. For all these reasons, for some decades now, within the field of heritage conservation and restoration, research

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has been carried out both in the laboratory and in the field, with the aim of integrating these plant stabilizers as a more sustainable alternative.

2. Objective

The study presented here is part of a doctoral research, whose objective is the study of sacrificial mortars of earth added with mucilage of cactus species for its application in the conservation work of archaeological structures in the Cochasquí Archaeological Park, Ecuador.

Firstly, the evaluation of the earthy material prepared in the laboratory is presented and the adhesion resistance of raw earth mortars with the addition of mucilage from cacti: *Opuntia huajuapensis* (Bravo) and *Austrocylindropuntia subulata* (Mühlenpfordt) Backeb., together with reference mortars, is evaluated.

3. Methodology

3.1. Preparation of test tubes

3.1.1. Preparation of earthy material

To approach the characteristics of *chocoto* (earth rich in soil used in construction and its maintenance), commercial materials have been used.

3.1.1.1. Volcanic tuff

Volcanic tuff from Burés Profesional was used, with a granulometry that initially ranged between 0 and 6 mm.

The STD was subsequently screened in the laboratory. of Architecture of the UPV to obtain a granulometry of less than 2 mm.

3.1.1.2. Clay material

The black refractory paste (PRNF) from the Barcelona company Sio-2 was selected. It contains 40% chamotte and particles ranging between 0-0.5 mm. Table 1 shows some interesting characteristics of this material.

Table 1 – *Technical data of interest* (O. Medina, 2024).

Refractory paste (PRNF)	
Humidity	Drying shrinkage
21%	7.0%

3.1.2. Incorporation of vegetable gums

The extraction system carried out to obtain the mucilage was by maceration at room temperature for 72 hours. This system was selected after the evaluation of the kinematic viscosity (η) at different temperatures and times (Medina, Carrascosa & Osete, 2022). The fragments and cladodes were collected from mature and healthy plants. Immediately upon collection, they were washed, de-thorned and peeled, using deionized water in a 1:1 (v/v) ratio for wood processing. Once the mucilage or gums were obtained, they were applied with their mother concentration, which we refer to as 100% and also at other dilutions: 75% and 50%.

3.1.3. Prepared test tubes

The specimens made of raw earth are grouped into three groups: the reference group (REF), the HUA group, and the group AUS in the proportions: 50, 75 and 100% (Table 2).

4. Instrumentation and evaluation tests

4.1. The earthy material intended for study

4.1.1. Granulometric study

The commercial tuff used had to be sieved to reach a maximum particle size of 2 mm, according to the characteristics of *chocoto* earth.

The granulometric study consists of separating the material into granulometric fractions by means of a series of sieves and their quantification by weighing. For this purpose, a total of 11 test sieves were used that meet the specific regulations for this purpose (Standards: EN 933-2, ISO 3310-1 and ISO 3310-2).

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Table 2 – *Test tubes studied* (Medina, 2024).

Group	Subgroups	Acronym
1	Raw earth rich mixed with water	REF
2	Raw earth rich mixed with mucilage from Opuntia huajuapensis (Bravo), diluted 50% in water	HUA50
	Raw earth mixed with mucilage from Opuntia huajuapensis (Bravo), diluted 75% in water	HUA75
	Raw soil mixed with mucilage from Opuntia huajuapensis (Bravo), obtained directly from the maceration 1:1 (w/w)	HUA100
3	Raw earth mixed with mucilage from *Austrocylindropuntia subulata* (Mühlenpfordt) Backeb., diluted 50% in water	AUS50
	Raw earth rich mixed with mucilage from *Austrocylindropuntia subulata* (Mühlenpfordt) Backeb., diluted 75% in water	AUS75
	Raw earth rich mixed with mucilage from *Austrocylindropuntia subulata* (Mühlenpfordt) Backeb., obtained from the mash 1:1 (w/w)	AUS100

The mass of the particles retained in each of the sieves is represented as a percentage of the initial mass used. The values are obtained following the following formula where:

$$y = 100\sqrt{t/D} \quad (1)$$

y = Represents the percentage that passes through the sieve of diameter t; t = It is the opening of the sieve and D = Maximum aggregate size.

These values are represented graphically to obtain the corresponding granulometric curve of the material.

4.1.2. Plasticity test

It consists of a very simple test that determines the quality of the earthy material, classifying it according to its properties in clay, sandy or clay-sandy earth. To carry it out, the material is moistened and molded into a cylinder with a diameter of 1.5 cm. It is then held in the air and the length of the detached fragment is measured. According to the length obtained, the material is classified into: sandy: 0 - 5 cm, sandy-clay: 5 - 15 cm and clay: 15 cm or more. For this study, three cylinders were made with different proportions of clay and volcanic earth: 1:2, 1:3 and 1:4 (v:v).

4.1.3. Dry strength test

It consisted of making a series of earth discs 3 cm in diameter and 1.5 cm thick. These were dried for 48 hours and subsequently broken manually to qualitatively estimate their fracture resistance. 5 discs were made in two different proportions of clay and volcanic earth: 1:2 and 1:3 (v:v).

4.2. Evaluation of the mechanical properties of earth blocks with and without the addition of mucilage

4.2.1. Determination of adhesion resistance

This laboratory test can evaluate the adhesive strength between earth test tubes with and without additives on different substrates: fired brick, raw earth and stone. In the following figure (Fig. 1) you can see the appearance of the test specimens.

Fig. 1 – *Specimens made on raw earth supports.* (Medina, 2024).

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Table 3 – *Fractions collected in each of the sieves* (Medina, 2024).

Sieve	Retained weight	% Retained	% Retained Accumulated	% Passing	% Fuller
64	0,00	0,00	0,00	100,00%	100,00%
32	0,00	0,00	0,00	100,00%	100,00%
16	0,00	0,00	0,00	100,00%	100,00%
8	0,00	0,00	0,00	100,00%	70,71%
4	0,00	0,00	0,00	100,00%	50,00%
2	347,60	63,52	63,65%	36,35%	35,36%
1	126,10	23,09	86,74%	13,26%	25,00%
0,5	32,70	5,99	92,73%	7,27%	17,68%
0,25	12,40	2,64	97,16%	4,63%	12,50%
0,125	9,80	1,79	98,57%	2,84%	8,84%
0,063	7,70	1,41	99,84%	1,43%	6,27%
Tray	6,90	1,26		0,16%	0,00%
Final weight	545,20				
Initial weight	546,10				

To carry out the test, a layer of raw earth 1 cm thick was applied to each support and given a circular shape 5 cm in diameter. After drying, a 5 cm diameter metal disc or pad is adhered to the layer of earth using an epoxy resin. After the resin has cured, the disc is coupled to a Neurtek Instruments KN-10 adhesion meter with which a traction force is applied. This test ends at the moment in which the clay specimen detaches from the surface or fragments, recording the force used for this (kilograms of force) and the type of breakage: adhesive or cohesive, according to the specifications of the UNE-EN 1015-12:2016 regulations. The results are obtained using the following formula:

$$fu=Fu/A \quad (2)$$

Where the adhesion resistance (fu) is achieved through the relationship between the recorded breaking load (Fu) and the surface area (A), being expressed in Mpa.

5. Results and discussion

5.1. Granulometric study

As can be seen in Table 3, from the 8 mm sieve, 70% of the total screened weight is counted, approximately 50% and 35% in the 4 and 2 mm sieves respectively. 25% of the particles are concentrated on the 1 mm mesh sieve. The following apertures corresponding to 0.5 mm, 0.25 mm, 0.125 mm and 0.063 mm collect 17.68, 12.5, 8.84 and 6.27% respectively. The sum of these percentages results in a granulometric modulation of 6.341%.

Figure 2 represents the granulometric distribution obtained for the tuff compared to the Fuller adjustment, which corresponds to an optimal granulometry to achieve greater compaction of the material, with a continuous distribution of particle sizes.

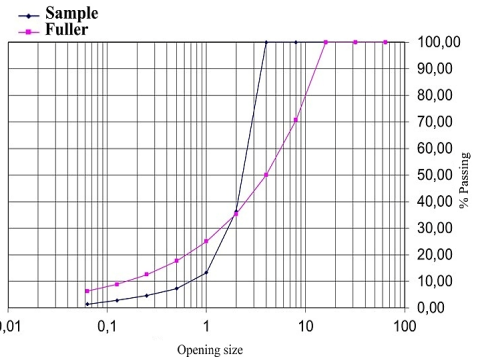

Fig. 2 – *Distribution of the granulometry of the tuff to be experimented and comparison with the Fuller adjustment* (Medina, 2024).

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As can be seen, the analysis indicates that the granulometry of the tuff sample does not fit perfectly to the Fuller model. These imbalances indicate that the tuff is deficient in fines (clay), so the incorporation of these is necessary to achieve greater compaction of the material. Between 0.5 mm and 2 mm, the sample curve and the Fuller curve are quite similar, which indicates that in this fraction the material has a granulometric distribution closer to the theoretical model. From 2 mm to approximately 4 mm, the sample follows the trend of the Fuller curve relatively well, although with slight deviations.

5.2. Plasticity test

The results obtained from the cylinder corresponding to the 1:3 ratio (clay-tuff), were located between the clay and clay-sandy ranges, obtaining measurements between 14 and 15 cm. For the 1:2 ratio (clay-tuff), measurements greater than 16 cm were obtained, corresponding to a clay earth and in the 1:4 ratio (clay-tuff), within the sandy values.

5.3. Dry strength test

The discs could not be pulverized with fingers. It was also difficult to break them with one hand. Therefore, according to earth selection manuals (Morales et al., 1993 and Minke, 2008), they could respond to a medium-high resistance. This type of behavior would respond to the clay character of the earth. Regarding the proportions studied: 1:2 and 1:3 (clay:tuff), no appreciable differences have been found in terms of their dry mechanical behavior.

5.4. Determination of adhesion resistance

5.4.1. Adhesion on fired brick support

The results obtained on this support were previously published along with other trials (Medina & Carrascosa, 2022). However, to facilitate comparison with other media, the data recorded at the time is presented again below. The following graph (Fig. 3) represents the values in Mpa of three independent tests carried out for each of the material types. As seems to be characteristic of this type of tested gums (Medina & Carrascosa, 2022; Medina et al., 2022), the results are very heterogeneous. Furthermore, the adhesion levels recorded are so weak that some test tubes do not reach the minimal sticking values (less than 0.05 Mpa).

The highest levels (0.06 MPa) correspond to both test tubes without mucilage (REF-1A) and other test tubes with different percentages, being: HUA100-2A, AUS50-3A, AUS75-1A and AUS100-3A. Regarding the lowest records, they are recorded for the test pieces: HUA100-2A, AUS50-1A and 2A and AUS100-1A. It should be noted that the most homogeneous behavior was that observed for the AUS50 specimens, which would indicate that the presence of 50% mucilage helps to homogenize the mechanical behavior of the material.

The type of breakage observed in all cases was cohesive failure, which consisted of the separation of the earth disks from the brick support, leaving remains of the earth mortars in the incisions of the latter. The specimens that left the most remains (the circumference of the discs is perfectly drawn) on the brick support were: the REF, AUS50 and AUS75 subgroups. With a more discontinuous shape, it is followed by HUA75 and AUS100. Regarding the HUA100 subgroup, specimens 1 and 3 leave very few remains, barely drawing the circumference and leaving few remains in the incisions of the brick. On the other hand, in test tube 2, traces of earth remain in all the incisions and the circumference of loose earth is perfectly drawn. Finally, the HUA50 subgroup is the one with the least traces of earth on the support.

5.4.2. Adhesion on raw earth support

In this case, a superficial breakage of the raw earth support occurs, even in the reference specimens. Furthermore, in the latter (REF-1A, 2A and 3A), they did not register any adhesion

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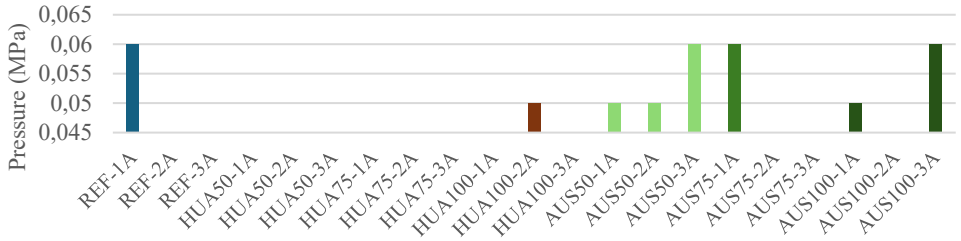

Fig. 3 – *Results obtained from adhesion resistance on fired brick support* (O. Medina, 2024).

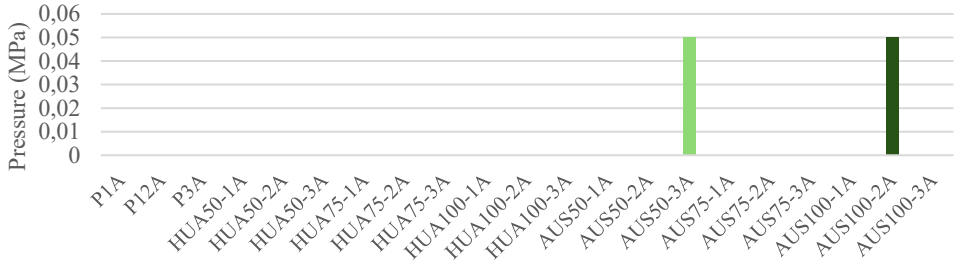

Fig. 4 – *Results obtained on the adobe support* (Medina, 2024).

strength, like the HUA family, made with the mucilage of the *Opuntia Huajuapensis* (Bravo) cactus. Strength values could only be recorded for two specimens of the *Austrocylindroopuntia subulata* (AUS) family: one made with 50% mucilage (AUS50-3) and another made with 100% mucilage (AUS100-2), both with 0.05 MPa (Fig. 4). The breaks observed correspond to superficial failures of the substrate, that is, the earthy support, without notable distinctions between the experienced groups.

5.4.3. Adhesion on raw earth support with a layer of mucilage

The incorporation of a layer of mucilage prior to placing the specimens on the surface of raw earth does not reveal significant changes either, as seen in Figure 5. Some values are recorded for two of the families studied and also in the reference specimens. In the latter, the REF-2A specimen reaches 0.05 MPa, compared to 0.06 MPa in HUA75-2A (*Opuntia huajuapensis*) and AUS75-3A (*Austrocylindropuntia subulata*). Both records coincide in the concentration of mucilage, being 75%. But like the previous case, the mortar-support adhesion values obtained must be higher than those recorded. This is because the support fails in the vast majority of discs, with the exception of the test specimens: HUA100-2, AUS100-2. HUA50-1 and REF-1, which could be considered 100% adhesive failures. The support failure occurs 100% in the specimens: AUS75-1, HUA75-1, 2 and 3 and REF-3. At 75% in the test pieces: AUS100-1 and 2 and AUS50-1. At 50% in the specimens: AUS100-3 and AUS75-2 and 3. For the rest of the specimens, the percentage of earth support removed after the test does not exceed 20%, so these breaks in the support make it impossible to know the exact results of adhesion resistance.

5.4.4. Adhesion on stone support

On a stone support, differences can be seen with respect to the other supports, since for the reference specimens (REF) no values are recorded in the equipment (indicative of a resistance lower than the minimum: 0.05 Mpa),

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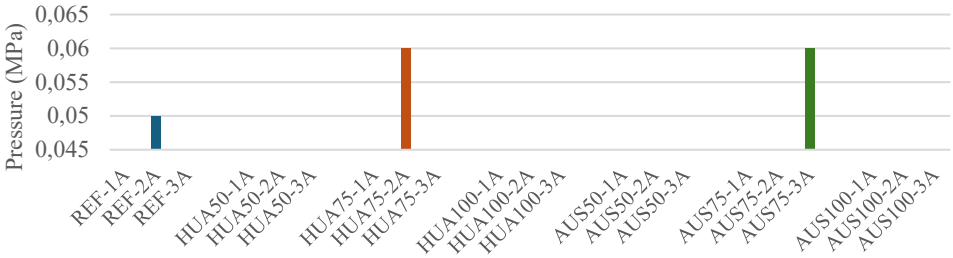

Fig. 5 – *Results obtained on the adobe support with an intermediate layer of mucilage* (Medina, 2024).

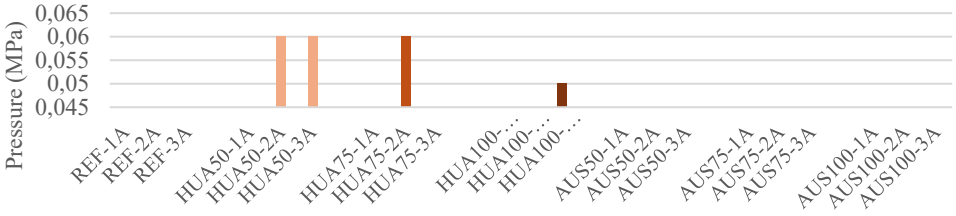

Fig. 6 – *Results obtained on stone support with a layer of mucilage* (Medina, 2024).

while for the specimens made with one of the mucilage families (HUA) numerical values of adhesion resistance have been recorded (Figure 6). In this case, two specimens at 50% (HUA50-2A and 3A) and one at 75% (HUA75-2A) are the ones that show superior resistance results (0.0.6 MPa) and HUA100-3A, the one with the lowest value (0.05 MPa). This suggests an increase in the internal cohesion of the material associated with the presence of mucilage. Regarding the separation of the clay discs from the support, some earthy particles from the discs can be seen in the latter, while in the mortar some whitish particles from the surface of the stone material can be identified.

6. Conclusions

The results obtained reflect the complexity of the interaction between plant stabilizers and the different supports analyzed. In general, the adhesion resistance of raw earth mortars added with mucilage has been low in all tests, although certain patterns have been identified that allow relevant conclusions to be drawn:

- Influence of the granulometry and plasticity of the material: The volcanic tuff used does not completely fit Fuller's theoretical model, which could have affected the cohesion and compaction of the material. However, the plasticity tests show that the 1:3 ratio (clay-tuff) presented intermediate values between clay and clay-sandy plasticity, suggesting that this ratio could optimize the workability of the mortar.
- Mechanical behavior of dry mortars: The mortar discs demonstrated a medium-high dry strength, without significant differences between the proportions of clay evaluated. This suggests that the cohesion of the material depends to a greater extent on the granulometric composition and the drying process than on the type of stabilizer added.
- Adhesion resistance on different supports, Burnt brick: The highest adhesion values were obtained compared to other supports, although the results were heterogeneous. The breaks were cohesive, in the brick and stone supports,

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which indicates that the internal resistance of the mortar is lower than its adhesion capacity to the support.

- Adhesion resistance on different supports, Raw earth: Adhesion was significantly lower and no resistance values were recorded in most of the specimens, except in some formulations with Austrocylindropuntia subulata, which could suggest a slight improvement in the internal cohesion of the mortar. In this case, the earth support has few remains of the mortar, and the mortar has superficial remains of the stone support attached.
- Adhesion resistance on different supports, Stone: Only mortars with Opuntia huajuapensis showed measurable adhesion values, although these were very low. With the incorporation of a layer of mucilage, no significant improvements in adhesion were observed, although the specimens with a concentration of 75% of mucilage recorded slightly higher values.

Regarding the effects of mucilage on adhesion, although previous studies have pointed out the stabilizing potential of cacti mucilage, in this work its effect on adhesion has been limited and highly variable.

It was observed that the specimens with 50% mucilage showed a more homogeneous behavior, which suggests that this concentration could favor a better distribution of the stabilizer within the mortar.

7. Final considerations

The results suggest that, although mucilages from *Opuntia huajuapensis* and *Austrocylindropuntia subulata* can influence some properties of raw earth mortars, their effect on adhesion is limited. The variability in the results can be influenced by factors such as the heterogeneity of the material, the texture of the supports and the variability in the collection and processing of mucilage.

To improve the effectiveness of these stabilizers, it is recommended to carry out additional studies by adjusting the granulometric composition of the mortar and exploring other application methods.

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Preservation of Earthen Architecture in Spanish Archaeological Sites: Proposals for a Sustainable Action Diagram

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Abstract

Throughout history, the conservation of architectural structures for cultural reuse in archaeological sites has been a complex exercise in decision-making based on multiple factors, including construction, state of conservation, and sociocultural and socioeconomic context of the time. When structures classed as earthen architecture, less known and more vulnerable to degradation agents, are to be intervened these difficulties have traditionally increased. These complications also occur when the intervention is approached from the angle of sustainability. Accordingly, there is a vast spectrum of solutions in the architectural panorama conserved, potentially causing confusion to visitors and in the process for the selection of technical interventions. This paper aims to examine structured decision-making for conservation actions, using a database of 85 archaeological sites in Spain, with earthen architecture in varying degrees of exposure, applying sustainability parameters for recently identified heritage. Thus, a practical diagram or matrix can be offered to provide a clear vision focusing on the different aspects of sustainability, as well as recommendations on the different starting points for conservation.

Keywords: *heritage; archaeology; cob; adobe; rammed earth; traditional construction*

1. Introduction

The conservation and enhancement of archaeological sites has traditionally been highly complex given the fragile and heterogeneous nature of excavated remains, and the desire to transmit knowledge to the viewers, requiring multidisciplinary action projects. However, earthen architecture is the most affected by degradation due to its material characteristics and the absence of social awareness and recognition by citizens and professionals.

In recent years, the scientific community, both national and international, has gone to great lengths to identify this type of architecture correctly (Knoll et al., 2019; Lorenzon et al., 2020; Sénépart et al., 2016) and to preserve it (Daneels & Guerrero Baca, 2015; Gandraeu & Sandozai, 2014; Soria López & Guerrero Baca, 2016). This is not without its share of challenging issues, as the conservation of earthen architecture often involves navigating complex technical dilemmas.

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The matters addressed and discussed include the acceptable limits of invasion when planning the preservation of earthen architecture (Mileto & Vegas, 2017), and good practices for identification, documentation, and immediate preservation, both following excavation (Arjonilla Álvarez et al., 2024; Pastor Quiles, 2017) and in the long term (Cooke, 2010). However, this valorization process is long-standing and has caused conflict from the point of view of the conservator, trapped between retaining authenticity and the lack of maintenance. In view of this problem, in addition to the recent interest in this type of architecture and the availability of numerous systems, a high degree of heterogeneity has been observed in recent years (Manzano-Fernández, Mileto, et al., 2024b), not only in enclaves, but in earthen structures conserved in situ in a single site.

In the field of sustainability, recent research focusing on vernacular architectural heritage has highlighted the importance of the environmental, sociocultural and socioeconomic aspects (Correia et al., 2014). At an archaeological level, these factors have a specific application (Manzano-Fernández, Vegas López-Manzanares, et al., 2024) and are of particular interest for the cultural transmission of the construction cultures of past societies to the wider public, without compromising the structural stability and volumetric integrity for future research. Quite frequently, these aspects can be compromised when satisfying the demands for preventing the effects of natural degradation agents. For example, when the remains have lost their original protections, additional difficulties arise in the design of solutions.

Nevertheless, some general guidelines can be established for individual interventions even though the decision-making process will always need to follow a detailed and validated project combining specific conditioning factors and particularities for each archaeological site (Gandreau, 2017). This article aims to simplify the process for selecting actions among those currently available after excavation, using a common matrix to combine factors driving pragmatic decision-making, while taking into account sustainable adaptation, current degradations, and degree of intensity.

2. Methodology

This research is based on the reflections upon the examination of numerous case studies affected by these problems in the territory, and on the application of contemporary sustainability definitions to vernacular architectural heritage.

2.1. Case studies

The state of conservation, degree of sustainability, and interventions of up to 85 case studies in Spain have been examined as a result of observation and in situ data collection (Fig. 1). The archaeological structures executed using different earthen construction techniques and conserved in situ with varying degrees of degradation and invasive actions were selected and featured as case studies. These therefore include domestic, productive and funerary typologies, mostly dating from the period from protohistory to Roman times, although some cases from prehistory and the Middle Ages are also included (Manzano-Fernández, Mileto, et al., 2024c).

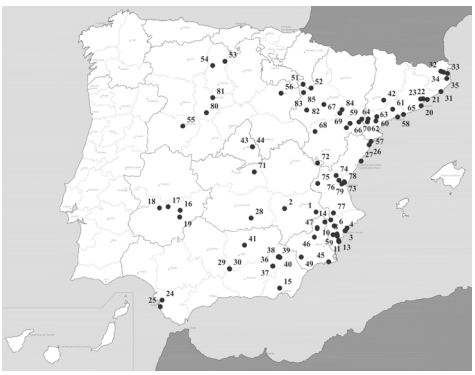

Fig. 1 – *Case studies used for laboratory and field data collection.*

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Field data collection was conducted using an organized fiche, database management software, and GIS environments, in order to statistically discriminate the values of interest to the study. The research group's background and experience in developing restoration projects in recent years for earthen structures have also made a major contribution to the classification of the various intervention projects.

2.1.1. Sustainability: decisions and criteria

As a result of previous research, both completed and in process, by the authors (Manzano-Fernández, Vegas López-Manzanares, et al., 2024) the degree of suitable compatibility for the different conservation interventions has been incorporated. Thanks to this analysis new links to the effects of degradation are identified in order to generate a useful, practical, and visual decision-making matrix.

This compatibility has been considered in relation to the three dimensions of sustainability for architectural heritage (environmental, sociocultural, and socioeconomic) (Correia et al., 2014) and adapted to the archaeological context. Thus, residential factors such as suitable location, contributions to quality of life, the reduction of natural threats, the promotion of autonomy, and the optimization of construction efforts have been ignored. At the same time, factors relating to cultural use, including the case of the use of compatible and local materials, resource saving, useful life, landscape protection, intangible values, and building cultures, and the promotion of local activities, have become more prominent.

3. Results

3.1. Preventive conservation and maintenance

While preventive maintenance and conservation are difficult to apply in these enclaves – primarily for socioeconomic reasons – these must be recommended to limit damage, so that less invasive interventions, guaranteeing the preservation of authenticity, are required in turn. Thus, suitable ventilation of structures, superficial sloping (Gandreau, 2017) drainage systems, and deeper ones for more severe cases, will minimize the impact of damp and efflorescence. This is also the case of the undermining of the lower sections of walls in more advanced phases, as these measures will also reduce resistance in these sections. Equally, carefully considered manual clearing, without pulling out roots violently, will prevent uncontrolled growth of vegetation. Plague control, for instance against potter wasps, beetles and spiders, will reduce the appearance of holes on the surface, also hindering the entry of new degradation agents. On a structural level, the monitoring of cracks and fissures is especially important in all phases, ensuring swift and suitable decision-making when these are active, and thus require the remains to be stapled and stabilized.

Although most of these actions are considered highly sustainable, the use of invasive mechanical means for clearing and uprooting plants, the application of render with a high hydraulic lime or cement content to cover damp, the installation of drainage damaging facings without reasonable benefits (Bendakir, 2009), or the use of aggressive biocides to control plants and insects, can generate new pathologies in the structures. This entails a low level of sustainability.

3.2. Backfilling

Backfilling is presented as a strategy of interest for any state of conservation in which the surface lies exposed and unprotected from degradation agents, except in the case of capillarity and structural problems. This makes it an extremely popular choice for cases in which the integrity of constructions is to be prioritized. Nevertheless, it must be combined with good execution practices such as the use of fine gravel or clean sand to prevent roots from growing, infill using local earth (avoiding the surface layer, which has a greater proportion of organic waste), and

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separation using geotextiles (preferably 300 g/m^2) or other resistant and waterproof fabrics. If necessary, separate rustproof metal mesh can be incorporated to control burrows and rabbits (Arjonilla Álvarez et al., 2024).

However, this system cannot be considered highly sustainable, as weight on the geotextiles inevitably causes stress on the structure (particularly at the corners), potentially deforming them in time. At the same time, sociocultural risks are increased if they are no longer visible (Fig. 2), which in turn leads to an underrepresentation of the system.

Fig. 2 – *Backfilling of earthen structures at the Mas Castellar, Pontós (Girona, Spain).*

3.3. Consolidation, chemical treatments, encapsulation and restoration

Once the loss of material has been confirmed, the extent of invasive conservation is highly variable. Firstly, consolidation uses materials analogous to the original ones (Fig. 3), while the use of chemical treatments such as ethyl silicate or nanosilica solutions can halt slight surface erosion, render losses, water runoffs or small holes. This is considered to provide a high level of sustainability for the mortars, but a medium level in terms of the irreversibility of the treatments. The level of sustainability can be reduced to low if resins or acrylic emulsions that can alter colours or the level of breathability, among other factors, are used (Chiari, 1990; Martín Peinado, 2014).

Fig. 3 – *Consolidation of damages in Cancho Roano, Zalamea de la Serena (Badajoz, Spain).*

In cases of greater loss, or where protection is required, structural encapsulation (Fig. 4) is a common practice. Although the application of this sacrifice layer may be compatible, it can have a serious impact on the appearance of the structure, homogenizing its characteristics and reducing the wealth of constructions of this type of architecture in the area. In these cases the degree of sustainability is considered to be medium-low.

Fig. 4 – *Damaged encapsulation of an earthen structure at the Tos Pelat, Moncada (Valencia, Spain).*

Any structures which have lost considerable volume from their section, endangering their stability, may be candidates for restoration interventions. These must prioritize the use of analogous materials and the reproduction of original construction techniques whenever possible.

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If cement-lime mortar or hydraulic lime is used for any of the solutions, jeopardizing their compatibility by increasing rigidity and breathability, the level of sustainability will be considered low.

3.4. In situ and ex situ reconstruction

The reconstruction of remains (Fig. 5) must be subject to specific conditions of substantial loss. Given their impact, it is possible to consider an ex situ representation using highly sustainable original techniques, and contributing to dissemination. However, while ex situ techniques reproduce the original materiality, they noticeably alter the remains. This leads to a medium level of sustainability, which in turn increases the risk of potential falsification through dissemination of imprecise signposting. In any case, ex situ and in situ reproductions using incompatible modern materials are considered to display a low degree of sustainability.

Fig. 5 – *In situ reconstruction of lost adobes at La Mata, Campanario (Badajoz, Spain).*

3.5. Capping, coverings, buildings and relocations

If the structure of the remains is sufficiently stable, coverings are a common solution, making it easier to preserve their authenticity. In its most basic expression, capping (or protection of the crowning) is minimally invasive, although the use of materials which visually alter the whole can reduce associated cultural sustainability.

Offering a higher degree of protection it is possible to propose the installation of permanent partial or full coverings. These allow the original architecture to be read while offering shade and protection from rain, albeit shifting the focus of interest. In the more complete versions, including side closures, this limits touching or trampling by visitors and local fauna, but so strips the elements of context, reducing them to museum pieces.

In compact locations or specific buildings it is possible to install large-scale roofs with a great impact on the landscape (Fig. 6), even executing container buildings for the remains, totally reducing the effect of agents such as rain or wind, but occasionally increasing damp and condensation if proper ventilation is not planned. This balanced proposal, halfway between benefits and drawbacks, earns a classification of medium sustainability.

Fig. 6 – *High-impact permanent shelter for the protection of earthen structures at Lepida Celsa, Velilla de Ebro (Zaragoza, Spain).*

On occasion, the structures can be moved from their original location. These interventions vary in suitability and are an acceptable response to a move to an adjoining place on a piece-by-piece basis to ensure safety from the threat of destruction. This is more harmful in cases, such as a move to a museum, where context is completely lost, ultimately leading to a disconnection between the remains, their original environment and their historical significance.

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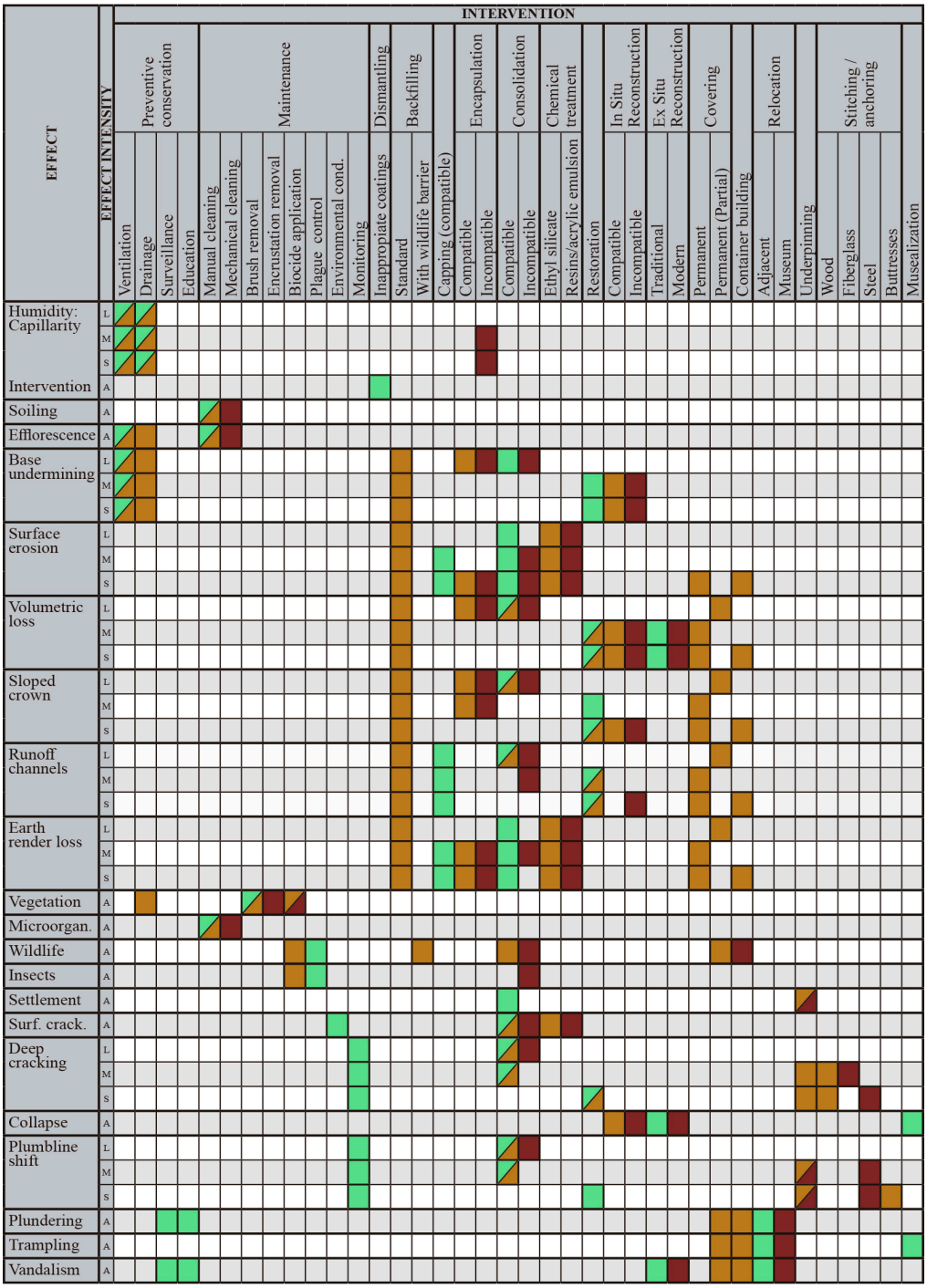

Fig. 7 – *Decision-making matrix based on damage intensity (L = low, M = moderate, S = severe) and sustainable contribution (■ = high; ■ = medium; ■ = low).*

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3.6. Structural interventions

Structural damage usually requires a more invasive intervention, seeking to definitively stabilize the elements, except in cases of consolidation due to surface fissuring.

Anchoring due to severe cracks is usually carried out by stapling sections. It can be made more sustainable by using wooden pieces or stakes and similar mortar, or more invasive by using fibreglass rods or metal elements. In the case of collapses or differential settlements it is necessary to assess the suitability and scope of an underpinning action, as well as potentially stabilizing with compatible buttresses. These interventions inevitably entail a medium-low level of sustainability depending on different needs. In cases of complete collapse ex situ didactic reconstructions are usually carried out.

3.7. Musealization and education

Finally, interventions of a social nature should be examined for the cultural use of the site, contemplating actions for musealization, signage, and definition of routes to prevent accidental trampling of structures and guarantee a suitable transmission of knowledge (Manzano-Fernández, Mileto, et al., 2024a).

Furthermore, the population and professionals must be involved in education and training tasks in order to limit vandalism and looting, which can ultimately harm the survival of the remains.

4. Conclusion

Sustainable intervention in archaeological sites currently constitutes a problem, given the high number of threats and solutions available. Reflection on the degree of invasiveness during the decision-making process, taking into consideration the severity of the damage, is crucial to ensuring minimal intervention and to guaranteeing the transmission of constructive and ethnological knowledge to visitors and future researchers.

This decision-making matrix is intended as an auxiliary tool which can summarize the known spectrum, facilitating an optimal response to suit different needs.

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Raw Earth Construction and Restoration Technique: Experimental Protocol and Interventions in the Historic Village of Al Jazeera Al Hamra (United Arab Emirates)

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Abstract

The evolving relationship between contemporary practice and inherited structures necessitates sustainable strategies for the preservation and reinforcement of heritage assets, safeguarding their functionality over time. This study investigates the mechanical properties of traditional and innovative mortar-based materials for the repair of architectural elements, with a particular focus on artistic stuccoes and decorative features. The research aims to reduce their vulnerability to environmental, seismic, and anthropogenic factors, including pollution and climate change, which accelerate material degradation and ageing. The mix designs of artificial stone materials appropriate for the proposed strategies make use of natural rocks (e.g., limestone, alabastrine gypsum) and different constituents (e.g., vegetable sisal fibres, siliceous/siliceous-aluminous pozzolana); innovative raw earth-based mortars are also studied for plastering, rendering and repair of earthen buildings. In particular, a minimum of three specimens for each mix design will be tested through flexural mechanical tests in an undergoing phase of the research and using a displacement-controlled testing machine, following a standardised protocol –scientifically recognised at an European level– specifically developed for mortars (elements that exhibit material affinity with the interventions addressed in this study). The results will then be comparatively assessed, considering not only the structural performance but also the material compatibility for potential field applications. Finally, with reference to a case study, a design approach is presented allowing for interventions on existing structures and the creation of new architectural shapes in an intimate, seamless dialogue: emblematic –following the example of San Francesco di Assisi– of an essentiality able of communicate with clarity and power.

Keywords: *earthen architecture; vernacular architecture; restoration; raw earth materials; reuse*

1. Introduction

'Blemishes', 'adiposities', 'scars', are only some of the imperfections and unsightly effects which heritage buildings may get under or on their 'skin'. Appearances of the passage of time and how it transforms each character of an architecture, regarded as a living organism, constantly evolving: materials, safety of structures, functions, socio-cultural role etc. In

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the historical-social contexts these issues concern not only the buildings themselves but also their decorative apparatus, in general really fragile (Belardi et al., 2022). Similarly, indeed, the environmental factors determine the occurrence of material degradation phenomena on these art works, an action that is accelerated in case of climate change effect or in presence of extreme events like earthquakes, with tragic consequences beside the material aspect. To this the responsibility of man must be added. It proves to be reckless, when an artefact lacks maintenance, and criminal, referring to the destruction of cultural identities during wars.

1.1. Objectives and methodology

In the first part of the paper the degradation phenomena common in heritage are briefly described in order to underline the essential relations between the material features, physical breakdown and construction techniques in mortar-like and earthen materials. In particular, the dissertation is referred to an assessment of the state of conservation conducted by the Authors on a case study, part of valuable heritage settlement in the United Arab Emirates (UAE). A site anciently inhabited by fishers and pearl divers characterized by its earthen architectures in *shell*-based and unfired earth blocks and named Hamra Old Village in Ras Al Khaimah. Then, the analysis of the state of these deteriorating structures and the selection of strategies to be used in structural repair are discussed with reference to the recent restoration works and to the development of an experimental campaign –still ongoing– aimed at the optimization of materials and restoration techniques involved. More in detail, a standardised protocol, scientifically recognised at a European level (British Standards Institution. 2019), will be adopted that is specifically aimed for mortars characterization, intended as elements that exhibit full material affinity with the types of interventions object of the present research.

2. Material degradation

As the construction site ends, all buildings suffer of physical breakdown, decay and disintegration of materials' molecules into smaller molecules or fragments. Degradation can be initiated by external influences such as heat, moisture, chemicals, exposure to UV light, fungi or bacteria –only to mention some– and is enhanced by mechanical stress, due for example to earthquakes action (El-Gohary, 2017). The distinction to be made, from a phenomenological point of view, can be summarised as follows:

- alteration, a change that has occurred in a material that –while changing some of its characteristics– does not necessarily undermine its conservation;
- degradation, a gradual and irreversible process that leads an architectural or structural element to lose its characteristics of shape, colour, resistance, reliability and durability, until it becomes unfit for the original function.

The alterations are most of times physiological, they do not necessarily compromise the architectural-structural features of an artefact but can sometimes emphasise its expressive potential. Instead, interventions are only mandatory when past or ongoing degradation phenomena caused irreversible damages that undermines the material properties. The complex interplay between these factors must be analysed critically and in the big picture by designers in the heritage conservation field.

In general, the deterioration of architectural surfaces is regulated according to UNI 11182:2006 (Ente Italiano di Normazione, 2006), which aims to recognise and classify the forms of decay of different stone materials, which can be divided into two macro-categories:

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- natural e.g., rocks such as marble, limestone, granite, sandstone, onyx, alabaster, porphyry, gneiss, etc;
- artificial i.e. elements, often multi-phase, obtained by man through chemical-physical processes from natural stone materials e.g., concrete, stuccoes, ceramics, bricks, bedding mortars, plasters, etc.

The present contribution is focused on the study of the second category of materials, especially the ones aimed at the heritage decorative apparatus realization: e.g., stuccoes, plasters, bas-reliefs etc. From and historical-iconographical research emerges how, although the use of various natural additives (Ronca, 2024; Moropoulou et al., 2005) of plant –e.g., hemp, flax, broom– or animal origin –e.g., casein, animal gelatines, egg yolk– can be observed in ancient stuccoes, the most recurring matrices are undoubtedly hydraulic lime and gypsum (Moropoulou et al., 2005). This applies for the western world. Instead, in the Middle East raw earth-based materials are used for the same purposes since ancient times (Biscontin et al., 2021; Gomes et al., 2019). Raw earth, also in combination with other sustainable materials (e.g. canvas, straw, rice husk, etc.), can indeed be used in the form of plaster, earthenware and bricks for new constructions, restoration and finishing interventions. Furthermore, the possibilities of uses of different soils, as well as the installation procedures are many: starting from the traditional construction techniques as adobe (i.e., compressed earth blocks dried in the sun), rammed earth in the form of cob (i.e., subsoils built wet) or earthbags and superadobe (i.e., sturdy sacks filled with organic material usually available on site), GREB (i.e., combination of a wooden structure, straw bale insulation and cast plaster) and contemporary technologies as 3D printing. In addition, earthen structures need a fraction of the energy required to manufacture and process an equivalent amount of ordinary bricks or concrete elements (low embodied energy), require lower carbon emissions for construction (low carbon footprint) and consume less operational energy than conventional structures (high energy efficiency). Based on previous experiences of the Authors (Cluni et al., 2023) in the field and in light of the above reasons, this type of materials was included in the present research.

3. The case study

Al Jazeera Al Hamra (in Arabic الجزيرة الحمراء, meaning in English the Red Island) is a former coastal village in southern Ras Al Khaimah Goulf region that was abandoned at the time of the formation of the UAE (United Arab Emirates) in the late 1960s and 1970s (Schofield, 1990; Heard-Bey, 2005). Once an active fishing and pearl diving community it is considered one of the last traditional towns in the country and actually consists of a fort (*hisn*), several mosques, a market (*souq*), a wind tower home and over 100 houses. The buildings were made with traditional techniques using local materials. Its masonries are composed of various lithologies. Uncut blocks of coral stone; natural sedimentary rocks primarily composed of sand from coral, shells, and other marine organisms; and cobbles of 'fossilised' beach rocks; limestones with carbonate remains of fossils; and mortars and plasters made in raw earth (Fig. 1).

Moreover, mangrove tree beams, date palm trunks, matting, ropes and layers of seashells for drainage were used in the roofs realization. At the turn of the century, the village comprised about 500 houses and was occupied by the *Zaab* tribe. Sheikh Rajib bin Ahmed Al Zaabi, the ruler of Jazeera Al Hamra in 1820, was one of four independent signatories to the original 1820 treaty between the Trucial States and the British following the battle at *Dhayah* Fort in 1819 (Schofield, 1990; Heard-Bey, 2005). In that time, it was a tidal island split into two parts, the smaller northern quarter of *Umm Awaimir*

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Fig. 1 – *Al Jazeera Al Hamra Heritage Village. One of the houses object of the research. In the close-ups respectively the coral stones, the raw earth plaster, the earth-based mortar and the beach 'fossilized' rocks.*

and the southern quarter of *Manakh*. The *Zaab* tribe maintained a fleet of 25 pearling boats and tended some 500 sheep and 150 cattle until the crash of the pearl fishing industry in the 1920s. Archaeologists have recorded the discovery of Al Jazeera Al Hamra's ancient mosque with 20-domes that is pictured on an 1820s British map. Narrow alleyways connected the houses to the *souq* and the village mosque. Plain and ornamental archways and other time-sensitive decorative elements and apparatus made in gypsum were discovered in the site.

Following an agreement between Sheikh Khalid bin Ahmad Al Qasimi of Sharjah and Sheikh Sultan bin Salim Al Qasimi of Ras Al Khaimah in 1914 the town became part of Ras Al Khaimah but was often in dispute with the Ruler. With the discovery of oil, these circumstances resulted in the majority of the tribe accepting an offer from Sheikh Zayed bin Sultan Al Nahyan to move to Abu Dhabi, the inhabitants left the Al Jazeera Al Hamra village between 1968 and 1971. This movement left behind an almost completely abandoned village which housed in the past 2,500 people (Schofield, 1990; Heard-Bey, 2005).

3.1. Actual state and interventions

Until 2024 a great amount of buildings was still in ruins, especially various former houses in which the symptoms of degradation manifested as a lack of maintenance (Fig. 2). Cracks in the raw earth plaster are observable and may be the result, during the decades, of evaporation of moisture from the masonry made in coral stone blocks and fossilised beach rocks, subject in addition to the actions of sun and wind which can cause map cracking or dry shrinkage cracks. Deeper damage patterns are related to the presence of openings, which weaken walls characterized by an irregular masonry texture in the aforementioned stone elements and natural lime or raw earth mortars. As a consequence, detachments of plaster occurred with, in some cases, the creation of gaps exposing the underlying masonry, made by porous materials, to the detrimental action of environmental factors. During last months, a lot of work was being undertaken by the UAE to valorise this old village. The original mosque is now fully restored with work continuing on many other buildings. While much remains in ruin, some construction sites finished this year, like the one involving the house critically analysed previously (Fig. 2).

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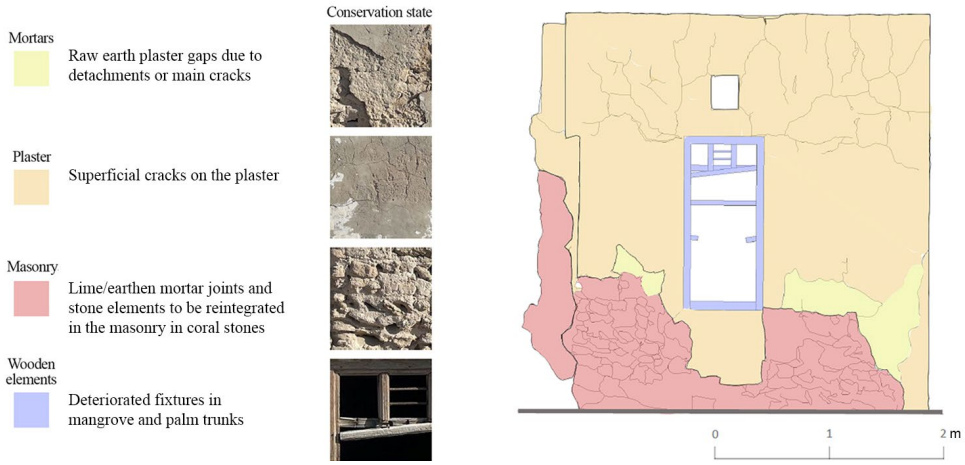

Fig. 2 – *Extract of the technical sheets designed for the deterioration analysis of the ancient houses.*

In addition, from January 31 to February 28 the village will host the 13th Annual Ras Al Khaimah Art Festival 2025 (founded in 2013). This edition of the festival celebrates the intricate beauty of 'memory' as its theme –as described by the says festival guest curator Alfio Tommasini– and exhibits contemporary installations like the one of the Italian artist Baldo Diodato, (Sheikh Saud bin Saqr Al Qasimi Foundation, 2024). The architectures were reused and the spaces repurposed in order to fit to the new functions required to a contemporary open-air museum (Fig. 3). Different interventions were done to restore to architectural surfaces and masonry elements the lost compactness and adhesion between individual layers, increasing their mechanical behaviour and safety. In addition, it is worth noting that the ruins were dignified through the realization of cappings and copings used to cap the tops of masonry parapets and freestanding walls in order to prevent rainwater from penetrating into the constructions below (Fig. 3).

This approach, common in archaeological sites, is now becoming increasingly frequent also as a first aid intervention in disasters and armed conflict areas. This methodological experimentalism of protection and valorisation that, along with the aforementioned activities (Cluni et al., 2023), offered promising outcomes; encouraging the Authors to deepen the research and to conduct an experimental

Fig. 3 – *Pictures taken after the interventions of reuse in contemporary open-air exhibition space. In the first photo, the cappings realized in earth-based mortars, for the protection of the masonry constructions below.*

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campaign on raw earth and mortar-like materials for natural, compatible and reversible interventions on heritage architectures.

4. The experimental campaign

There are no construction standards regulating the realization, repair and restoration of decorative apparatus in stuccoes or precious plasters in raw earth. Consequently, remarking that these elements belong to the category of artificial stone materials, the Authors chose to conduct an experimental campaign according to European standard BSEN1015-11-2019 (British Standards Institution, 2019), which regulates the geometry, realization criteria and methods for the mechanical testing of mortars. An approach aimed at attributing repeatability and scientific rigour to the experimental campaign that, by way of comparison, will involve specimens with different mix designs. The mechanical tests will consist of a three-point bending test, which will be used to verify the elastic and post-peak behaviour of the specimens. More specifically, in a future perspective, at least three specimens for each category will be subjected to testing. The data acquired –including displacement, load, and damage evolution– will be evaluated with reference to all the samples, which differ solely in their mix design. Curing times, specimen geometry, and testing conditions will be kept consistent across all tests.

Each prism will be placed in a testing machine with one side facing the two support rollers – with a span of 10 cm– and with the longitudinal axis normal to the aforementioned constraints, Fig. 4. The load will then be applied vertically by means of the barycentre roller, the latter insists on the side face of the prism opposite to the supported one. The servo-hydraulic test machine in displacement control allows the load to be increased evenly and at a constant speed until the prototype breaks. Therefore, the trial can be carried out at a reduced and constant speed; a necessary condition at this juncture (for previous experience 0.1 mm per minute). The tests outcomes will be then evaluated in terms of maximum bending induced stress (f_{cf}) and critically analysed by comparing the different load-displacement histories and the emerging cracks initiation and propagation patterns.

4.1. The mortar-like prototypes

The experimental tests will be carried out on prismatic specimens with square base and measuring 16x4x4 cm. Historical mortars are composite materials formed by a binder (or mixture of bindings), a variety of inert materials (mostly a mixture of inorganic compounds, not always of crystalline nature) and some additives (sometimes of organic nature), added in proper quantities in order to reduce shrinkage cracking (e.g., natural fibres) or for the improvement of

Fig. 4 – *From the first picture, the red pozzolana is finely sifted both in the form of powder and of fine sand; the raw earth put in place wet and ambient cured in formworks, end of a test on a fine-grained (alabastrine) gypsum sample.*

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the mechanical behaviour of the mixture (e.g., *terra theraica, pozzolana*) and of the performances towards better adhesion, workability or compatibility. In this field, the technological innovations concern the raw materials used, the technology of lime (burning temperature, slaking time, water proportion) as well as the production techniques (mixture ratio and granulometry of binder to aggregate) and, not list, the expertise of the craftsmens. Various mix designs, that differ in type and size of natural additives and aggregates, are analysed. For each of the following mixtures to be tested, three samples are realized at the same time and all prototypes will cure at least 28 days:

A. *Gypsum* + *sand*. Proportions: 3 sand + 1 gypsum. Volume ratio 3 to 1. Mineralogical type: river/siliceous sand; soft mineral composed of calcium sulfate dihydrate mixed with rock flour (from now on, designed in the text as 'gypsum'). Grain size: sand 0/3 mm;

B. *Gypsum* + *black pozzolana*. Proportions: 3 black pozzolana + 1 gypsum. Volume ratio 3 to 1. Mineralogical type: gypsum; broad variety natural siliceous or siliceous-aluminous materials, mainly deriving by ashes and lapilli emitted during eruptions in the Naples area (from now on, designed in the text, in its varieties, as 'pozzolana'). Grain size: gypsum <0,2 mm, pozzolana 0/6 mm;

C. *Lime* + *pozzolana*. Proportions: 1.5 black pozzolana + 1.5 red pozzolana + 1 lime. Volume ratio 3 to 1. Mineralogical typology: inorganic hydraulic natural lime mortar (NHL) aged 60 months in handmade production –according to the rule of art– and cooked in limestone fed with bundles (from now on, designed in text as 'artisanal hydraulic slaked lime'); black pozzolana, red pozzolana. Grain size: black and red pozzolana 0/6 mm;

D. *Lime* + *earthenware powder*. Proportions: 3 crock powder + 1 lime. Volume ratio 3 to 1. Mineralogical typology: artisanal hydraulic slaked lime; crushed shard from various recycled elements such as tiles/others. Grain size: earthenware powder 0/10;

E. *Lime* + *pozzolanic cement* + *pozzolana*. Proportions: 1.5 black pozzolans + 1.5 red pozzolana + 0.5 lime + 0.5 pozzolanic cement. Mineralogical type: artisanal hydraulic slaked lime; black pozzolana, red pozzolana; pozzolanic cement. Grain size: black and red pozzolana 0/6 mm;

F. *Lime* + *pozzolanic cement* + *tiles/others powder*. Proportions: 3 earthenware powder + 0.5 lime + 0.5 pozzolanic cement. Mineralogical type: artisanal hydraulic slaked lime; crushed shard from various recycled ancient elements such as tiles/others; pozzolanic cement. Grain size: black and red pozzolana 0/6 mm;

G. *Lime* + *sand*. Proportions: 3 sand + 1 lime - Volume ratio 3 to 1. Mineralogical type: artisanal hydraulic slaked lime; river sand/siliceous sand. Grain size: sand 0/3 mm;

H. *Lime* + *sand* + *pozzolanic cement*. Proportions: 3 sand + 0.5 lime + 0.5 pozzolanic cement. Mineralogical type: artisanal hydraulic slaked lime; river/siliceous sand; pozzolanic cement. Grain size: sand 0/3 mm;

I. (L.) *Alabastrine gypsum* + *(with and without) carded sisal fibre*. Proportions: H_2O/gypsum ratio equal to 100/140. Mineralogical typology: calcium sulphate hemihydrate powder, obtained by grinding of gypsum stones of particular characteristics, subsequent coocked in methane furnaces at constant temperatures and refined in fine grains. Natural additives: sisal fibres made by cellulose (65,80%), hemicellulose (12,00%), pectine (0,80%), H_2O (10,00%), lignins (9,90%), water-soluble substances (1,20%), fats (0,30%);

M. (N.) *Red pozzolana (sifted and not sifted through)* + *pozzolanic cement*. Proportions: 3 red pozzolana + 1,5 pozzolanic concrete. Mineralogical typology: stabilized raw red pozzolanic soil, workable through the addition of water and open-air dried.

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5. Conclusions

The present study discusses the adequacy of innovative interventions on stone elements, with particular attention to mortar-like materials, plasters, artistic stuccoes and decorative apparatus of the architectural heritage of different regions of the globe. From a historical-iconographical research and direct design experiences, the essential relations between vulnerability of stone elements to weathering and extreme events, that can speed-up the physiological ageing and cause material degradation and severe damages, are addressed. As a possible solution for the problem, and in the perspective of first-aid, repair and restoration intervention design, different sets of prismatic prototypes were made. Different mixtures, in some cases innovative. - based on the most recurring techniques observed through the research are adopted: gypsum, hydraulic lime, stabilized raw earth, belonging to the category of artificial stone materials, an assumption necessary to relate the experimental campaign to codified, and replicable, testing protocols. The first experimental tests, currently in progress, are aimed at the critical analysis of the mechanical response of the different prototypes to three-point bending tests. In addition, in the future, compression and accelerated ageing tests, by wetting-drying cycles, will be done.

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Research and Comparative Analysis of Earth Mortars for Conservation and Restoration of Archaeological Structures. The Case of the Sant Jaume Site (Alcanar, Catalunya, Spain)

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Abstract
This report presents a physico-chemical characterisation of mortars used on the walls of Sant Jaume's fortified residence in the early Iron Age (c. 650-600 BC). The report includes a comparative study of various oil mortars to determine the most suitable for use in conservation-restoration campaigns at the site. The motivation is previous studies showing lime was not used as a binder and prompted experimentation with different oil mortars. The state of conservation of the architectural ensemble was evaluated by studying its deterioration factors. The physico-chemical analysis included a chemical-mineralogical characterisation, a particle size distribution, and an estimated dose of the original mortar. The initial replacement mortar were prepared for the comparative study. These specimens were grouped into two types of mortars: the first was formed by a mixture of sediment and olive oil, and the second by sediment and linseed oil. The specimens that performed better also contained linen threads or agave string. These have undergone laboratory tests to evaluate their physical-mechanical characteristics, surface hardness, and water behaviour through water drop absorption and porosity determination tests. The results allowed us to establish the possible limitations of the materials proposed for the conservation of the walls and make corrections to formulation, thus guaranteeing the optimal result in the intervention processes.

Keywords: *conservation; earth mortar; replacement oil mortar; wall lining; sustainable intervention*

1. Introduction

The present research explores using earth mortars for sustainable conservation of archaeological structures. The protohistoric site of Sant Jaume in Alcanar, Catalonia, Spain, is presented as a case study for experimentation. The original earth mortar and sediment are characterised to inform use in conservation. Additives such as olive oil, linseed oil, linen fibres and sisal rope fibres are studied to improve resistance and cohesion. The objective is to produce efficient, accessible earth mortars for conservation.

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2. Objectives

The overarching objective of the research endeavour is to undertake a comparative analysis of the physicochemical characteristics of replacement mortars, with the aim of ensuring the suitability of the materials. This objective is realised through the analysis of the historical context of the architecture and the identification of the primary factors contributing to deterioration. The chemical and mineralogical characteristics of the original mortars are identified, and the physicochemical characteristics of the replacement mortars are evaluated.

The subsequent analysis involves a comparative evaluation of the results to ascertain the effectiveness of the intervention. Moreover, the present research is congruent with several of the Sustainable Development Goals, particularly those pertaining to heritage protection, sustainable resource management, and waste reduction. In this regard, the protection of cultural assets, the utilisation of materials with minimal environmental impact, and the recycling of waste materials from the textile and agricultural industries are encouraged (ONU, 2015).

3. Methodology

In order to achieve the set objectives, the methodology is divided into four phases. Firstly, a documentary research phase is carried out, during which different bibliographic sources are studied. Subsequently, fieldwork is conducted, and all conservation work undertaken on site is reviewed and organised in relation to the experimental phase in the laboratory. In this phase, the original mortar is characterised and the physicochemical properties of the mortar specimens are evaluated. The fourth phase involves the various dissemination proposals that will be developed in the near future.

4. Materials and analytical techniques

The specimens were prepared using a yellow sediment from Sant Jaume as the primary component. The sediment was processed to obtain granulometric fractions between 4 mm and 63 μm, thereby eliminating the larger aggregate fractions. The most prevalent aggregate fractions are 1 mm and 0.25 mm, analogous to the original mortar samples. The use of additives, such as olive oil and linseed oil, has been proposed to enhance the water resistance of the mortar. 5 mm sections of linen and sisal rope fibres have also been demonstrated to enhance cohesion and mechanical strength. The preparation of mortar specimens entails the incorporation of 3%, 10%, or 18% of each oil type, along with 25%, 50%, or 75% of vegetable fibres, respectively. Preliminary investigations were conducted into textural and morphological properties. These included granulometric analysis in accordance with the UNE-EN 1015-1 standard and morphological characterisation via optical microscopy using a Leica® S8AP0 stereoscopic microscope and a Leica® DMC 6200 digital imaging system. The chemical and mineralogical analysis was performed using ATR-FTIR spectroscopy with Vertex 70 equipment (Bruker Optics) and an FT-IR detector. The insoluble residue post-acid attack test was also conducted to facilitate the evaluation of the composition and carbonate content of the materials under study. Subsequently, a series of tests were conducted to ascertain the physical and mechanical characteristics of the materials. These included an absorption test using a drop of water according to the RILEM 25-PEM 1980 standard; a determination of surface hardness using a Shore type D hardness tester with an HD hardness scale according to the DIN 53505, ASTM D 2240 and UNE 53130 standards; and a determination of porosity according to the UNE-EN 1936 standard.

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5. Fortified residence Sant Jaume

5.1. Historical context

Sant Jaume is an Early Iron Age (800–600 BC) settlement 224 metres above sea level on a high plateau of the Montsià mountain range in Tarragona, Spain. The site is 5 km north of the Sénia river and 20 km south of the Ebro delta. The subject is currently being studied by the Grup de Recerca en Arqueologia Protohistòrica (GRAP) at the University of Barcelona, under the leadership of David Garcia Rubert. The site is interpreted as a fortified residence and socio-political centre of the Sant Jaume Complex, comprising a group of settlements. The following locations have been identified: Cogula, Ferradura, Moleta del Remei, and Ulldecona Castle (Tarragona, Spain).

Fig. 1 – *Sant Jaume* (GRAP, UB).

Sant Jaume covers an area of approximately 700m² and was occupied during the final decades of the 8th century BC and the first decades of the 6th century BC. The site, which is semicircular in shape, has been designed to adapt to the terrain, with construction groups arranged in a perpendicular configuration. These groups consist of two-storey buildings, with the upper storey having been used for storage.

The construction system is characterised by medium-sized, irregularly shaped stone walls that are joined with earth mortar (Fig. 1) (Garcia Rubert, 2016; Mateu, 2015). With respect to the activities undertaken at the site, it is evident that agriculture constituted the primary economic foundation, complemented by livestock farming. Evidence of metallurgical production has also been found, and the large quantity of loom weights recovered is particularly notable (Garcia Rubert, 2016).

5.2. State of conservation of the structures

Sant Jaume has been well preserved due to its brief occupation and lack of significant remodelling. The violent attack and subsequent fire that marked its occupation have contributed to the conservation of the structures and materials.

The site was constructed using durable materials such as stone, and the ground was never cultivated. Various pathologies have been identified at the site, which are classified according to their origin. Post-depositional processes have resulted in the collapse of roofs, the partial collapse of some walls, and the detachment of rocks. The deterioration of exposed structures is attributable to the combined effects of water and wind. Conversely, the blackening of surfaces is attributable to atmospheric pollution. The predominant cause of deterioration of biological origin is the propagation of plants that result in the formation of fissures due to the force exerted by their roots. Anthropogenic factors such as utilisation, destruction, fire, and the process of excavation itself have the potential to induce deterioration. (Moreno, 2016).

Given the substantial size of the site, the present research focuses in particular on one of the interior fronts of area A5 (Fig. 2).

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Fig. 2 – I*nterior front of the wall UE0005 of area A5* (GRAP, UB, 2024).

This surface still preserves the remains of an earth covering, which had a separation between strata. During the preceding archaeological campaigns, the area underwent intervention through the injection of ethyl silicate consolidant (Estel 1000 and Estel 1100) and the application of an earth mortar containing olive oil around the perimeter of the cladding, with the objective of providing reinforcement. In general, the earth mortar that was utilised yielded satisfactory outcomes, although it was found to be somewhat powdery to the touch. To date, the material had not been characterised by analytical techniques; therefore, its study would facilitate the determination of its suitability and durability for in situ application. The intervention conducted utilising this particular mortar signified the commencement of research endeavours aimed at characterising the original mortar and conducting a comparative analysis of various proposals for earth mortars.

6. Experimental research and analysis

6.1. Characterisation of the original mortar

Firstly, the samples of original mortar extracted from the internal wall of area A7 are characterised. The two samples are composed of a disaggregated material that exhibits a dark brown colouration and variable granulometry. The granulometric analysis revealed that in both cases, the most abundant fractions correspond to 1 mm and 0.250 mm, respectively. Additionally, a notable presence of fractions smaller than 63 µm was observed, which would be equivalent to silts and clays.

Subsequently, the fractions of 0.250 mm and smaller than 63 µm were analysed by FTIR spectroscopy in order to ascertain their chemical-mineralogical composition. The presence of calcite, quartz, kaolinite and montmorillonite was identified in both fractions, indicating the coexistence of carbonaceous and siliceous materials. Furthermore, an acid attack test was conducted on small samples of these granulometric fractions, confirming the presence of significant quantities of siliceous material and clay minerals, with percentages ranging from 20.67% to 30%.

6.2. Experimentation with the test specimens

The preparation of test specimens facilitates the evaluation of the behaviour of earth mortar of varying composition, enabling analysis of its texture, strength, and stability as a function of the additives utilised. In this instance, oils and vegetable fibres have been incorporated into the material under investigation in order to study their effect on the cohesion and durability of the material. The preliminary stage of the process is the preparation of the soil mortar matrix, which is achieved by mixing the processed sediment and adding water until a homogeneous texture is achieved. Subsequent to a 24-hour hydration period, the various percentages of vegetable oils and fibres are introduced. Following the integration of the additives, test specimens measuring 5 x 5 x 1 cm are moulded and subsequently left to dry for a period of three months (Fig. 3).

As the quantity of olive oil increases, a discernible change in the colour of the mortars is observed, with the tubes darkening at different rates. It has been demonstrated that the consistency of the matrices improves in mixtures with a higher percentage of oil, and, in general, they are easier to handle thanks to the incorporation of fibres. Once hardened, the specimens exhibit a certain pulverulence, which decreases as the oil content increases, thereby enhancing their strength.

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These characteristics are also evident in the specimens treated with linseed oil, where a discernible tonal gradation is present. The incorporation of fibres has been demonstrated to enhance both texture and cohesion. In contradistinction to the preceding test specimens, it is noteworthy that the presence of powderiness is not discernible in these mortars.

Furthermore, it has been observed that the specimens containing the highest percentage of oil demonstrate a greater degree of resistance, necessitating the application of significant force, often requiring the use of a chisel, to achieve their fracture.

6.3. Results of physico-chemical analysis of the test specimens

Optical microscopy is used to examine the surfaces and cross-sections of the specimens in order to provide a comprehensive textural characterisation. In the case of the olive oil mortars, small, elongated, shallow pores were observed. Flax fibres do not generate cracks, while the sisal rope favours them, and there are slight separations of the earthy matrix around the more superficial fibres. A visual examination of the cross-section reveals that the mortar particles exhibit a predominant adherence pattern to the flax fibres (Figs. 4 & 5).

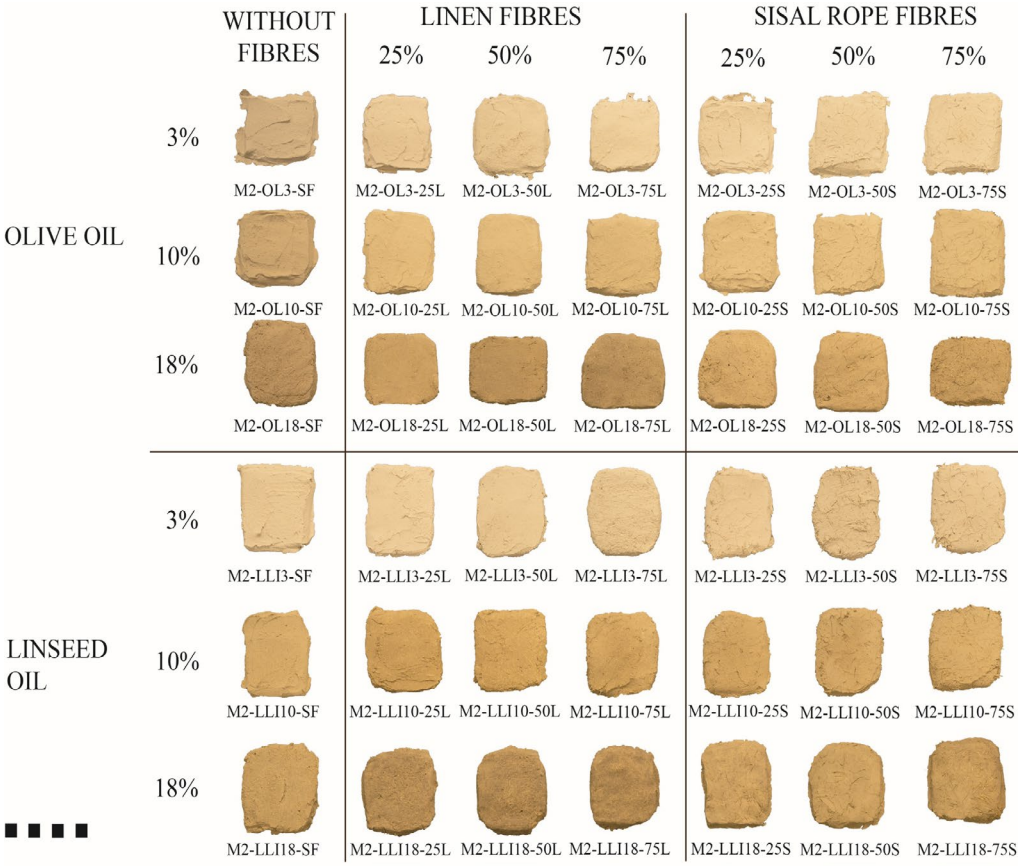

Fig. 3 – *Mortar test specimens with olive oil, linseed oil, linen fibres and sisal rope fibres* (Roca Cabedo, 2023).

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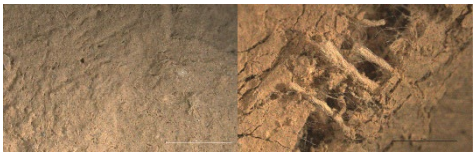

Fig. 4 – Microphotographs of surface and cross-section of specimen M2-OL10-50L (Roca Cabedo, 2023).

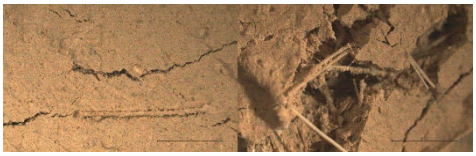

Fig. 5 – Microphotographs of surface and cross-section of specimen M2-OL10-50S (Roca Cabedo, 2023).

The linseed oil specimens are more compact and exhibit a lower degree of porosity, which decreases in proportion to the amount of oil incorporated. The integration of the two types of fibres has been shown to have the same effect as in the previous group of specimens. Micro-cracks are also generated with the sisal rope, and in both cases an internal fibre network is created (Figs. 6 & 7).

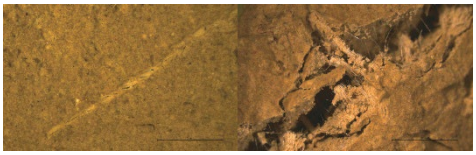

Fig. 6 – Microphotographs of surface and cross-section of specimen M2-LLI10-50L (Roca Cabedo, 2023).

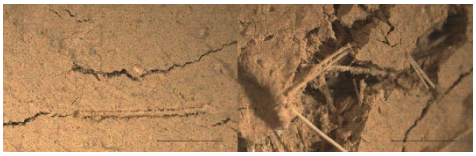

Fig. 7 – Microphotographs of surface and cross-section of specimen M2-LLI10-50S (Roca Cabedo, 2023).

The water drop absorption test is a method of evaluating the water absorption capacity of the mortar, as well as the key factors in its durability and moisture behaviour. The findings indicate that the mean absorption time increases in proportion to the percentage of oil added to the mortar. In the absence of fibres, the absorption time is prolonged, while the incorporation of this additive leads to a reduction in absorption, albeit more gradually in the case of flax fibres compared to sisal rope. Furthermore, it is evident that the specimens treated with linseed oil exhibit a substantially prolonged absorption time in comparison to those treated with olive oil. This observation suggests the presence of a differential effect on the material's structure by these two oils.

The porosity test was conducted on mortar specimens prepared with 3% and 10% olive oil. Linseed oil and both types of fibres at 50% were selected for the study. The test is passed by four types of mortar, which are detailed in Table 1.

Table 1 – *Porosity determination test results* (Roca Cabedo, 2023).

Types of mortar	Porosity (%)
M2-LLI3-50L	31.97
M2-LLI10-SF	23.95
M2-LLI10-50L	28.23
M2-LLI10-50S	36.00

The results indicate that the porosity of the pieces with vegetable fibres is relatively high. Furthermore, an increase in the porosity of the material is observed as the amount of fibres added increases. In particular, the M2-LLI10-50S mortar presents the highest value (36.00%), while the M2-LLI10-SF mortar, without fibres, registers the lowest porosity (23.95%). However, the M2-LLI3-50L and M2-LLI10-50L specimens demonstrate intermediate values (31.97% and 28.23%, respectively), thereby indicating that the type and amount of fibre exert a significant influence on the porous structure of the material.

The findings of the surface hardness determination study indicate that the highest values correspond to materials with an oil addition of 3%, both in specimens with olive oil and in specimens with linseed oil.

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In addition, the highest recorded hardness values correspond to the specimen devoid of fibres. Conversely, as the quantity of fibres increases, the surface hardness decreases. A comparison of the properties of linseed oil and olive oil reveals that the former provides greater hardness in the material than the latter.

7. Discussion

Firstly, the characterisation of the extracted mortar samples allows for the determination of the replacement mortar's compatibility with the original. These factors include the presence of siliceous components and clay minerals, which facilitate the binding capacity and plasticity of the sediment, and the particle size fraction with the new mortar would be adequately integrated (Minke, 2005). The materials under consideration for the fabrication of the test specimens are as follows. The primary material utilised is the sediment extracted from the excavations, which constitutes the predominant waste product generated in archaeological activities in situ. In order to enhance the properties of the material, a range of additives of vegetable origin are subjected to testing, yielding favourable outcomes in certain instances.

During the preparation of the test specimens, it was observed that the incorporation of oils and fibres increased the consistency and cohesion of the pastes. The fibres influence the rate of moisture absorption, with flax fibres exhibiting a more gradual rate of absorption compared to the faster rate observed in sisal rope. It has been determined that 75% of the fibres in the mixture contribute to the challenge of homogenisation, a factor that is especially salient in the case of sisal rope. Following the drying process, specimens composed of flax fibres showed no visible cracks, while those constructed with sisal rope exhibited surface cracks, likely resulting from shrinkage during the drying procedure. Moreover, the flax fibres demonstrate superior integration within the mortar matrix. This phenomenon can be attributed to the irregular morphology of the yarn. This morphology facilitates enhanced adhesion of the paste compared to the considerably smoother and more uniform surface of the sisal.

A comparison of the behaviour of the oils indicates that an increase in oil percentage is associated with a greater perception of paste cohesion. Of the two oils under scrutiny in this study, linseed oil was found to yield optimal results due to its status as a drying oil, which facilitates the formation of a reticule. However, the results of the surface hardness analysis indicate that the highest values correspond to the lowest percentages of oil added. This finding suggests that, in specimens with a higher quantity of oil, a polymeric surface film of a plastic nature is formed. Conversely, at an internal level, the oil would function analogously to a consolidant, thereby reinforcing the structure and augmenting resistance to fracture.

The addition of oils to earth mortars has been demonstrated to enhance their internal structure, thereby increasing their resistance. Furthermore, the incorporation of fibres has been shown to regulate humidity and facilitate the transpiration of the material, thus reducing the absorption time of water droplets and increasing porosity. The combination of materials would result in the production of a resilient mortar with the requisite degree of permeability, thereby ensuring the optimal conservation of the structures. It is estimated that an amount of linseed oil ranging from 3% to 10% could be effective, and it is hypothesised that this would be more efficient than olive oil. With regard to the fibres, it has been demonstrated that the two typologies can yield favourable outcomes by incorporating 50% of the paste's volume. In instances where higher levels of performance are required, such as in the case of linseed, this proportion can be elevated to 75%.

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8. Conclusions

As previously outlined, the present study has sought to explicate the various phases that have been executed. In conclusion, an assessment has been made of the importance of research in the field of conservation and restoration, with the objective of developing respectful ways of protecting the site's walls. Preliminary results of the comparative analysis indicate the effectiveness of earth mortars containing linseed oil and flax or sisal fibres. In line with the Sustainable Development Goals, we propose giving new uses to materials available locally, or using those with a low environmental impact, as promoted by bio-construction. This could involve exploring the use of waste products from industries such as textiles or agriculture to produce durable, affordable mortars that can be adapted to the original materials according to the needs of each intervention. Finally, research is continuing along several lines of study. Currently, in-depth ageing, durability and adhesion tests are being conducted to improve our understanding of how mortars behave in the presence of different deterioration agents. It is also planned to expand the scope of the research by incorporating other materials and analysing their impact on the mortar's properties.

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Restoration and Conservation of the Earthen Architectural Complex in Tazumal Archaeological Park, El Salvador, Central America

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Abstract

The Tazumal Archaeological Park is part of the Chalchuapa archaeological zone, which has been occupied since its earliest settlement around 1200 B.C. and continues to be an active site to this day. American archaeologist Stanley H. Boggs began excavations at Tazumal in 1942, concluding them in 1953 and establishing the site as El Salvador's first national archaeological park. Throughout his excavations, Boggs studied the site's cultural sequence and focused on conserving its pre-Hispanic architectural structures, applying cement to the original earthen coverings. However, despite these efforts, the structures continued to deteriorate due to environmental exposure (rain, sun, wind, and other factors). In 2005, a new restoration project was launched using a mortar mix of black scoria, volcanic tuff, white pumice, clay, brown soil and hydrated lime, developed in 1997 by Mr. Ismael Girón, head of restoration at the Chalchuapa archaeological project, under the guidance of Professor Kuniaki Ohi. During this restoration, it was determined that white pumice was suboptimal, and amount of brown soil was increased, enhancing the mortar's durability. In 2023, with funding from the Government of El Salvador as part of investment project 8094 for infrastructure improvements at Tazumal Archaeological Park, restoration efforts commenced across the site's four architectural sectors. This presentation will cover the 2023 restoration and conservation processes of Tazumal's earthen architectural complex, conducted from February to March, and discuss the outcomes achieved through these efforts.

Keywords: *Tazumal; earthen architectural complex; morter mix; compacting*

1. Introduction

The Republic of El Salvador lies between 13° and 14° North latitude and lies in the tropical zone. From an archaeological perspective, this Central American country was part of the southeastern area of the Maya region within the Mesoamerican civilization. El Salvador has over 700 registered archaeological sites, and the Chalchuapa archaeological zone, located about 80 km northwest of the capital, San Salvador, is one of the most important sites in the country. Human occupation in Chalchuapa began around 1,200 BCE and continues to the present day. The Tazumal area is part of this zone, along with nine other areas (Shibata, 2021b, p.275). The Tazumal Archaeological Park preserves an earthen architectural complex that served as the center of the region from the 4th to the 10th century CE. During this period, 13 superimposed structures were built, each progressively larger than the last (Shibata, 2021a, pp.185-188).

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The first archaeological investigation at Tazumal was conducted by the American archaeologist Stanley H. Boggs between 1942 and 1953 (Boggs, 1943a, 1943b, 1944, 1945). The objectives of the archaeological research were to excavate the architectural complex, conserve it, and display the archaeological materials found during the excavations in the site museum. Therefore, a cement plaster, a mixture of cement and sand, was applied over the original earth-made surface, as this conservation method was permitted at the time. However, the architectural complex has continued to deteriorate due to rain, sun, wind, microorganisms, and other factors.

This article addresses the method of restoring pre-Hispanic earth-made architecture, improvements in the mortar mix during its applications, and the process of the most recent restoration of structures at Tazumal Archaeological Park to preserve El Salvador's pre-Hispanic cultural heritage.

2. Restoration Methods

2.1. Expertise in Mortar Mixing

In 1991, I had the opportunity to visit and observe the restoration and conservation work on earthen structures at the Joya de Cerén archaeological site, which was later designated as a UNESCO World Heritage site in December 1993. Mr. Víctor Manuel Martínez "Murcia" led these efforts using the viscous sap from the *escobilla* grass, which was applied to the excavated pre-Hispanic structures at Joya de Cerén (Shibata, 2021b, p.313). At that time, I was involved in the Kaminaljuyú Archaeological Project in Zones 7 and 11 of Guatemala City, under the direction of Professor Kuniaki Ohi of Kyoto University of Foreign Studies. Mr. Martínez "Murcia" collaborated with his Salvadoran team in restoring the pre-Hispanic earthen structures we were excavating, using the *escobilla* mucilage mixture.

Fig. 2 – *Perspective view of the B1-1 and B1-2 architectural complex* (Author, 2024).

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However, several years after the project's completion, the restoration work applied to structure B-I-1 (Mongoy), which had been left exposed outdoors, proved to be ineffective (Shibata, 2021b, p.313).

In 1997, the Chalchuapa Project officially began under Professor Ohi's direction in the Casa Blanca area of the Chalchuapa archaeological zone. Mr. Ismael Girón Rodríguez, one of Murcia's disciples, served as the head of restoration and conservation for the project (Girón & Ohi, 2000, pp.240-243), as Ismael was knowledgeable in traditional earth architecture construction and mortar mixing techniques (Shibata, 2021b, p.314).

2.2. Compacting the Mortar Mix

Based on the failure of the restoration at structure B-I-1 (Mongoy) at the Kaminaljuyú archaeological site, the *escobilla* mucilage mixture was abandoned, and a new mortar mix was introduced in the Casa Blanca area of Chalchuapa.

This mix consisted of volcanic tuff, white pumice, black scoria, clay, brown soil, and hydrated lime. During the restoration of structure 1 in the same area, Ismael observed that when the new mortar mix was compacted and hardened, the color and texture of this material resembled the original one. This led to the idea of compacting the mortar plaster with wooden mallets at the end of the restoration process (Shibata, 2021b, p.314).

2.3. Outdoor Adobe Experiment

To verify the effect of compacting the mortar plaster, an outdoor adobe experiment was conducted at Casa Blanca Archaeological Park. Nineteen adobe bricks were classified into ten categories, two of which were covered with compacted mortar plaster. Ismael Girón applied the plaster, and the elements were observed over four years, from 1999 to 2003 (Kato, 2010, p.239).

The four untreated adobe bricks were completely destroyed within a year, whereas the two bricks with compacted mortar remained well preserved for two years. However, in the third year, small insect-caused holes were observed. By the fourth year, at least two compacted and plastered adobes remained in good condition aside from the small holes (Kato, 2010, p.239).

2.4. Improving the Mortar Mix

Despite the experiment and analysis of adobe to assess the effect of plastering and compaction, restoration of excavated pre-Hispanic structures continued at Casa Blanca using this mortar mix (Shibata, 2021b, pp.298-301).

In October 2004, most of the south side of structure B1-2 at Tazumal collapsed. This structure had been restored with cement plaster under Boggs' direction. Following the collapse, discussions arose between architects and archaeologists regarding the fate of B1-2. Some architects suggested reconstructing the collapsed portion with cement, while archaeologists proposed excavating for substructures that could be restored, conserved, and displayed, based on photographs taken by Boggs during the excavations.

Ultimately, the National Council for Culture and the Arts approved the archaeologists' proposal, leading to archaeological investigations and restoration efforts on structure B1-2 over 20 months, concluding in November 2006 (Shibata, 2021b, p.282). Three key principles guided the restoration (Ohi, 2000, pp.225-237):

1. fidelity,
2. stability,
3. beauty and harmony.

During the first restoration season, the mortar mix was used to consolidate the excavated substructures in the collapsed sector. However, a year later, porosity was observed in the restored sections of the south side of B1-2, caused by the

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"volcanic tuff and white pumice" material (Shibata, 2021b, p.283) (Table 1). It is considered that the volcanic tuff and whitepumice weakened the resistance of the plaster, because of its greater porosity compared to black scoria.

Table 1 – *Ratio of a old mortar mix* (Personal communication with S. Kato).

Material	Ratio
Black scoria	5
Volcanic tuff with white pumice	2
Clay	3
Brown soil	1
Hydrated lime	1

Consequently, a new mortar mix was established, comprising of black pumice, clay, brown soil, and hydrated lime. This formula remains in use today and has proven effective for conservation (Table 2). The increased proportion of brown soil in the new mortar mix is hypothesized to increase its hardness.

Table 2 – *Ratio of a new mortar mix* (Shibaita, 2021b, p. 283)

Material	Ratio
Black scoria	6
Clay	3
Brown soil	6
Hydrated lime	2

3. Restoration Process in 2023 at Tazumal

3.1. Brief History of the Restoration of Architectural Complex B1-1 and B1-2 at Tazumal

Between 1942 and 1953, the B1-1 and B1-2 architectural complex was excavated under Boggs' direction, applying a cement plaster over the original earth-based plaster to preserve it. This effort was successful, and the Tazumal architectural complex became part of El Salvador's archaeological heritage. However, over time, the cement-plastered sections continued to deteriorate due to rain, sun, wind, microorganisms, and other factors.

In 1997, the restoration of the Columns Building within the B1-1 architectural complex was carried out using cement and stone. However, five years later, the restored section of the south wall in the central chamber of the same building collapsed (Shibata & Murano, 2008, p.1059), and no immediate intervention could be made.

In 2006, influenced by archaeological research alongside the restoration and conservation of structure B1-2, restoration began on the collapsed wall of the Columns Building. Adobe was used as the core of the wall over a stone base, and mortar mix was applied as plaster (Shibata & Murano, 2015, pp. 129-142).

In 2012, the vertical wall at the northeast corner of the Great Platform was restored. This section had been damaged by leafcutter ant activity, and the same method used for restoring the Columns Building wall was applied (Shibata, 2021b, pp. 284-286). For ten days, starting at the end of January 2018, restoration was conducted on the Columns Building, particularly its façade and the basement structures on the south side.

However, restoration remained pending in other sectors of the architectural complex, including the archaeological window to the east of the Great Pyramid, the staircase on the north side of the Great Platform, the sloped wall on the west side of the Great Platform, and the east wall of structure B1-2 (Fig. 2).

3.2. Restoration Under Investment Project 8094

Aligned with the cultural policy of the Central Government, two investment projects were proposed for the archaeological parks managed by the Ministry of Culture of El Salvador. One of them was designated as "*Investment Project 8094*" which focused on infrastructure improvements at Tazumal Archaeological Park in 2023. Component 6 of this project involved the

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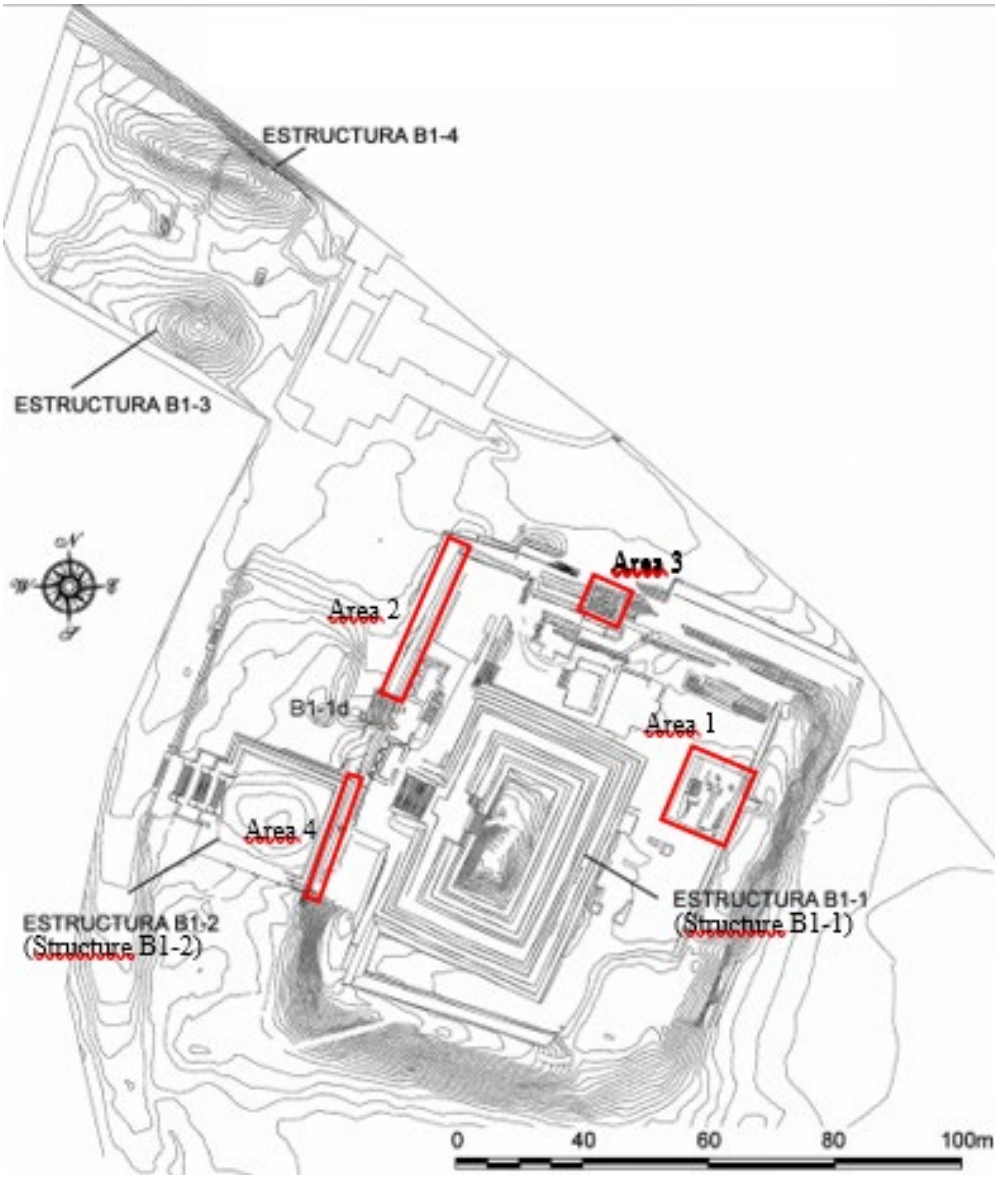

Fig. 2 – *Plan of the B1-1 and B1-2 architectural complex* (Author, 2024).

restoration of the archaeological window located east of the Great Pyramid, the staircase on the north side of the Great Platform, the sloped wall on the west side of the Great Platform, and the east wall of structure B1-2, which had previously been awaiting intervention.

Restoration began at the archaeological window, where the edges of the Great Platform from different stages of eastward expansion are visible (Shibata, 2021a, pp.184-188) (Fig. 2: Area 1). First, holes and cracks were cleaned, removing porous earth cores.

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Second, the areas to be restored were moistened with water to ensure proper adhesion of the mortar mix to the core. For large holes, stones were added to the mortar mix for reinforcement. In very large holes, adobe bricks were placed. Finally, a mortar plaster was applied and compacted using a wooden mallet made of Balsam or other hardwood once the moisture in the mortar plaster had reduced. A large hole was found in the sloped wall on the west side of the Great Platform (Fig. 2: Area 2). To restore it, the cement plaster was removed, and the interior section was cleaned.

Adobe bricks were then placed, followed by the application of a mortar plaster on the surface. Notably, the mortar mix used in this instance was combined with molasses to prevent surface cracking of the restored sloped wall due to abrupt temperature changes. This precaution was necessary because the west section of the Great Platform is heavily exposed to direct sunlight in the afternoon, causing the surface temperature of the sloped wall to rise to approximately 60°C.

Traditionally, molasses was mixed with mortar and used to form the inner layer of earthen ovens in the Chalchuapa region to withstand the high temperatures generated by wood-fired cooking. To verify this function, Ismael and I constructed an earthen oven, which withstood temperatures up to 250°C, and to date, only a very thin crack has been observed. In the sections of the staircase on the north side of the Great Platform (Fig. 2: Area 3) and the east wall of structure B1-2, small holes were observed (Fig. 2: Area 4).

Therefore, the mortar mix was applied as previously described. The restoration process for component 6 began on February 13, 2023, and was completed on March 30 of the same year. To date, the restored areas remain in good condition.

Fig. 3 – Staircase of the archaeological window (Author, 2024).

Fig. 4 – *Sloped wall on the west side of the B1-1 architectural complex (Before and After)* (Author, 2024).

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4. Conclusion

The pre-Hispanic structures at the Kaminaljuyú archaeological site, located in Zones 7 and 11 of Guatemala City, are made of soil. At the beginning of the Kaminaljuyú Archaeological Project, the chemical consolidant OH was applied to the surfaces of pre-Hispanic floors and walls. This chemical material worked well; however, it was economically expensive and uncomfortable to apply manually.

Therefore, after learning about the *escobilla* mucilage mix used to consolidate pre-Hispanic earth dwellings at the Joya de Cerén archaeological site in El Salvador, Professor Ohi decided to use it for the restoration of the excavated earth structures in Kaminaljuyú. However, while the *escobilla* mucilage mix performed well under shelter, it did not work effectively in outdoor conditions.

Before the start of the Chalchuapa Project, I had the opportunity to contact Mr. Ismael Girón Rodríguez through Mr. Víctor Manuel Martínez "Murcia." Due to Mr. Girón's extensive experience, he already possessed significant knowledge and skills in masonry and the conservation of earthen architecture at Joya de Cerén. Additionally, Mr. Girón always observed various factors with a scientific perspective, which led him to discover the method of compacting mortar plaster. This method was successfully applied to the restoration of pre-Hispanic earthen structures.

To date, the content of the mortar mix for outdoor restoration of earth structures has been empirically established, along with the compaction method. Now, further physical-chemical studies are needed to gain a deeper understanding of compacted mortar mix for the conservation of pre-Hispanic earthen structures, especially analysis regarding the effect of brown soil and black scoria on the properties of the mortar mix.

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Studies of Material Intervention to Conserve the Living Archaeological Site of Shuijingjie Distillery Site in Chengdu, China

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Abstract

The Shuijingjie Distillery site, located in the core urban district of Chengdu, is a historic liquor production site with over 600 years of history. It was designated as a National Monument Site in 2006 and listed as a National Industrial Heritage site in 2019. As part of the site's museum, liquor production remains operational. However, seepage from the fermentation pits has caused significant deterioration, including partial collapses of the earthen walls within the excavation pits. Additional damage to bricks and natural stone has also been observed. This article presents studies stabilizing the archaeological excavation using compatible and reversible materials. To mitigate seepage from the excavation walls, a locally available natural clay with low permeability (2.3–3.8 × 10^{-7} cm/s) was identified and tested. The clay was used as an anti-seepage grout material, tested in scaled simulation soil reconstructed in laboratory. Multiple injections of modified clay grouts reduced effectively speed and volume of moisture from simulated reservoir source. This study explores the use of locally sourced, retreatable materials in archaeological site conservation, offering a reference for the preservation of similar sites.

Keywords: *archaeological sites; industrial heritage; Shuijingjie distillery site; retreatability; clay grout; seepage control*

1. Introduction

The site of the Shuijingjie Distillery（Fig. 1), Chengdu, was excavated in 1998, unearthing cellars, drying halls, distillation bases and a large number of wine utensils and other cultural artefacts from the Ming and Qing dynasties (1368-1910 B.C.), which are important objects for the study of the historical origins of liquor and the traditional brewing-distilling process (Chengdu Institute of Cultural Relics and Archaeology et al., 2013). In 2000, Shuijingjie Distillery Site was listed as a national key cultural relic protection unit. In 2012 the Shuijingjie Distillery Site Museum was inaugurated and in 2019, the site was listed one of the National Industrial Heritage Sites of China. The centre of the Shuijingjie Distillery Site is the archaeological site area of about 280 square metres, and immediately adjacent to the site area

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is the production area, where liquor production activities are still taking place. Both archaeological site and the brewing-distilling process are open to the public (Fig. 2). According to the definition of the Chinese heritage classification (Xu, 2008), the Shuijingjie Distillery Site is both a static heritage that preserves the archaeological site and other artefacts, and a living heritage that perpetuates the original production function. As an industrial heritage under the perspective of "living heritage", the preservation of both "static" and "living" features is the key to the conservation of the Shuijingjie Distillery Site.

Fig. 1 – *Shuijingjie Distillery archaeological site* (Authors).

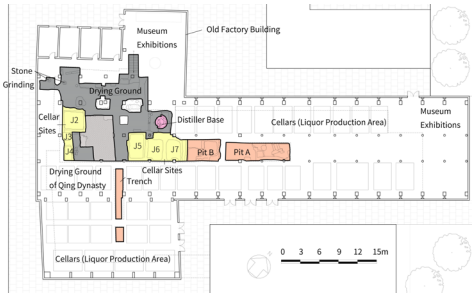

Fig. 2 – Plan of the Shuijingjie Distillery site (Authors).

Fig. 3 – *Typical deterioration types in site area* (Authors).

Since the excavation in 1998, the relics at the Shuijingjie Distillery site have exhibited varying degrees of deterioration. Xie et al. (2005) conducted a compositional analysis of the site's soil and monitored temperature and humidity at different locations. Their findings indicated that fluctuations in temperature and humidity destabilize the montmorillonite components in the soil, leading to cracking and brittleness. Over two decades since the site's excavation, the deterioration has worsened, necessitating a comprehensive assessment of the site's material degradation. A technical conservation program is urgently required to preserve the site's core structure while ensuring that brewing-distilling activities and site exhibitions remain unaffected.

2. Defects and intervention intentions

Based on site investigations, mapping and material analysis, the typical forms of deterioration at the site can be categorized into three types, i. e. deterioration related to seepages, chalking and spalling of archaeological surfaces and mechanical damages (Fig. 3).

2.1. Deterioration related to seepages

Seepage primarily occurs on the inner walls of exploratory pits formed after excavation. It is caused by the infiltration of liquids from the brewing cellar into the soil. In affected areas, visible microbial growth is commonly observed, alongside pronounced cracking of the topsoil, weathering, detachment, and occasional flooding.This type of deterioration poses a significant threat to the structural stability of the archaeological walls and compromises their suitability for display.

2.2. Chalking and Spalling

Chalking and spalling are the most prevalent forms of deterioration on the archaeological surface. They affect a wide range of materials, including site soil, adobe, clay motars, grey and red bricks, sandstone blocks, and the masonry bases of distiller, with adobe bricks and

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sandstone blocks being the most severely impacted. These issues are primarily attributed to the migration of soluble salts to the surface of the materials under the influence of water, followed by repeated crystallization. Additionally, fluctuations in air humidity and temperature exacerbate the chalking of the soil surface.

2.3. Mechanical damages

The investigation identified localized damage to masonry artefacts, including broken blocks, missing bricks, and the loss of bonding materials. These issues are particularly evident in the Qing Dynasty drying hall and the base of the distiller, where structural integrity has been compromised.

2.4. Intervention measures

It is essential to take measures to enhance the structural and surface material stability of the site. Successful archaeological site conservation in humid areas primarily depends on controlling the hydrogeological environment (Wang, 2015). Since there are no standard technique to stabilize the materials on one hand, to maintain the distilling activities and display functions on the other hand, all kind of interventions shall be studied prior to implementation. Following tests have been completed both in the laboratory (Fig. 4) and on site (Fig. 5): impregnation consolidation with ethyl silicate, crack repairing and retouches using lime-earth mortars and seepage control. All test results will be published in the coming academic exchange. This paper, however, only concentrates the experimental results of seepage control.

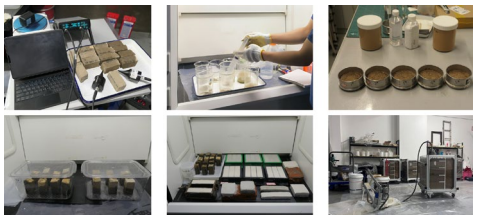

Fig. 4 – *Laboratory experiments. Left- consolidation experiments using TEOS; Middle-analysis and reproduction of historical lime mortars; Right- anti-seepage experiments using cellar cap clay* (Authors).

Fig. 5 – *On-site tests. Left- consolidation of an adobe wall; Middle- anastylosis of displaced masonry with lime mortar; Right- experiment using cellar cap clay as clay mortar* (Authors).

3. Laboratory conservation experiments on seepage control

3.1. Conservation concepts and principles

The National Industrial Heritage Management Measures, issued by the Ministry of Industry and Information Technology, emphasize key principles for protecting industrial heritage: government guidance, public participation, protection alongside rational use, dynamic inheritance, and sustainable development (MIIT China, 2023). The Shuijingjie Distillery Site is a unique industrial heritage, serving as both an archaeological site for cultural preservation and a museum for cultural display. The adjacent brewing-distilling cellars showcase the brewing process and lees production, adding educational value. Due to its unique significance, conservation of the site should adhere to the principles of minimal intervention and retreatability, ensuring that conservation efforts minimize impact on both cultural relics and the brewing process.

The principle of retreatability (or re-treatability), “is one that is often more helpful in evaluating treatments than the idea of reversibility itself.” (Appelbaum, 1987). It has been argued that the principle of reversibility is nearly impossible to fully implement in practice and should be replaced by the principles of compatibility of the protective material and reprocessability of the intervention (Teutonico et al., 1997). This approach ensures that the conservation materials applied do not damage the object itself and that

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the intervention, along with the materials used and their ageing process, does not hinder future conservation efforts. The principle is crucial when treating a living site like Shuijingjie Distillery with a sensitive bio-environment for brewing.

3.2. Selection of seepage prevention technique and material

Common methods addressing water seepage in archaeological sites include installing impermeable curtains (Li et al,, 2022) or constructing drainage ditches and catchment wells (Zhang et al., 2018). At the Shuijingjie Distillery Site, the water source (cellar) is only 0.9-1.2 meters from the seepage point horizontally, making these methods difficult to implement. To address this, grouting can be used to diffuse slurry into the soil between the cellar and the site, filling fissures and forming an impermeable barrier to stop seepage (Fig. 6).

However, the existing grouting materials, such as organic polymers, water glass, and cement slurries, when applied in earthen site environments, often lead to significant changes in the pH value of the soil or large amounts of water-soluble salts, which are not treatable when those grouts are deteriorated.

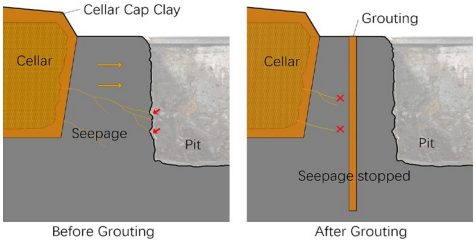

Fig. 6 – *Concept for seepage control* (Authors).

The impact of these materials on the microbial communities that are essential for the brewing process and on the mash itself remains unknown.

After evaluating several materials (Table 1), it was decided to use cellar cap clay from the Shuijingjie Distillery cellar to formulate the slurry. This mud, made from local "Chengdu clay," serves as a seal during fermentation (Liao et al., 2012) and has extreme low permeability (k_v=2.34×10^{7}cm/s, k_h=3.86×10^{7}cm/s). Using this material reduces uncertainties in the intervention.

3.3. Slurry Preparation

In this experiment, two slurries with water-to-binder ratios of 1.5:1 and 1:1 were prepared for comparison. The water-to-binder ratio, which refers to the mass ratio of water to the binding materials, is a key factor influencing the flowability of the slurry.

Table 1 – *Types of grouting materials commonly used for earthen site anti-seepage and their advantages and disadvantages* (Authors, 2024).

Material	Anti-Seepage Mechanism	pH value	Byproduct	Retreatability
Organic polymers (e.g. polyurethane)	Cures to an elastic insulating film, against gaseous and liquid water	Neutral	Soluble salts	Very poor, no natural degradation
Potassium waterglass	Forms hydrophobic silica colloids to block capillary pores	8-11, Alkaline	Soluble salts	Mediocre
Silicone micro-nano emulsion	Forms a hydrophobic silicone film, reduces capillary liquid water penetration.	5.5-6, Weakly acidic	None	Mediocre
Cement grouts	Hydraulic setting, forming a rigid impermeable mortar layer	10-13, Alkaline	Soluble salts	Poor
Clay Slurry (Chengdu Clay)	Reduce penetration of liquid water; better passage of gaseous water (practical data not yet available)	Neutral	None	Very good retreatability

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It also affects the slurry's permeability within the soil and its curing process. First, the cellar cap clay was crushed to a diameter of approximately 5 cm. Water was then added according to the specified ratios (1.5:1 and 1:1), and the mixture was soaked for 24 hours. After soaking, the slurry was stirred using a hand-held mixer (DCA® Φ160mm, 1010W) for 10 minutes. The mixture was then filtered through a sieve with a 5mm pore size. Any undispersed mud was further stirred and dispersed, while stones, debris, and difficult-to-dispersed mud chunks were discarded, resulting in the prepared slurry. Some basic properties of the slurry were tested according to *Geotechnical Experiment Standard* (GB/T 50123-2019). The slurry with a 1:1 water-to-solid ratio exhibited a lower water secretion rate and higher viscosity, making it more suitable for grouting operations.

3.4. Simulated grouting experiment

The simulated grouting experiment involved creating a scaled model in the laboratory that replicated the soil conditions of the site. Grout was injected into the model to assess the feasibility of the grouting materials and techniques, as well as to test the effectiveness of the grouting. A soil experiment box was constructed using aluminium alloy profiles and transparent acrylic panels (Fig. 7), with one side panel movable to facilitate subsequent testing. The site contains multiple cultural layers with significant amounts of broken bricks, tiles, and other materials.

To simulate the site's soil conditions, the experiment mixed clay and river sand in a 3:1 ratio, added a layer of broken bricks and tiles, and tamped the mixture in layers to a depth of 50cm within the box. The back of the box was filled with 15 cm of vermiculite, matching the height of the simulated soil layer. After grouting, water was injected into the vermiculite to simulate the leakage of liquids from the adjacent cellar into the site soil.

The experiments compared two seepage control methods: pressure grouting and narrow slot grouting (Fig. 8), with an experimental box without seepage control used as the blank control group.

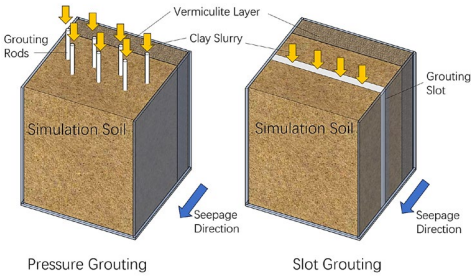

Fig. 8 – *Two grouting options* (Authors).

For pressure grouting, a hand-pressure grouting pump (DESOL HP-6020) was used. Grouting rods (Φ20mm, 450mm in length) were inserted every 10 cm into the soil to inject the slurry under pressure, allowing it to infiltrate and fill the fissures, forming an anti-seepage curtain. For narrow slot grouting, a 30mm-wide groove was excavated in the soil. Slurry was poured into the

Fig. 7 – *Experimental boxes* (Authors).

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slot until it was full. After grouting, a pressureless secondary replenishment was carried out about 10 minutes later to fill any openings. After the grouting, the surface was covered to reduce water evaporation, allowing the slurry to solidify before the next phase of experiment. The exposed portion of the grout dried and solidified quickly, resulting in localized shrinkage. In the pressure grouting method, the grouted openings showed localized cracking, while in the narrow-slot grouting method, drying and shrinkage were more pronounced. This led to 4-5 penetrating cracks, about 1 cm wide, perpendicular to the slot.

One year after the grouting experiment, the cracks in the narrow-slot grout were replenished before testing the impermeability. The same slurry used in the initial grouting was used for regrouting, and it was allowed to flow naturally into the cracks without pressure. After one week of curing at room temperature, the seepage control effect was evaluated.

3.5. Evaluation of grouting effects

Cold water was injected into the vermiculite layer at the rear of the experimental box, allowing the gaps between the vermiculite particles to be thoroughly soaked. After soaking, the vermiculite layer operated as the cellar in the site filled with fermenting mixtures, where water pressure increases with depth, and water continuously permeates into the soil. At the top of the vermiculite layer, plastic bottles filled with ice cubes were inserted. As the ice cubes melted, the water in the vermiculite layer was replenished, maintaining its water level and pressure. The seepage situation of the exposed side of the simulated soil body was observed periodically, with infrared and visible light photos taken.

After injecting water into the vermiculite layer, 24 hours later (1 day), water seepage caused color changes at the bottom of the untreated control group soil. By the third day (40 hours later), the soils treated with grouting began to show

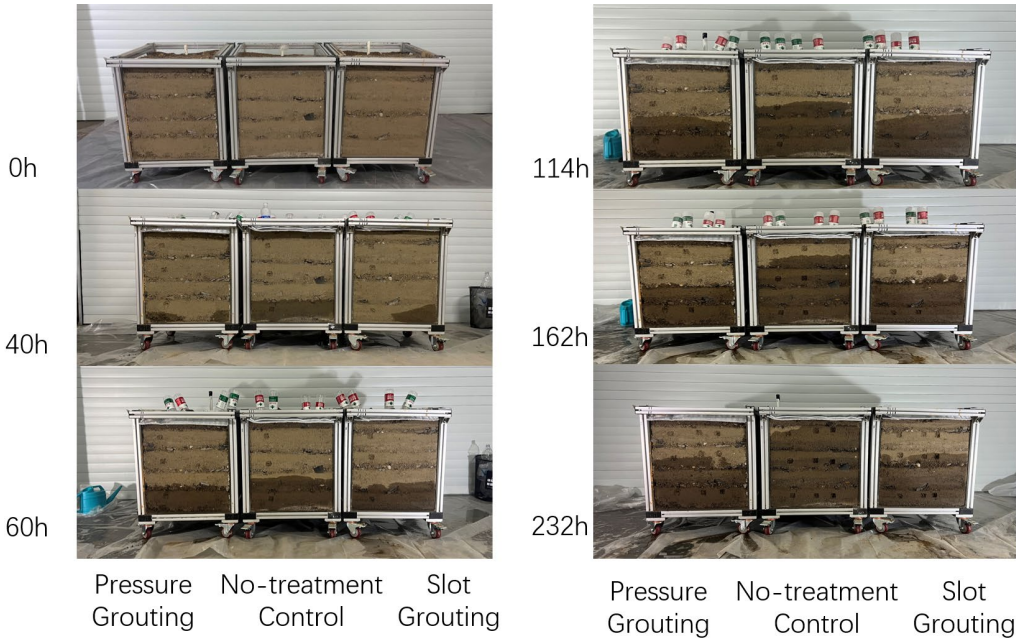

Fig. 9 – *Documentation of moisture transportation* (Authors).

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moisture at the bottom corners. On the fourth day (60 hours later), the bottom of the soil in all three boxes was saturated, but the rate of water level rise differed, with treated soils showing a significantly slower increase in water level. On the 10th day (232 hours later), the control group's simulated wall was almost fully saturated, while in the two grouted groups, the water level had risen slightly above half (Fig. 9).

Soil samples were taken before water application, 7 days (162 hours) later, and 10 days (232 hours) later, with moisture content measured by drying and weighing. Before application, the control group had slightly higher moisture content. After 7 days, all soils had about 20% moisture in the bottom layer, but treated soils had lower moisture in the upper layers. After 10 days, moisture in the bottom layers remained stable, while the middle and upper layers increased. Pressure grouting reduced moisture by 12.68%, 19.42%, and 1.32% from top to bottom, while narrow-slot grouting showed reductions of 12.74% and 5.50%, with a slight increase of 0.74% in the bottom layer. Thus, both pressure grouting was slightly more effective than narrow-slot grouting in preventing seepage (Fig. 10).

Although both seepage prevention methods reduced the rate of water penetration into the simulated soil in the test, but they do not stop the liquid water penetration. This may be due to gaps between the simulated soil and the experimental box. After grouting, a barrier was formed in the soil, causing water to infiltrate through these gaps, initially seeping at the bottom corners and then rising via capillary action, gradually spreading towards the center and upper parts. This phenomenon demonstrates the effectiveness of the seepage prevention barrier.

4. Conclusion and discussion

Through field surveys and laboratory studies, three major deterioration patterns were identified at the Shuijingjie Distillery site: deterioration related to seepages, chalking and spalling of artifacts, and mechanical damages. To address the seepage issue, grouting can be used to create a seepage barrier within the soil.

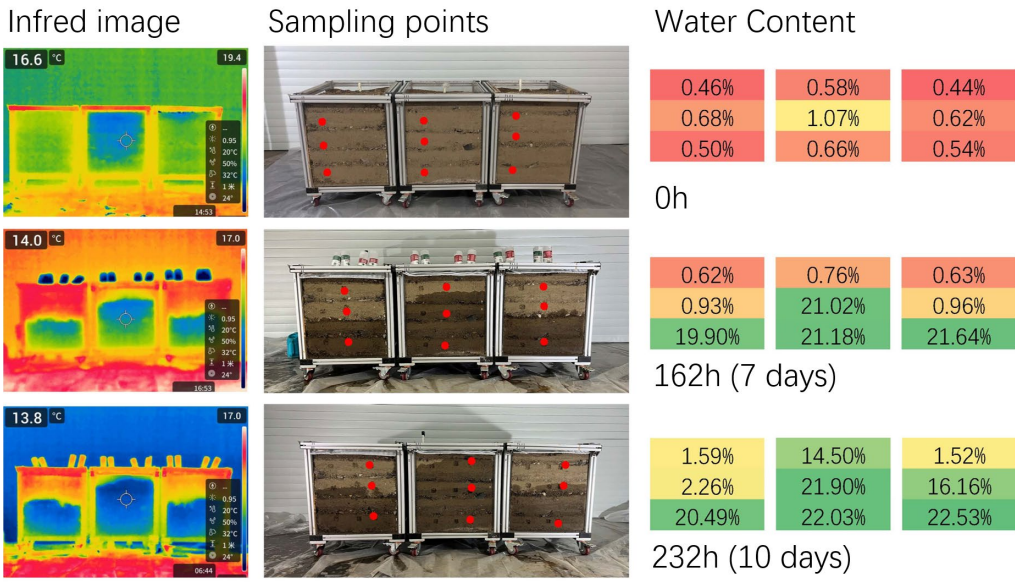

Fig. 10 – *Inferred image and soil moisture sampling* (Authors).

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By preparing a slurry using the cellar cap clay employed in liquor production at the Shuijingjie Distillery, and applying pressure via a grouting pump, the slurry can spread fully, filling the voids of the site and significantly enhancing the permeability resistance of the site's soil. As a local natural material, the use of cellar cap clay for conservation work offers good re-treatability. This technique will be implemented in the near future. However further research and field tests are needed to improve the slurry's anti-seepage properties and assess the long-term effects of grouting.

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Conservation and Sustainability of an Earth Architectural Heritage located in the Historic Center of Lima (Peru): House Museum, Challenges and Opportunities

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Topic: T2.5. Energy efficiency and sustainable design projects

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Abstract

Cities continue to face increasing challenges caused by climate change and urbanization, and the conservation of architectural heritage is no exception to this, having become a priority. In this context, an adobe building located in the Historic Center of Lima is analyzed in order to evaluate its conservation, the environmental impact of its rehabilitation and the possibilities of integrating sustainable energy solutions adapted to the building's current use as a museum. In this way, the building presents both challenges and opportunities for its conservation in the current environment. Firstly, the architectural and constructive characteristics of the building, which reflect a significant cultural heritage, are evaluated, followed by the identification of the structural and typological elements, such as the existing "teatinas", which require conservation to ensure their long-term integrity. From an environmental approach, alternatives to optimize the building's energy consumption without compromising its historical value are analyzed and sustainable rehabilitation solutions are explored. The benefits of a rehabilitation that not only preserves the cultural heritage, but also reduces the ecological footprint of the building are highlighted. This approach not only protects cultural heritage, but also plays a fundamental role in the revitalization of historic centers, contributing to the cultural identity and environmental sustainability of cities in the face of the challenges of the 21st century.

Keywords: *heritage conservation; sustainability; energy efficiency; historic center; earthen building*

1. Introduction

The conservation of architectural heritage is fundamental to preserve the cultural identity and history of communities. However, it is important that this process be compatible with environmental and energy sustainability requirements. Earthen buildings, which have played a fundamental role in the traditional architecture of various regions around the world, require a specific approach to their conservation so that their integrity is not compromised. These buildings face particular challenges related to climate, materiality and adaptation to contemporary uses, such as museums.

In this context, the analysis of the Casa de la Cultura Criolla Rosa Mercedes Ayarza building, located in the Historic Center of Lima, is essential to identify both the opportunities and

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challenges associated with its rehabilitation. The building was constructed using the traditional adobe technique. This analysis is of great importance to integrate sustainable energy solutions, ensure the preservation of its heritage value and improve its operational efficiency.

Lima's viceregal houses, built between the 16th and 19th centuries, which are still preserved, have been the subject of multiple studies from different perspectives. However, the focus on environmental and energy aspects, as well as thermal comfort, has been limited. Some relevant works include the studies of Wieser, who investigated the improvements in thermal and lighting conditions provided by the Teatinas (Fig. 1) on the roofs of houses, and Agüero, who made a similar interpretation with respect to viceregal balconies. However, it should be indicated that both authors addressed the energy performance of traditional buildings in Lima. Therefore, it is pertinent to mention that, to date, very few studies have been carried out in this area.

In terms of thermal comfort, one of the main challenges faced by traditional museum buildings is the preservation of their functional characteristics. In the city of Lima, it is common for museums to keep their doors open during visiting hours, which affects thermal regulation. These aspects, together with the morphology, orientation and quality of the spaces, generate both challenges and opportunities for their use as museums. On the other hand, traditional adobe dwellings located in regions with climates similar to that of Lima must address issues that impact both the preservation of artworks and the safety and well-being of visitors, while also considering the inherent benefits of adobe as a building material.

The case study building, known as the “Casa de la Cultura Criolla Rosa Mercedes Ayarza” (Fig. 2), is located in the original layout of the foundation of Lima, in an expansion area known as the “damero” of Pizarro. Despite the absence of direct historical sources about the building, archaeological studies have revealed the existence of a viceroyalty canal nearby. The proximity to the Church of San Marcelo, established in the mid-16th century, suggests that this environment was still in an initial phase of population development, although it maintained the orthogonal layout characteristic of the founding of Lima, with dwellings occupied by the humble population. At the end of the 16th century, the area was described by Father Bernabé Cobo as impoverished, with the church under development and surrounded by modest dwellings.

Fig. 1 – *Aerial photography and Teatinas on the roof* (Diaz, 2024).

Fig. 2 – *Facade of the study building* (Diaz, 2024).

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In the 17th century, the urbanization intensified, reflecting the urban consolidation and the progressive occupation of the territory. The name of the street on which the building is located as “Calle Mariquitas” is a testimony of the period, while today it corresponds to block 3 of the jirón Moquegua. The city experienced two earthquakes of considerable magnitude, in 1687 and 1746, which caused the devastation of a large part of the area, leaving structures in ruins and walled lots. The rehabilitation and recovery of historic buildings, such as the Casa de la Cultura Criolla Rosa Mercedes Ayarza, presents an opportunity to integrate heritage conservation with the development of sustainable energy solutions. This study not only contributes to the preservation of architectural heritage but also provides insight into how to adapt traditional buildings to contemporary requirements without compromising their cultural and architectural values.

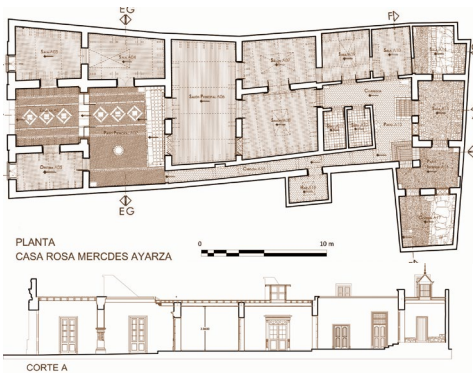

Fig. 3 – *Floor plan of the Casa de la Cultura Criolla.* (PROLIMA Documentary Archive 2022).

2. Objective

This study focuses on evaluating the state of conservation of an earthen heritage building, built using the traditional adobe technique. For this purpose, the environmental impact of its rehabilitation will be analyzed and the possibilities of integrating sustainable energy solutions will be explored, taking into account the temperate climate of the region and the current use of the building as a house museum.

3. Methodology

The research began with the compilation of bibliographic documentation and historical background of the environment and the building, as well as the compilation of documents on the history of the building. It was organized in several phases, including a visit to the building and an evaluation of its current state of conservation and functionality.

Based on this exhaustive analysis, a graphic and historical database of the building was generated. Subsequently, the construction system and the representative architectural elements were analyzed, identifying the construction elements, including dimensions, shape, materiality, state of conservation and pathologies associated with the material.

Once the constructive recognition of the building was completed, a record of shots and measurements was taken in certain areas of the museum, with the purpose of identifying climatic and lighting data in interior areas during the hours of operation of the museum. For this purpose, Testo measuring instruments were used and a photographic record was taken.

With the information gathered and the online information from the city's weather stations, an analysis of the climate and lighting was carried out, taking into account the characteristics of the building and its location.

Finally, sustainable energy solutions were explored, integrating them with the functionality, materiality and conditioning factors of the environment.

4. Results

4.1. Chapter: Historical Background of the building

The House Museum, located in the Historic Center, reflects an architectural evolution from the viceregal era to the remodeling of the 19th and 20th centuries. According to the PROLIMA

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report and on-site observations, its construction combines load-bearing adobe walls and quincha systems that are wooden frameworks, filled with a weave of reed and a layer of mud on which the plaster coating is found with wooden ceilings. Despite subsequent interventions, original features such as pebble floors and wall paintings are still preserved.

However, with the growth of Lima and the need to optimize traffic, many of these structures were buried under stone slabs throughout the nineteenth and twentieth centuries, gradually transforming the urban space and giving way to a more modern subway water distribution system (PROLIMA, 2019).

The property, object of the present analysis, has also been home of outstanding personalities in the social context, being this the case of the Marquise of Torre Tagle, owner in the second half of the XIX century. However, the building achieved great cultural relevance as the residence of Rosa Mercedes Ayarza de Morales, who lived there until her death in 1969. Ayarza, composer, singing teacher and researcher, was a key figure in the development of Lima's music. Her legacy lives on through institutions such as the Escuela Nacional de Arte Lírico, now part of the National Conservatory of Music, as well as her pioneering role as the first woman to conduct an orchestra in Lima. Her impact has spread throughout the country's musical arts, marking a milestone in their development.

The integral restoration of the building was completed in 2022, as part of the Master Plan for the Historic Center of Lima (2029-2035), which was approved in December 2019. The architectural restoration intervention executed in the building has allowed its reconversion as a cultural space dedicated to the traditional music of the Peruvian coast.

This cultural transformation has been a key factor in the consolidation of Lima's cultural identity, while highlighting the intrinsic heritage value of the city of Lima. In this sense, the property not only preserves the legacy of Rosa Mercedes Ayarza de Morales, but also reflects the evolution of Lima's hydraulic and urban heritage, from its vice-royal hydraulic infrastructure to its modernization today (Prolima, 2019).

4.2. Architectural and constructive characteristics of the House Museum: historical and technical analysis

The House Museum, located in the Historic Center, shows a series of architectural and constructive characteristics, whose observation allows tracing its evolution from the viceregal period to the remodeling carried out in the 19th and 20th centuries. According to the archaeological report Casa Rosa Mercedes made by PROLIMA, and based on what was observed during the visits to the site, the building is mainly constructed with adobe load-bearing walls and quincha systems, which are wooden frames, filled with a cane or reed fabric and a layer of mud on which the plaster coating or plaster is found; while wood is used in the ceilings. In spite of the successive interventions, it has been possible to verify that vestiges of its viceregal origin are conserved, such as cobblestone flooring and the mural paintings that adorn the interior of the building.

The House Museum has a spatial organization typical of vice regal houses, with a hallway (zaguan), two courtyards (patios) connected by a side corridor and rooms distributed around these courtyards (Fig. 4), which favors circulation and ventilation. Currently, several rooms house thematic exhibitions aimed at explaining the history of the building and its link to musical culture.

Fig. 4 – Photograph of Zaguan and patio (Diaz, 2023).

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In the analysis of the existing walls, different wall thicknesses were observed, which gives an answer to the different characteristics of the walls. The architect Daniel Flores, current director of the museum and who carried out the restoration project, explained in an interview that there are five types of walls in the building (Fig. 5). The ceramic brick walls correspond to more recent interventions, located on the façade, which shows modifications dating from the 20th century. However, the viceregal stone façade, which is one of the most emblematic elements of the original façade, has been preserved.

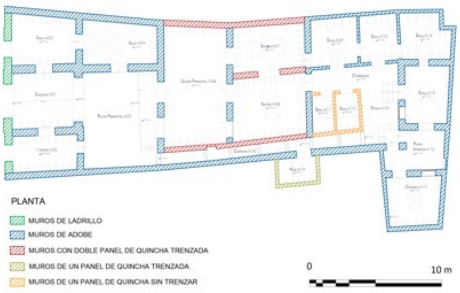

Fig. 5 – *Floor plan of the Casa de la Cultura Criolla. Own elaboration* (Flores, 2024).

The rest of the walls of the building are made of various systems based on adobe and quincha. The use of walls built with a double panel system of quincha (interlaced reeds) with an interior air chamber, as well as walls made of a single panel of simple quincha, stand out. This construction system, characteristic of traditional architecture, is also observed in the walls that delimit the restrooms, which are composed of contemporary quincha panels, made of non-woven reeds and therefore a lighter material.

It is well known that adobe, as a building material, has thermal properties. In the particular case of the quincha wall construction system, Scaletti (2024) examines the performance of the double quincha panel in his article “Double Quincha in Lima, Peru: Innovation, Adaptation and Comfort in the XVII–XIX Centuries”. According to Scaletti's (2024) studies, the thermal properties of double quincha walls show a significant improvement compared to simple quincha and adobe in terms of insulation capacity, buffering and thermal lag (Table 1).

Table 1 – *Thermal properties of components, wall and roof* (Scaletti, 2024).

Wall	Thermal Transmittance (U Value) W/m2·K	Decrement factor	Time lag (h)
Adobe	1.070	0.07	7.11
Viceroyal Quincha	1.563	0.74	4.59
Viceroyal double Quincha	0.778	0.40	9.50
Brick	2.183	0.79	3.98
Concrete	4.245	0.77	3.39
Mud cake (roof)	1.494	0.62	5.20

Although double quincha exhibits similarities to adobe in terms of thermal inertia and lag time, its insulating capacity is superior, resulting in greater efficiency in terms of thermal comfort. This finding is particularly relevant, as double quincha has significant advantages over contemporary construction alternatives.

Regarding the floor systems, PROLIMA's report highlighted the presence of a pebble floor under the modern coatings in the kitchen area, suggesting the preservation of original construction elements. In addition, the presence of a smaller secondary channel projected to the south has been identified, as well as ceramic fragments used to cover the interstices between surfaces. These findings contribute significantly to the enrichment of knowledge about the construction techniques used in the past.

Another architectural element of relevance in the Museo Casa de la Cultura Criolla are the teatinas, zenithal components that were used as vertical windows placed on the roof of the rooms, which were mostly made of wood (Fig. 2). This element has been extensively studied by Wieser, who affirms that the teatinas were systematically used in the buildings of the city of Lima from the middle of the 18th century until the end of the 19th century. These architectural devices served mainly for ventilation and natural lighting. In the

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restoration process of the building, the theatinas were subject to rehabilitation due to the damage caused by xylophages to the wood, including the glass component to protect the restored spaces, allowing their preservation and functionality. With regard to the roofs of the House Museum, a common feature of Lima's buildings can be observed, where the low incidence of rainfall favors the use of flat roofs without a pronounced slope.

With regard to the architectural characteristics of the House Museum, there is a tendency representative of the architectural typology of the Historic Center of Lima, characterized by the presence of flat roofs without a pronounced slope. This configuration, which is manifested in the roof structure, composed of wood, with a framework of beams and joists of rectangular section, which transmit the loads to the load-bearing walls, and an external layer of clay approximately 10 cm thick, used as a protective layer, reflects an adaptation to the climatic environment of the region, where rainfall is scarce.

In addition to its representative value, this element reinforces its spatial functionality due to the presence of the Teatinas integrated into the roof (Fig. 6), which provides improvements in terms of ventilation and natural lighting to the interior spaces.

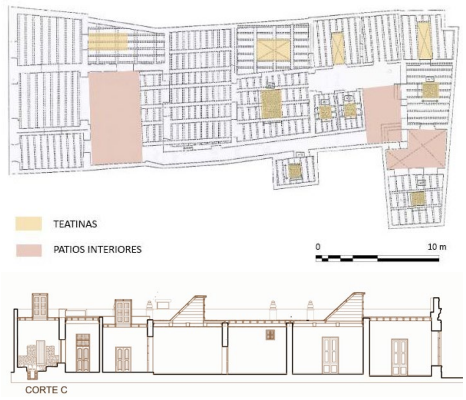

Fig. 6 – *Floor plan and Teatinas Casa de la Cultura Criolla* (PROLIMA Documentary Archive 2022).

The house follows the architectural patterns of viceregal residences described by Hart-Terre and reflects, according to Crespo, a dynamic architecture designed to be inhabited and adapted to the needs of its users. In this case, its transformation into a museum implies a significant change in its original function, maintaining its residential essence while assuming a new cultural role.

In 2022, the building was restored and rehabilitated as the Rosa María Ayarza Museum and House of Creole Culture. It is an outstanding example of viceregal architecture, adapted over time through interventions that respect its original structure. The use of traditional materials such as double wattle and adobe, together with passive ventilation and lighting systems such as the teatinas, highlights the sustainability and effectiveness of ancient construction techniques compared to modern ones.

4.3. Environmental analysis - climate data for the city of Lima

The climate of the city of Lima has features of a temperate climate, characterized by an absence of sudden variations in temperature. This condition is attributed to its geographical location close to the equator and the influence of the Pacific Ocean. For the elaboration of this study, specialized computer tools have been used, such as the CBE Clima Tool software, which has allowed meteorological data to be obtained from reliable sources. Specifically, the data has been extracted from the databases provided by the Meteonorm program, covering the period between the years 2000 and 2019. In addition, the analysis has been integrated with data from the Photovoltaic Geographical Information System (PVGIS-SARAH2), which covers the period from 2005 to 2020.

The results obtained show that the hottest months are between January and March, with a maximum of up to 27.39 °C. On the other hand, the months with the lowest temperatures are observed between June and October, with minimum values of up to 14.17 °C. Finally, the transition months are identified, comprising April, May, November

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and December, where the minimum temperature recorded in the mornings is 14.9 °C, and the maximum, 25 °C. In the Historic Center of Lima, temperatures usually range between 14 °C and 29 °C, although the heat island phenomenon raises temperatures in central urban areas. However, since 2023, the National Meteorology and Hydrology Service (SENAMHI) has reported more extreme variations, reaching 33°C in summer and 10°C in winter.

The behaviour of relative humidity in the city center has been analyzed, observing that it presents a moderate behaviour during the summer months, with a minimum average value close to 52%, and an increase in winter, reaching 78%. The results of the measurements taken in the building bear out the above. The seasonal variability of atmospheric humidity is influenced by local climatic phenomena, such as the presence of low clouds and occasional light drizzle. With regard to temperature and relative humidity parameters, it can be seen that Lima's climate is moderate throughout the year. Rainfall is practically non-existent and solar radiation levels are generally high. Consequently, these conditions allow for thermal comfort during the summer months. However, the House Museum is affected by the existing neighboring buildings, which affects the hours of sunlight on the building.

The analysis carried out using Revit software (Fig. 7) reveals that at 7:00 a.m., the building is completely covered by the shadow of the adjacent building to the east; at 6:00 p.m., the building is completely shaded by the adjacent building to the west; and at 1:00 p.m., part of the analyzed building is shaded by the adjacent building to the west.

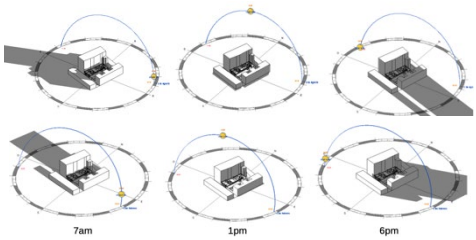

Fig. 7 – *Solar Path, Revit Software* (Author, 2025).

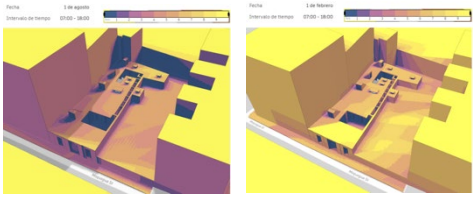

Fig. 8 – *Hours of sunshine, Autodesk Forma Software* (Author, 2025).

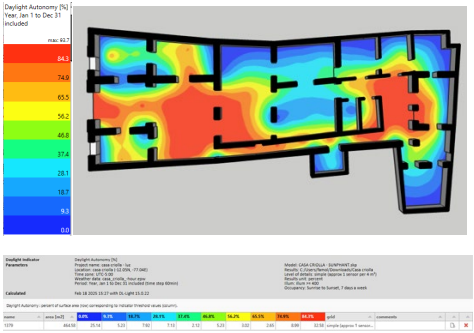

Fig. 9 – *Optimization of the use of natural light (400 lux), De Luminae Software* (Author, 2025).

Finally, the optimization of natural light in interior spaces was analyzed, considering the function of the building and establishing illumination levels of 400 luxes necessary for museum use (Fig. 9).

The results obtained are presented by year, the red tones determined that 84. 3% of the hours in a year, the spaces exceed 400 lux of natural light and the blue-toned spaces never exceed 400 lux of natural light, as this level of light is never reached.

5. Discussion

One of the main challenges facing the restoration of the Casa Museo building and in temperate climates such as Lima's, lies in the need to achieve a balance between the conservation of the original structure and the incorporation of modern solutions, both in terms of energy and accessibility.

Adapting the building to contemporary standards of safety, accessibility and energy efficiency without compromising its historical value is a complex task.

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On the other hand, Lima's temperate climate offers a unique opportunity for the development of sustainable solutions based on passive design and efficient energy use. Taking advantage of the building's natural features, such as thermal inertia and natural lighting, is advantageous for reducing the museum's energy footprint.

Furthermore, the growing interest in architectural heritage and sustainable practices has the potential to transform this type of building into reference models for the rehabilitation of historic buildings globally.

6. Conclusions

The conservation of earthen architectural heritage in historic centers located in temperate climates requires a methodology that integrates technical aspects and sustainable solutions adapted to the climatic and social particularities of the environment.

The exhaustive evaluation of the state of conservation, the use of ecological materials and the implementation of renewable energies and passive design principles are essential to preserve these buildings without compromising their sustainability. In this sense, the rehabilitation of buildings such as the so-called house museums not only contributes to the conservation of architectural heritage, but also stands as a model of best practices for the restoration of traditional architecture in contemporary urban contexts.

Museums built with adobe in temperate climates face challenges derived from humidity, thermal variations, constant maintenance and compliance with modern regulations. However, they also offer valuable opportunities, such as energy efficiency, strengthening of cultural identity, environmental sustainability and boosting tourism. To maximize these benefits and reduce risks, a design that combines traditional techniques with contemporary innovations is essential, ensuring functionality, safety and heritage authenticity.

Acknowledgements

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Compressed Stabilized Earth Blocks for Improving the Durability of an Ancient Technique

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Abstract
In both ancient and contemporary times, structural earthen building elements have been produced on the basis of a mix, where the main raw material (sufficiently clayey earth) is combined with other ingredients with different functions: to increase the mechanical characteristics; to decrease the shrinkage during drying; and to stabilize the mixture. The problem of the perishability of earth building materials has been a well-known critical issue (especially for its vulnerability to water), which has been faced with different technical and design strategies, as well as maintenance strategies. The goals of reducing emissions and limiting the erosion of non-reproducible natural resources in the building sector have favoured research into earthen construction as an appropriate alternative for contemporary scenarios in recent decades. In particular, numerous studies have focused on the stabilisation of earthen bricks or blocks, mainly using lime and cement as additional binders to the clay component of the earth, in order to counteract perishability and increase mechanical strength. The technique of compressing the blocks before drying has significantly increased the material's performance for structural elements. The paper proposes a general overview of research focused on the stabilisation of compressed earth blocks (SCEB). The ambition to modernise this building material, which has considerable current potential, by linking it to more distant uses, is the cultural context of reference for this study.

Keywords: *stabilized compressed earth block (SCEB); perishability; durability*

1. Introduction

The use of unfired earth in construction has a thousand-year-old tradition, which covers most of the geographical areas where man has built stable settlements during his existence. The use of unfired earth, which has been widespread since ancient times, both for the construction of load-bearing structures and for the finishing elements, has found different expressions according to the geographical contexts and natural resources present in the areas, which have been used as aggregates or stabilisers of various types to improve performance in terms of durability and resistance, especially to the action of atmospheric agents. The main characteristic of unfired earthen building techniques is that the mixture hardens without firing. This peculiarity concerns both the adobe technique, in which the bricks are moulded and then laid, and the technique of rammed earth and moulds by formwork. In both cases, and more generally in all unfired earth constructions, another aspect that distinguishes this building material is its environmental sustainability. In

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fact, greater use of this building material could help to limit, on the one hand, the depletion of non-renewable natural resources and, on the other, the production of climate-changing gases, both phenomena to which in general the building sector contributes significantly, especially in richer countries: «In G7 countries alone, material efficiency strategies, including the use of recycled materials, could reduce greenhouse gas emissions in the material cycle of residential buildings by over 80 per cent in 2050» (UNEP 2022, XXI). In spite of the reasons that would favour the diffusion of unfired earth in construction, there are still immaterial and material obstacles that prevent it. With regard to the former, earthen techniques remain confined to an operational niche because they generally elude standardisation and normalisation, and because they require constant rather than occasional maintenance, which is fashionable in the absence of an authentic and socially shared maintenance culture. For the obstacles of a material order, the intrinsic perishability prevails over all (Germanà, 2023). In the light of these considerations, the theme of revitalising raw earth as a building material for contemporary sustainable architecture, if it is not to remain in vain, must confront and overcome these obstacles under the banner of a unified approach to managing knowledge (Masera, 2011).

2. Objectives and methodology

Despite the fact that the use of unfired clay in the building sector is a subject that is frequently explored and studied in the world of research, the same cannot be said for technicians and designers, who in most cases remain unfamiliar with the acquisition of earthen techniques skills. Even the recognition and identification of ancient architecture or individual elements made of unfired earth has made the dissemination of analytical and contemporary studies of specific applications useful for appropriate cognitive processes more complex. In this context, it is appropriate to highlight how a niche of the scientific and academic world is increasingly questioning the use of stabilised unfired earth as an alternative to contemporary construction techniques that have a heavy environmental impact, with the aim of preserving, enhancing and updating ancient building forms in line with the principles of environmental sustainability. Compacted earth blocks are becoming increasingly popular, as they counteract the perishability of traditional techniques with enhanced characteristics such as mechanical and abrasion resistance. It is precisely the reduced resistance to weathering and the need for repeated maintenance and restoration practices that has stimulated the research community to investigate stabilisation processes for the contemporary use of unfired earth as a structural material.

Within the different stabilisation processes of unfired earth, the focus of the present contribution is to increase the knowledge process regarding the realisation of Stabilised Compressed Earth Blocks (SCEB). The Palermo Research Unit is moving in this direction within the project "Earthen Heritage in the Eastern Mediterranean between Archaeology and Sustainability" (EARTHERITAGE). From a methodological point of view, a general review of the state of the art on the subject of raw earth stabilisation represents the cognitive basis on which the protocol of experiments currently underway is being defined. The analysis focused on 24 researches among those produced since 1997 (Table 1). These researches were developed in different continents: 5 from Asia (Al-Rawas et al., 2005; Greepala et al., 2008; Deepika et al., 2016; Ma et al., 2017; Kumar & Singh, 2022); 5 from Africa (Bahar et al., 2004; Millogo & Morel, 2007; Izemmouren et al., 2014; Busieney et al., 2014; Adedokun et al., 2014); 5 from Europe (Morel et al., 2007; Galàn-Marín et al., 2010; Maskell et al., 2014; Maskell et al., 2015; Scalisi & Sposito, 2015; Lozano-Lunar et al., 2018; Ouedraogo et al., 2019; Scalisi & Sposito, 2019; Rivera et al., 2021; Lam et al., 2023); 3 from America (Yong & Ouhadi, 2007; Lima et al., 2012; Villamizar et al., 2012); 1 from Australia (Walker & Stace, 1997).

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Table 1 – *Research on stabilising component of earth blocks* (authors, 2024).

#	Year	Country	Type of soil	Stabilizer 1 (cement; lime)	Stabilizer 2 (others)	Reference
1	**1997**	Australia	Soil from mixing dark and red soil	Cement and lime	No one	Walker & Stace, 1997
2	**2004**	Algeria	Clay soil	Cement	No one	Bahar et al., 2004
3	**2005**	Oman	Clay soil	Cement and lime	Sarooy(artificial pozzolana)	Al-Rawas et al., 2005
4	**2007**	Unjted Kingdom	Clay soil	No one	No one	Morel et al., 2007
5	**2007**	Burkina Faso	Clay soil	Lime	No one	Millogo & Morel, 2007
6	**2007**	Canada	Marly soil	Cement and lime	No one	Yong & Ouhadi, 2007
7	**2008**	Thailandia	Lateritic soil	Cement	Sugarcane bagasse ash	Greepala et al., 2008
8	**2010**	United Kingdom	Clay soil	No one	Alginate and sheep wool fiber	Galàn-Marín et al., 2010
9	**2012**	Brasil	Clay soil	Cement	Sugarcane bagasse ash	Lima et al., 2012
10	**2012**	Colombia	Clay soil	Cement	Cassava peels and coal ash	Villamizar et al., 2012
11	**2014**	United Kingdom	Clay soil	Cement and lime	No one	Maskell et al., 2014
12	**2014**	Algeria	Clay soil	Lime and sand	No one	Izemmouren et al., 2014
13	**2014**	Kenya	Soil (not specified origin)	Cement	Sugarcane bagasse ash	Busieney et al., 2014
14	**2014**	South Africa	Sandy loam soil	No one	Sugarcane bagasse ash	Adedokun et al., 2014
15	**2015**	United Kingdom	Dark brown sandy silt soil	Cement	Metakaolin	Maskell et al., 2015
16	**2015**	Italy	Clay soil from Sicily	Cement and sand	Laponite	Scalisi & Sposito, 2015
17	**2016**	India	Not specified type of soil	Cement	Sugarcane bagasse ash	Deepika et al.,2016
18	**2017**	China	Clay soil	Cement	Fly ash	Ma et al., 2017
19	**2018**	Spain	Siliceaous sand	Cement and lime	Electric Furnace	Lozano-Lunar et al., 2018
20	**2019**	France	Quarryfines and soil with quartz	Lime	Natural polymers (polysaccharides and protein)	Ouedraogo et al., 2019
21	**2019**	Italy	Clay soil from Sicily	Cement	Halloysite	Scalisi & Sposito, 2019
22	**2021**	Portugal	Clay soil	No one	Fly ash and glass waste	Rivera et al., 2021
23	**2022**	India	Clay soil	Cement	Sugarcane bagasse ash	Kumar & Singh, 2022
24	**2023**	France	Clay soil	GGBS	No one	Lam et al., 2023

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This shows that the issue of stabilising the unfired earth is widely shared by a large part of the international scientific community. Of the papers analysed, 12 deal specifically with compacted blocks (Walker & Stace, 1997; Morel et al., 2007; Bahar et al., 2004; Lima et al., 2012; Villamizar. et al., 2012; Busieney et al. ,2014; Izemmouren et al., 2014; Adedokun et al., 2014; Scalisi & Sposito, 2015; Deepika et al., 2016; Scalisi & Sposito, 2019; Rivera et al., 2021), while the others refer to not compressed blocks. The study presented here has highlighted the components of the mix designs used in the previous research, in order to guide the experiments to be carried out in the EARTHERITAGE project. The first component is obviously the soil, whose clay content, which is not always specified in the research reviewed, is considered optimal at between 15 and 30% (Walker & Stace, 1997). The components of the mix design that will be discussed in more detail here are the stabilisers, which are used to improve the binding capacity of the clayey soil and, in particular, to increase the mechanical strength and abrasion resistance, which are fundamental aspects for the durability of the building material. The other ingredients, which are not specifically related to the stabilising function, will not be discussed in detail here: fibres, which are mainly used to reduce the shrinkage effect during the setting of the mix, and which are only mentioned in a few of the studies analysed, such as those that specify the addition of of reeds, straw or other natural fibres (Galàn-Marín et al., 2010; Scalisi & Sposito, 2015); glass from industrial waste or recycling (Maskell et al., 2015; Lozano-Lunar et al., 2018; Rivera et al., 2021).

In terms of stabilisers, ordinary Portland cement (Walker & Stace, 1997; Bahar et al., 2004; Amer Al-Rawas et al., 2005; Yong & Ouhadi, 2007; Greepala et al., 2008; Lima et al., 2012; Villamizar et al., 2012; Maskell et al., 2012; Izemmouren et al., 2014; Busieney et al., 2014; Maskell et al., 2015; Scalisi & Sposito, 2015; Deepika et al., 2016; Ma et al., 2017; Lozano-Lunar et al., 2018; Scalisi & Sposito, 2019; Kumar & Singh, 2022) and lime (Walker & Stace, 1997; Al-Rawas et al. 2005; Millogo & Morel, 2007; Yong & Ouhadi, 2007; Maskell et al., 2012; Izemmouren et al., 2014; Lozano-Lunar et al., 2018; Oueadrogo et al., 2019) were the most commonly used, accounting for 70% and 30% respectively of the studied cases. The addition of ordinary Portland ranged from 4% to 40% of the mixtures tested. More recent research has experimented with the additional components, to further stabilise the earthen blocks. These are organic binders or bio-based materials (Greepala et al., 2008; Lima et al., 2012; Villamizar et al., 2012; Busieney et al., 2014; Adedokun et al., 2014; Deepika et al., 2016; Ma et al., 2017; Kumar & Singh, 2022), or nanostructured materials such as laponite and aloisite (Scalisi & Sposito, 2015; Scalisi & Sposito, 2019), or natural polymeric materials such as polysaccharides and proteins (Ouedraogo et al., 2019). In the area of stabilisers, the use of materials derived from agri-food waste is worth mentioning. This trend seems to be becoming more and more widespread as part of the production cycle, which involves the reuse of materials that were previously considered only as waste to be disposed of (Germanà & Kharrat, 2025). With regard to stabilisers from agri-food wastes, the prevalence of research conducted in countries where earthen structures represent an important part of the built heritage and a cultural identity to be protected and preserved was noted (Bahar et al., 2004; Al-Rawas et al., 2005; Millogo & Morel, 2007; Villamizar et al., 2012; Izemmouren et al., 2014; Adedokun et al., 2014; Busieney et al., 2014; Deepika et al., 2016; Kumar & Singh, 2022). Some of the case studies addressed, for example in India (Kumar & Singh, 2015), in Kenya (Busieney et al., 2014) or again in Thailand (Greepala et al., 2008), have used ash from the disposal of sugar cane as a natural additive that allows the development of natural stabilisers that can complement cement.

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Specifically, the inclusion of between 8 and 10 % sugarcane bagasse ash increased 50% compressive strength. Another agri-food waste being experimented in Colombia is ash from the disposal of cassava peels, which again allows for lower cement use, with an increase in compressive strength (Villamizar et al., 2012).

3. Results

A review of the scientific literature on the stabilisation of unfired clay blocks has shown that the problem of the perishability of this building material has been widely addressed by the scientific community over the last 30 years. In general, the studies confirm that the mix designs, which depend on the type of soil used and on the local materials available, allow a significant increase in the strength properties and, in the case of bio-based or waste stabilisers, also in the environmental sustainability of the product. In particular, the incorporation of ordinary Portland cement increases mechanical strength by an average of 50%. By adding between 5 and 10% of ordinary Portland cement, in addition to achieving a significant increase in the compressive strength of the compressed blocks, less than 10% of the energy normally required to produce a fired clay brick or structural concrete element was used (Deepika et al., 2016).

It should be emphasised that the diversity of the scientific reference contexts of the experiments studied is a critical point, as it makes it difficult to fully compare the results. In fact, the different regulatory frameworks have led to a diverse panorama of protocols used in the different experiments. For example, in the case of mechanical resistance to compression, the comparison of the results of the different studies is complicated by the different ways of presenting the data, which in some cases are expressed as percentages and in others as volumetric ratios. It should also be noted that all the studies analysed, with the exception of a few (Walker & Stone, 1997; Bahar et al., 2004; Millogo & Morel, 2012; Greepala et al., 2008; Lima et al., 2012; Villamizar et al., 2012; Deepika et al., 2017; Ouedraogo et al., 2019; Kumar & Singh, 2022), focus on increasing compressive strength, neglecting flexural and abrasion resistance, shrinkage and sample absorption. These tests are basic analyses aimed at identifying mix designs capable of reducing the perishability of earthen structures and making them easier and more convenient to maintain and manage. Finally, it should be remembered that the scientific results of the laboratory experiments should be reinforced by the increasing number of operational applications, with in-situ tests on buildings constructed with SCEB (Figs. 1 & 2).

Fig. 1. – *GDA Sidi Amor Int. Summer School (Tunisia). Construction with earth blocks* (Germanà, 2023).

Fig. 2. – *SCEBs produced by SOIB, Bizerte (Tunisia).* (Germanà, 2023).

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4. Conclusions

The use of compressed, stabilised, unfired earth block as a building material is one of the most topical issues in the field of sustainable architecture, both in terms of reducing building emissions and in terms of preserving and actualise ancient earthen building techniques. For this last aspect, the research unit of the EARTHERITAGE project at the University of Palermo is carrying out some experiments aimed at improving the durability of this building material. The experiments are being carried out in collaboration with Guglielmino s.r.l., a company that has been working in the field of green building and unfired earth in Sicily for decades, often in collaboration with the University.

Despite the difficulties encountered in comparing the results of experiments in the scientific literature available to date, this study was essential to identify the mix design to be used to carry out new, original and useful experiments. Given the prevalence of ordinary Portland cement in the research carried out to date, and the need to use at least a certain percentage of cement to achieve a significant improvement in performance, the need to find an alternative cement whose production had a lower impact, certified by the relevant EPD (Environmental Product Declaration), became apparent.

A path that the EARTHERITAGE project intends to follow, and which has already been indicated by research carried out to date, such as the use of GGBS (Ground Granulated Blast Furnace Slag) (Lam et al. 2023), is the combination of cement with other stabilisers in order to reduce the component with the heavier environmental impact (in terms of use of non-renewable natural resources and emission of climate-changing gases). This is done in the awareness that the revival of unfired earthen building techniques (especially in structural applications) and their diffusion in cultural contexts where they have never been widely used or have been completely forgotten, must respond not only to environmental sustainability, but also to the increase of all performances related to durability.

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Difficulties and Opportunities for the Conservation of the Convent of San Bernardino in Cuenca de Campos, Valladolid. The Task of the 'Rehabitar Tierra de Campos' Foundation

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Abstract

The convent of San Bernardino in Cuenca de Campos, Valladolid, is a medieval building that has been suffering a process of deterioration since the beginning of the 20th century. The great economic difficulties of the congregation led them to sell the Mudejar coffered church ceiling in the 1920s. Today, the polychrome ceiling of the convent church is in the palace of the famous millionaire William Randolph Hearst, in California, along with many other treasures of Spanish art and architecture. The exclaustration of the nuns in 1967 and the sale of the convent to some farmers in the town accelerated its deterioration. Since the beginning of the 21st century, the building has been seriously threatened by ruin. In view of its deterioration and to guarantee its conservation, the 'Rehabitar Tierra de Campos' Foundation was created in 2018. This Foundation purchased part of the convent, with the support of numerous people concerned about the decline of many of the most unique heritage elements of the region, such as the traditional architecture. The purpose of the Foundation is to warn of the deterioration of the convent building and the architectural heritage throughout the region, while making its value known and placing emphasis on the risk of losing it. On the other hand, the aim is to find economic and social support for the building of the old monastery. The great difficulty for the Foundation is to obtain the necessary funds to stop the material deterioration of the building, as the region is subject to a great economic and population crisis: Cuenca de Campos is located in the center of the so-called 'España vaciada' (emptied Spain). At the same time, it is necessary to create a use for the old convent that allows it to continue, through a productive activity that guarantees its solvency and sustainability: the 'Tierra de Campos Architecture Rehabilitation Center'.

Keywords: *management and maintenance of historical buildings; restoration and conservation of earthen architecture; intervention and regeneration projects*

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1. Introduction

The convent of San Bernardino de Siena in Cuenca de Campos, in the province of Valladolid, is a group of buildings with origins in the Late Middle Ages. Founded in 1455, it was originally a medieval palace, which the Poor Clare nuns gradually transformed until it became a monastery, with a church and cloister, according to the Benedictine model (Fig. 1). The Poor Clare nuns abandoned the convent and sold it in 1967. The new owners, two brothers, farmers from Cuenca, used the convent premises as a home, warehouse, bakery, cellar, garage, etc.

2. Territory and society

Cuenca de Campos is located in the so-called "Tierra de Campos", a geographical area that is in the community of Castilla y León, Spain. It is a large plain dedicated to the cultivation of cereals and where the architecture has traditionally been based on the use of earth as the main construction material. This area has a rich legacy of earthen architecture, in which the typical farmer's house and buildings dedicated to agricultural work stand out. But there is also a rich architectural heritage legacy that includes castles, palaces, temples and monasteries or convents. Within the latter is the former convent of San Bernardino, in the town of Cuenca de Campos. The area is currently suffering a long economic and population decline, belonging to the so-called "emptied Spain".

3. The origin of the Rehabitar Foundation

Faced with the increasing deterioration of the church of the San Bernardino Convent in Cuenca de Campos (Valladolid) and the threat of its complete disappearance, a group of people from the town, and others, created a non-profit foundation, the 'Fundación Rehabitar Tierra de Campos', led by the then mayor of the town,

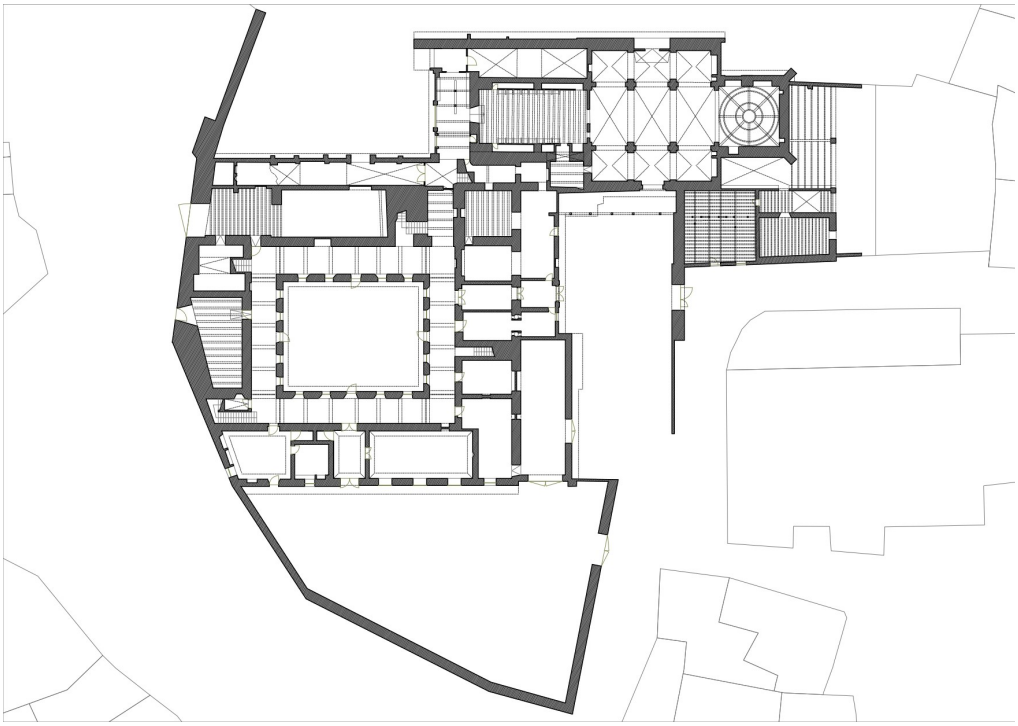

Fig. 1 – *Ground floor of the convent* (Fundación Rehabitar Tierra de Campos).

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Faustino González Miguel. The Foundation acquired the northern part of the convent, the most deteriorated and threatened area, and obtained funds from public administrations to rehabilitate the most damaged part, which was the roof of the nuns' choir and the roof of the apse.

The main objective of the Foundation was to stop the deterioration of the building. At the same time, efforts were initiated to give the complex a use that would allow an active presence, generating a permanent and continuous dynamism. In this way, it was possible to gather a number of people committed to the region and the heritage, who contributed significant financial amounts for the purchase of the northern part of the convent, as well as for the first repairs. These people had very heterogeneous characteristics; there were technicians, farmers, officials, businessmen, etc. There was, however, a common factor, their interest in the heritage and the economic and social development of the Tierra de Campos region. Initiatives and activities were first proposed that would contribute to the maintenance and adaptation of the heritage built using earth, the creation of employment and the repopulation of the region.

Fig. 2 – *Coffered ceiling of the "Count's room" in the Diocesan Museum of Palencia* (Meraz).

The central axis of the activity was to protect the cultural heritage of the region, undervalued and little known, and to promote economic development. At the same time, to establish permanent use there, it was proposed to recuperate the convent by turning it into a Training and Study Center for traditional architecture and historical and cultural heritage, which would contribute to the revitalization of the Tierra de Campos region.

4. The decline of the Convent of San Bernardino and its causes

It should be noted that the convent had been suffering great deterioration since the departure of the nuns, and the decay of various parts of the temple was especially severe. This deterioration was accelerated by inadequate interventions, sales of the most valuable pieces and replacements on the roof and walls. On the one hand, the fragility of the new roof of the church and the so-called "Count's room" increased when its coffered ceiling was dismantled; and on the other, the drilling of large holes in the walls increased the fragility of the complex.

These two factors generated changes in the general structure of the building and weakened its resistance. It is necessary to consider how the replacement of the church roof was carried out, when the nuns sold approximately 400 m2 of polychrome wooden coffered ceiling that covered the entire temple around 1925. The procedure carried out to remove the coffered ceiling, which affected the entire church, is not clear, but it is evident that the braces that held the walls were eliminated and this gave rise to cracks in the vaults, derived from the lateral thrusts and, consequently, exacerbating the inclination of the walls. In the case of the coffered ceiling of the "cuarto del conde" (Count's room), it was dismantled and transferred to the Diocesan Museum of Palencia when the nuns left in 1967 (Fig. 2). In this case, it is clear that the new roof was insufficient, as it was the first to collapse, being one of the earliest points to cause problems.

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Indeed, the roof began to leak and the entire area was poorly repaired at the beginning of this century with the inclusion of temporary roofs until it finally collapsed. Finally, the new owners who bought the convent from the nuns adapted the rooms to their needs. The opening made in the wall of the church in the northern area was another source of damage. The owner made a hole in the north wall for a large gate to access the interior with his agricultural machinery, mainly tractors, for safekeeping in the central nave of the temple. It was done without taking into account the functionality of the elements it affected, without joining up the separate parts and without understanding the functionality of the wall in the building as a whole. (Fig. 3).

Fig. 3 – *Opening in the north wall of the church, giving access to agricultural machinery* (Fundación Rehabitar Tierra de Campos).

Fig. 4 – *Photo of some of the attendees at the 2006 Earthen Architecture Congress* (Fundación Rehabitar Tierra de Campos).

This decline was accentuated because the damage remained unrepaired due to the high cost. The danger of ruin was evident to the numerous people who visited the convent in those years, and this led to the search for a solution. Thus, for several years in which the 'Congresos de Arquitectura en Tierra', organized by the 'Grupo Tierra' of the University of Valladolid, was held in Cuenca de Campos, those attending the congress visited the convent. Over the years, they were able to appreciate the building's decline (Fig. 4). The initiative of the Mexican professor Leonardo Meraz, to carry out an in-depth study of the convent, arose from these visits. Indeed, for three years, this professor organized a Documentation Workshop, with the participation of the Metropolitan Autonomous University of Mexico (Meraz, 2018).

5. The value of the Convent of San Bernardino and cost of conservation

The Convent of San Bernardino de Siena is a group of buildings whose cultural and historical value no one doubts. At the same time, its great economic value must be highlighted. However, the cost of repairing the monument is extraordinarily expensive, a consequence of more than a century of disinvestment, lack of protection and abandonment. For private owners, its repair has been very difficult, although it is noteworthy that the owners of the southern part (which contains the rooms and cells around the cloister) have been able to maintain their property with dignity, based on a continuous work of small repairs. The northern part, basically the church, is more vulnerable, and has fallen into a spiral of deterioration that has not yet ended. The public administration has financed small one-off repairs, but until now it has refused to address the large and expensive works that the temple needs.

In view of the progressive ruin of the convent, the Foundation has achieved the inclusion of the convent in the 'Hispania Nostra Red List', which includes those elements of Spanish cultural heritage in danger, with the aim of making them

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known and achieving their consolidation or restoration. The steps to be taken from now on are aimed at obtaining private funds for the repair of the temple through the launch of a crowdfunding campaign among companies and individuals to obtain financial funds to consolidate the building and develop the objectives of the Foundation; help is also being sought from the administrations .[1]

6. Creation of the 'Rehabitar Tierra de Campos' Foundation

After contacting numerous people interested in the conservation of heritage in earthen architecture, together with numerous residents of Cuenca de Campos and Tierra de Campos, and at the initiative of the mayor of Cuenca de Campos, Faustino González, a first meeting took place on March 3rd, 2017. This was the start of the work to establish a foundation whose main objective was the conservation of the Convent of San Bernardino, especially the northern part, the most deteriorated, through its acquisition. The 'Rehabitar Tierra de Campos' Foundation was publicly presented on February 22nd, 2018 in the Aula Triste of the Palacio de Santa Cruz, the Rectorate building of the University of Valladolid.

7. Why buy and try to rehabilitate a ruined convent?

Because it is a historical and cultural heritage of great value that is part of our society and this is clear from looking at its walls. Many people believe that the initiative to buy and rehabilitate a ruined convent is the work of crazy, but enlightened people, and that only a large amount of money, accessible to millionaires, is the solution. Since that amount of money is difficult to obtain, the answer is obvious to these people: there is no solution, there is no future for the convent and it is better to let it fall down completely. On the contrary, little by little, with small actions, which involve small interventions and small amounts of money, the convent of San Bernardino can be preserved, if people's trust is gained and their economic and also moral support, as well as the people, companies, organizations and administrations interested in the objectives and activities of the 'Rehabitar' Foundation.

8. The convent of San Bernardino de Cuenca de Campos considered as a document that narrates a part of the region's history

The different studies on the San Bernardino convent in Cuenca de Campos have revealed the great value of the said property, despite its precarious state of conservation. As a summary of its value, revealed by the different studies carried out, the following aspects can be highlighted:

The Convent can be considered as a constructed document that speaks of our society throughout various periods, a history linked to the territory of Castile, and especially to the region of Tierra de Campos, which explains its occupation in the Middle Ages and its transformation throughout the following centuries until the present day. The convent building is a reliable document of the history of the Tierra de Campos region, currently responding faithfully, with the decay of its walls, to the economic decline and depopulation that has been occurring in the region for more than a century. Its position in the territory is very clear; when the repopulation of the region took place in the Early Middle Ages, a small mound in the territory, the castle, was used as a defensive enclave.

[1] Available at: https://listaroja.hispanianostra.org/ficha/monasterio-de-las-claras-de-san-bernardino-de-siena/

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Once the Muslim threat had disappeared, it was transformed first into a palace and later into a female convent. Its decline responds to the decline of the religious orders, which strongly affected the monastery, causing the exclaustration of the nuns and the sale of the building. At the same time, its walls are an exponent of the different phases of religious architecture of the time, with a wide sample of the styles of female religious orders over five centuries.[2].

During the 19th and 20th centuries, numerous violations of the region's cultural heritage occurred. The vulnerability of the ancient religious centers left their treasured movable assets —paintings, altarpieces— in a truly vulnerable situation. They were sold to private individuals; at the same time, their walls crumbled under the impetus of modernity. The monasteries were abandoned, and their buildings were converted into farms strictly for agricultural and livestock purposes, as well as cheap quarries for building materials (Martínez-Ruiz, 2018, p. 257).

One of the saddest episodes is that of the sale of the Mudejar coffered ceiling of the church to the American magnate Williams Randolf Hearst and its transfer to California (1925). Furthermore, it is worth highlighting, in the set of buildings that make up the convent, the prominence of architecture in which earthen construction materials dominate (in the forms of rammed earth, adobe, plaster), in a period spanning five centuries, in which we can study the innumerable ways of solving the needs of the religious community, through various solutions full of imagination and inventiveness, in a continuous process of use and reuse of the same materials.

Many unique architectural elements are still identifiable in the convent, such as the medieval wall, which stands out for the size of the enormously wide sections of earth. Also noteworthy are the remains of the so-called "Count's room", whose coffered ceiling was dismantled, transferred to Palencia, and is currently exhibited in the Diocesan Museum of Palencia[3]; as well as the remains of arches from the medieval palace, prior to the convent, with pieces of wood and stone reused here and there, distributed throughout the convent. An in-depth investigation remains to be carried out on the sale of the Mudejar coffered ceiling to William Randolph Hearst. It is essential to identify in detail the different parts of the convent, in order to refine the instruments of intervention, when conserving and intervening in this heritage.

9. The Earthen Architecture Rehabilitation Center

With these premises, the means to achieve these objectives is to establish a Training and Advisory Center based in the Convent of San Bernardino in Cuenca de Campos, a Center around the traditional architecture and heritage of Tierra de Campos, paying special attention to the earthen architecture, contemplating the study of the materials used, the techniques developed by its builders, and the heritage it has generated, including new advances in materials and technologies. All of this aims to promote, as an ultimate goal, the settlement of new residents in the Tierra de Campos region, through the creation of a hub of activity around the historical places of the territory of Castile & León, and specifically the unique Convent of San Bernardino de Siena in Cuenca de Campos.

[2] The complexity of the group of buildings that make up the Convent of San Bernardino is notable. An introduction to the study of the different parts of the convent can be found in "Anexo 1. El rompecabezas de barro" by Pedro Villalón (Meraz, 2018).

[3] Some of the sections of the medieval wall are identifiable on the current plan of the convent, which is perfectly in line with its history, since Cuenca de Campos was a "well-fortified place with walls and ditches." Cited by Ortega Rubio, J. (1805).

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Fig. 5 – *Condition of the church entrance after the collapse on 2-1-2025 (*Fundación Rehabitar Tierra de Campos).

The Foundation is a project open to all those people, institutions and companies that want to contribute with their activity to its objectives and purposes.

There is a direct relationship between the formation and conservation of heritage. There is currently an absolute lack of labor with experience in the rehabilitation of traditional architecture.

In relation to earthen architecture, it is not advisable to stop carrying out awareness-raising and training actions, with informative courses and construction practices, training technicians and workers through rural centers and schools for the impact and positive consequences they bring to training in the sector.

The 'Rehabitar Tierra de Campos' Foundation, in the same way that is being done from training centers in other regions, will surely be one of the future drivers of training in earth construction that we hope to develop in Castile & León.

10. The collapse of the south wall of the church

On February 1st, 2025, a new misfortune occurred; as a consequence of this long process of decay, the south wall of the church collapsed (Fig. 5). The wall was exposed to the rain, while being pushed by the vaults of the church, creating a great weakness.

Its fall has made the belfry more vulnerable, which is now without the support of the wall and this has increased the threat of its demolition.

During these past years, we have seen pieces of the convent fall, the rain has been washing away the earthen walls, and the cracks have been getting wider and wider. We hope to stop the deterioration process and save the monument.

11. Conclusions

The convent of San Bernardino in Cuenca de Campos is a set of buildings of great cultural, historical and economic value.

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The conservation of this monument is an essential task that must be addressed by society as a whole, one that will help the recovery of the Tierra de Campos region. Only inefficacy and ignorance can justify its disappearance.

At this time, its rehabilitation, maintenance and conservation in a good condition is a great challenge. The economic difficulties of the region can be overcome through the modest contribution of the 'Rehabitar' Foundation and other similar associations that value our immense cultural heritage, by means of dissemination activities through an organization that brings together most of the initiatives.

Despite the economic sluggishness of the region, it is necessary to consider that the Convent of San Bernardino (and with it the cultural heritage of the entire region) is one of the essential bases for economic revitalization, through its promotion, dissemination and maintenance.

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Status and Protection Strategies for Low-Grade Vernacular Architectural Cultural Relics in Rural Chungking, China

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Abstract

The National Cultural Relics Census in China once predominantly focused on high-grade architectural relics with significant iconic value and r conservation status. This research, taking Chungking China as a study case, has identified a large number of traditionally undervalued rural architectural relics that are rapidly disappearing amidst the urbanization process. The study, focusing on the protection of low-level rural relics in Chungking, China, proposes recommendations for extensive surveys, the establishment of databases, and digital conservation. It also discusses the potential for preserving the most genuine rural historical culture and the transmission of artisanal wisdom through public cultural activities and artistic creation.

Keywords: *Chinese rural vernacular culture; Chungking region; low-grade relics; conservation strategies*

1. Introduction

China is conducting the fourth national cultural relics census to get accurately information about the preservation. Previous census highlighted architectural relics with iconic value, and have allocated considerable human, financial, and material resources for conservation. There is high anticipation for new discoveries of such relics in the ongoing census. However, it is regrettable that dispersed, small-scale, and rural relics have seldom received high classification in past surveys, leading to lack of management, such as limited funding and maintenance. Compared to architectural relics with large scales or volumes, these rural low-grade relics, closely related to local life.

Although they possess distinct rural historical characteristics and cultural identities, are not large in scale and lacking in eye-catching splendour and lost in large numbers, with many cultural details being lost before they can be understood and protected.

China society rooted in the rural areas. The low-grade rural relics continue to play significant role in the daily lives. As the national cultural relics census advances once again, it is better to emphasis the strategies to salvage the most genuine rural grassroots historical culture and the transmission of craftsman wisdom.

2. Investigation methodology

According to the data of the previous three cultural relics surveys and Chungking as an example, the research focused on the low-grade rural cultural relics.

China cultural relics protection level is divided into national, provincial, city/county types. The statistics show that 90% of the small volume of

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rural cultural relics in Chungking is rated as the third level (Chongqing Culture Relic Department, 2012). For example, ramming earth Watch tower, only one in Yunyang of Chungking has become first-level cultural relic, and the rest are third-level cultural relics. The disparity of public protection funds determined by grade difference is very large, and the architectural cultural heritage of low-grade has received very poor attention and financial support.

It can be found that with the development of urbanization, the number of low-grade cultural relics continues to shrink. For example, the number of the ramming Watch tower, from 1010 in the second census reduced to 250 in the third, the data reduction is extremely surprising but also reflects that the immovable cultural relics with lower grades are actually difficult to be protected in a real situation.

Field investigation showed that due to natural loss, as well as irreversible environment damage, the extinction of materials and techniques, and the change of life style, a large number of traditional countryside heritages have been destroyed and disappeared. The low-grade cultural relics originally covered during the third census period have lost their protection value. While some valuable cultural relics are not on the census list. In general, the protection of low-grade cultural relics in Chungking is not ideal.

3. Sample Research Background

Chungking is mountain city with continuous immigration over thousands of years, resulting in the formation of traditional vernacular dwellings and life equipment in the countryside for defensive purposes. These dwellings, belief and transportations equipment integrate culture and craftsmanship to satisfy the humid and rainy climate. However, the protection work currently lack professional knowledge of cultural relics and sufficient awareness of cultural protection, and the purpose of transformation and utilization is often for commercial profit, resulting in significant destructiveness.

4. Realistic Dilemma

4.1. Typical status of destruction

Recently, the watchtowers in Chungking are undergoing severe test. For example, from the current construction site situation, the Yang's watchtower manor in Shilong will cause a complete destruction with basic historical environmental loss (Figs. 1 & 2).

Fig. 1 – *Banan Shilong Yang watchtower original appearance* (Author, 2025).

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Fig. 2 – *Transformation of the modern landscape environment in progress* (Author, 2025).

Similar situations have not been isolated cases in Chungking. Previously, several watchtower manors have been irreparably and maliciously damaged due to reasons such as idleness collapse, loss of core rammed earth technology, and deterioration of the basic environment. It is obviously that will most likely be another traditional watchtower manor heritage in Chungking.

4.2. Typical case analysis

We have conducted sample research on low-grade rural cultural relics in Chungking through field surveys, literature reviews, and oral history methods. Currently, we analyse crises and challenges faced by three types of typical rural vernacular architectural remains.

4.2.1. Historical value and current state of destruction of Watchtower Manors

Chungking watchtowers are typical example of traditional rural architecture that has been gradually forgotten and destroyed. As one of the five traditional defensive residential buildings in China, Chungking watchtowers are condensed version of China defensive vernacular residences. Particularly, Chungking watchtower manors are rare "living fossils" of traditional Han ethnic stockade manors of the cultural integration within the Chinese nation and an indispensable key link in the study of the development of defensive residences, holding historical and cultural significance.

Watchtower residences are widely distributed and numerous in Chungking area. Currently, only one building has been in the national protection list, a few are covered in the city or district list and most of them have no defined protection list. The number of Chungking watchtowers has dramatically decreased from over 1,000 in the 1990s to just over 300 during the "Third National Cultural Relics Survey" period, and to over 200 by 2012 (Shu, Y., & Liu, Z, 2018). Although the data from the "Fourth National Cultural Relics Survey" is not yet available, the recent research conducted by the author indicates a less than optimistic situation. Such as Zhongshan Town and Simian Town in Jiangjin, some of the registered watchtower residences continue to be damaged, left idle and abandoned, or misused due to transfer of usage rights and deterioration of surrounding environment. The traditional rural culture of "farming in sunny weather and reading in rainy weather" has also vanished (Figs. 3 & 4).

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Fig. 3 – *The surrounding environment of Yanghui Villa watchtower has completely deteriorated* (Author, 2025).

Chungking watchtowers were regarded low level relic and it is difficult to protect. It will be a good approach to choose typical watchtowers with better statue to form “point-line-surface” (from one highlight building to more building group and environment) heritage application by combining them. However, the watchtowers are still facing issues such as abandonment, misuse, and improper renovation. The number of typical representatives continues to shrink. If it continues to deteriorate, Chungking will result in irreversible and significant loss of cultural relics.

4.2.2 Historical value and state of destruction of character Paper burning Pagodas

There are Paper Burning Pagoda concentration in Chungking which is unique materialisation of China veneration historical witness to the rural “Farming and Study passed on from family.” Pagodas and fiesta are mainly existed in the southern regions, with more preserved in Bashu, Hunan, Fujian, and Taiwan (Zhou, L, (2011). However, the largest and oldest groups of historically preserved Pagodas are mainly in the Bashu. At present, there are more than 250

Fig. 4 – *"Bayu most beautiful character Paper Burning Pagoda" Bishan Zhuyun Temple Wenfeng Pagoda without protection measures, the environment is deserted and inaccessible on foot* (Author, 2025).

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Pagodas existing in the country, among which more than 190 are preserved in Sichuan and Chungking (Shu, Y., & He, Y, 2021). Chungking has retained 71, distributed in 23 districts and counties, with a time span from the tenth year of 1484 to 1939. Among them, there are 50 clear chronologies, and from the perspective of the remains, there are 4 built in the Ming Dynasty (which is very rare nationwide), 65 in the Qing Dynasty, and 1 in the Republic of China period (Office of the CPC Jiangjin District Committee of Chongqing Municipality, 2023).

At present, the Pagoda group in Chungking is rich in stock and complete in preservation information, and many scattered in the fields of rural areas of Chungking and protection is not optimistic. Most of the Pagodas are naturally weathered and severely damaged. Due to the discontinuity of the cultural context, the traditional veneration of "cherishing written paper" associated with Pagodas has been lost in the countryside, becoming objects of incense worship and hanging Tibetan-style prayer flags, and even being smeared with chicken blood and pasted with chicken feathers. The misplacement of faith is very detrimental to governance at the grassroots and the spread of positive cultural dissemination.

4.2.3. Historical value and current state of destruction of Ancient Bridges in Chungking

Rural bridges have been greatly affected by environmental destruction. As a city of mountains and rivers, Chungking boasts bridge resources. According to the Third National Cultural Relics Survey, Chungking has 1437 ancient bridges from the Qing Dynasty distributed across 38 administrative districts (counties) (Chongqing Culture Relic Department, 2012). During the author's investigation, the

Fig. 5 – *The surrounding environment was destroyed when the Yanxi Bridge of Hechuan district Southern Song Dynasty was relocated* (Author, 2025).

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ancient bridges scattered in the countryside possess a profound history and exquisite techniques. They span across rivers, streams, and gorges, connecting old towns and ancient transportation arteries, and together with buildings and roads in towns and villages, they form the urban and rural texture of the Bashu region, holding dual values of transportation function and technology as well as art.

However, with the continuous expansion of city, the number of ancient bridges are facing the risk of destruction and relocation. Moreover, due to the uncertainty of records, many ancient bridges with high historical, scientific and artistic value have not protection. They have been damaged or disappeared. Currently, there are more than 100 ancient bridges with poor protection, and in recent years, 51 ancient bridges have disappeared for floods and human demolition (Fig. 5).

5. Suggestions for conservation

The protection of immovable cultural heritage in rural areas of Chungking, represented by watchtowers, Character Paper Burning pagodas and ancient bridges, reliant on long-term “Government Financial Transfusion," poses a financial burden on the local fiscal situation, especially considering the protection model in China that primarily depends on government funding and there is a lack of corresponding mechanisms for private and corporate donations for protection within the country.

This transformation is necessary to turn the "heritage burden" into cultural productivity and improve the current dire situation. It should be encouraged diverse investment and multi-party participation, establish special subsidy funds, and integrate social funds for joint development to enhance the awareness of cultural heritage protection across society.

This will promote the benign protection of a large number of low-level cultural relics and explore up-to-date activation methods, incorporating them into high-quality development.

5.1. Conservation concept transformation

Cultural relics of typical value are under centralized protection. Under the premise of limited government funding, it is possible to select many relic points with the most typical sample significance for joint application and grading, and obtain cluster attention. Overall package and upgrade are conducive to focused protection, establishing conservation samples, and motivation for cultural relics to actively utilize and activate. For example, the character paper burning pagoda group in Yanting County, Sichuan Province (32 pagodas), was packaged and applied for the key cultural relics protection unit of Sichuan Province, a case worth referencing and learning from.

5.2. Digital protection

The intervention of new technologies and the improvement of digital protection mechanisms. By conducting the "fourth general survey "to understand the situation, and utilizing aerial photography,3D scanning,3D modelling, BIM, GIS management and so on, comprehensive digital twin information database can be established to permanently retain complete survey data, images, and management information. This ensures the maximum integrity of information for cultural relics in the event of irresistible damage, providing a comprehensive and reliable basis for full historical information storage, monitoring services, protection and restoration, and subsequent activation.

5.3. Public culture services

It is a useful way to highlighting basic research on "Phenomenal" local characteristic cultural relics and promoting activation and utilization through artistic propaganda. The cultural value of low-grade rural cultural relics is generally unknown to the public. Raising public interest, awareness, and highlight cultural relic protection through artistic propaganda can enhance their visibility and facilitate the involvement of social capital in later stages. The watchtowers, pagodas,

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and ancient bridges themselves possess "Chungking story". It is a effective way to take the relics as a foundation and backdrop, artistic creations through various literary forms such as novels, poetry, prose, and song and dance to tell rural stories well, endowing relics with richer connotations and expanding their vitality and influence.

5.4. Integration of ideas

Enhancing the integration of relics with rural life and creating new scenarios for rural industries. By researching and excavating the humanistic activities of cultural heritage and restoring cultural scenes, with appropriate incorporation of contemporary elements, cultural relics and their activities can once again become a part of rural life.

This promotes the integrated development of cultural relics and rural industries, enhancing the cohesion and centripetal force of rural culture. Furthermore, relying on digital creativity and intelligent manufacturing, implementing virtual reality to restore historical scenes, and creating immersive experience spaces with multimedia-triggered artistic interactions. Developing cultural and creative products, interactive games, and applications to provide interactive products for the public of different ages, empowering local economies, achieving commercial utilization, and providing another way and possibility for promoting local traditional Chinese culture.

5.5. Technical control

Expert involvement is essential for protection and utilization. Before initiating typical protection, restoration, or activation and utilization of low-grade rural cultural relics, it is imperative to invite experts with professional training in cultural relic protection, practical experience, and on-site handling capabilities to participate in plan review, on-site consultation, phased inspection, and acceptance to avoid irreversible losses and man-made destruction.

6. Conclusion

The protection of low-grade traditional rural vernacular relics in China is a long-term and arduous task. Official investment remains the primary operational method at present, with both advantages and disadvantages.

Professional technical intervention can be an effective support for the protection of rural heritage, but it also imposes a significant financial burden on the government, which is a considerable dilemma for the protection of a large number of low-grade rural cultural buildings.

There are many issues that need to be addressed:

Firstly, it is essential for relevant departments to recognize the social and cultural value of low-grade relics, and shift their focus downward. This is the starting point for low-grade rural relics to be systematically and institutionally protected on long-term and stable basis.

Secondly, institutional innovation is required to attract diverse investment and multi-party participation from social funds. Obtaining sufficient financial guarantees is the direct reliance for implementing daily maintenance, technological research and development, and effective protection.

Thirdly, the involvement of new technologies should be encouraged. Commercially utilization of relics under the premise of effective protection and guided by professional technical forces can transform the financial burden into social resource.

This not only preserves cultural lineage but also serves the production and living needs of the current population, truly achieving rural revitalization in China. It can even become a new quality cultural productive force in rural areas, promoting a new development situation of urban-rural integration.

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UNESCO Management Plans and Community Collaboration: A Comparative Analysis from Lyon, Djenné and Yazd

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Abstract

This article compares the management plans of three UNESCO World Heritage cities—Lyon (France), Djenné (Mali), and Yazd (Iran)—to assess local community engagement in heritage conservation. The study explores cultural, social, and economic factors shaping participatory approaches, examining the roles of institutions, civil society, residents, and property owners. Management Plans and their implementation are analysed, which show how local initiatives are received and sustained over time. The comparison of the three cities reveals trends in community involvement, showing how spontaneous actions contribute to heritage durability, accountability and long-term preservation. Urban landscape preservation efforts further assess how proposed measures translate into practice and their impact across different contexts, examining how heritage awareness spreads differently in each city and emphasizing the importance of local engagement in achieving effective and sustainable conservation strategies.

Keywords: *historical urban landscape; management plan; earthen heritage; community engagement*

1. Introduction

Since its foundation in 1972, more than 322 World Heritage (WH) cities have been protected under the UNESCO aegis, including 75 earthen urban properties. In 2011, UNESCO published the Recommendation on Historic Urban Landscape (HUL), a holistic approach aimed at including social, cultural and economic factors in its conservation practices. This approach cascaded into the management plans of several of these WH cities. Since the mid-1990s, UNESCO has required each WH site to acquire a Management Plan (MP), a document for the preservation and governance of heritage sites. Analysis of these documents can help foresee the future direction of urban earthen heritage preservation. This paper aims to investigate the different approaches towards management plans and their role in urban heritage, stressing the importance of community engagement to raise awareness within the local population about the importance of heritage preservation. The authors identified three case studies from different geographical and cultural areas, united by similar earthen urban heritage. The cities are Lyon, France; Yazd, Iran; and Djenné, Mali. The rationale for their selection stems from the analysis of their governance

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systems and the different - but comparable - approaches to Management Plans. Djenné drafted a quinquennial plan in 2018 to address UNESCO requests. Yazd included its management plan directly in its 2017 inscription documents. Lyon interpreted the HUL recommendations to include a MP in a comprehensive *Plan d'action (2024-2030)* for the whole metropolitan area. The paper aims to provide useful insight and proposals on how to draft an MP taking into account participative and collaborative factors.

2. Methodology

The investigation started from the vast collection of open-access documents provided by UNESCO on its three properties. They were analysed to gain an understanding of the local contexts and their challenges, as well as how the different State Parties interpreted the preventive conservation approach of the MPs, especially towards community engagement in heritage governance. The combination of earthen heritage and community engagement has proven to be relevant in heritage practices, ranging from customary conservation to institutionalised co-creative activities. This combination unites the three case studies: they all present different forms and tools of local population involvement in heritage preservation. The customary *crépissage* (re-plastering) of the Great Mosque of Djenné; the hybrid systems of the *waqf* in Yazd; and the *inventaire participatif* of earthen heritage in Lyon are relevant examples. The comparison of the three Management Plans assessed the main similarities in the approaches adopted and the differences, to highlight similar international tendencies, especially towards the role of the locals.

A series of in-depth interviews was conducted with local interest-holders. Different opinions on the heritage site, its management and its future perspectives helped assess the strengths and weaknesses of Management Plan, and the topic of community collaboration each provided insights into the decision-making processes. The three methodological steps progressed as follow: a state-of-the-art assessment; a present-time critical comparison of MPs; and an informed final opinion of local stakeholders involved.

3. Community Engagement in Urban Heritage Preservation

Community participation in heritage protection, conservation and management processes is an internationally debated issue. It aims to promote inclusive and dynamic actions that can contribute to sustainable development, long-term conservation and co-management of heritage for the benefit of the heritage and the community (ICCROM, 2015). The promotion of participatory activities is based on the idea that 'conservation is about people' (Van Der Ploeg, 2004, p. 24). It is only through direct contact with local communities that it is possible to identify what they recognise and value, and to involve them in conservation and maintenance activities, thus developing the "heritage community" of the Faro Convention (2005). A paradigm shift regarding the role of communities in the recognition, conservation and management of WH sites was sanctioned in 2002 with the drafting of the Budapest Declaration. On this occasion, in order to ensure a fair balance between conservation, sustainability and development, States Parties were called upon to promote the active involvement of communities at all levels in the identification and protection of World Heritage properties. In addition, States Parties were invited to undertake communication activities to increase "public awareness, involvement and support for World Heritage" (UNESCO, 2002), recognising the important role of communities in heritage conservation.

In 2007, this approach was further strengthened by integrating the four strategic objectives of the World Heritage Convention identified in 2002 (credibility, conservation, capacity building, communication) and a new objective (communities). This change is motivated both by the recognition that "heritage protection without the involvement and commitment of communities is an invitation to failure" (WHC, 2007, p. 2) and

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by the awareness that "heritage protection should, wherever possible, reconcile the needs of human communities, because humanity must be at the heart of conservation" (WHC, 2007, p. 2). The 2011 Recommendations on Historic Urban Landscapes identify participatory processes as a fundamental tool for heritage management practice. Indeed, the Historic Urban Landscapes approach aims to preserve the quality of the human environment by learning from the traditions and perceptions of local communities, whose participation in decision-making processes contributes to a clear identification and understanding of the needs of the population and promotes the preservation of local cultural traditions. The involvement of local communities in the processes of cultural heritage conservation requires a profound change in the working methods of the bodies involved in this activity. Aware that "cultural heritage is created by people and for people" (ICCROM, 2015, p. 3) and that "communities have capacities and assets that outlast political or professional structures and complement specialised knowledge and skills" (ibid.), processes need to be developed that are capable of harnessing these capacities and assets.

With this in mind, the above case studies will be examined, with a focus on analysing the approaches adopted and the actions implemented, in order to identify possible future intervention strategies.

4. Djenné, Mali: customs and traditional practices in a crisis context

Djenné is famous for its earthen architecture, including the Great Mosque. A World Heritage Site since 1988, it was placed on the List of World Heritage in Danger in 2016 due to the deteriorating security situation in Mali. Ongoing instability has hindered the implementation of a new MP, with the latest version covering 2018-2022.

Djenné's heritage management follows a centralised model inherited from French colonial rule. The Ministry of Culture, based in Bamako, oversees heritage sites through regional branches and cultural missions that manage WH-listed sites. The MP reflects this structure, highlighting the

Fig. 1 – *Replastering ot Djenne mosque by the community in 2012* (Mission Culturelle de Djenné, F. Yamoussa).

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Cultural Missions as the main local stakeholders (DNPC, 2018, pp. 54-58). Community engagement is briefly acknowledged in the MP, but is not actively encouraged. Instead, the plan prioritises partnerships with international organisations such as the Aga Khan Trust and focuses on awareness campaigns rather than direct local engagement (DNPC, 2018, p.80).

Despite state control, customary institutions remain central. The *chefférie* (village chiefdom), led by the *chef du village*, regulates public life and professional corporations, including the *maçons* (builders), responsible for maintaining the Great Mosque (Joy, 2012). Religious leaders also influence preservation decisions. With state governance weakened by conflict, these traditional structures have regained importance. A key example of local conservation is the annual *crépissage* of the Great Mosque (Fig. 1), a collective event where the community, led by *maçons*, replasters the mosque with fresh mud (Joffroy & Yamoussa, 2011). This tradition not only preserves the building, but also allows artisans to refresh its decorative elements.

International institutions such as UNESCO and the Aga Khan Trust have challenged this practice and advocated standardised restoration techniques. The Aga Khan Trust's first 'modern' restoration of the mosque was controversial because it altered the existing form based on historical images (Joy, 2012). As Lassana Cissé explained: "The Aga Khan decided to intervene. The rehabilitation of the mosque was derived from historical images [...] thus giving it a form that was never the original one" (Cissé, L., personal communication, Feb. 2024). Nevertheless, traditional *crépissage* has proven effective, especially in the absence of conservation strategies. Local builders and communities have played a crucial role in preserving Djenné. As Charlotte Joy noted: "Since the conflict, the local community has become central [...] The fundamental part of heritage conservation is still happening" (C. Joy, personal communication, Aug. 20-24).

The case of Djenné illustrates the challenges of heritage conservation in a fragile socio-political context. The effectiveness of an MP is difficult to assess in such circumstances, but community involvement remains essential. Recognising and integrating traditional conservation practices into institutional strategies will ensure long-term conservation and a balance between formal policies and local knowledge.

5. Yazd, Iran: awareness-raising in a top-down governance

The case of Yazd demonstrates a hybrid approach to urban earthen heritage conservation, where centralized governmental structures work alongside local institutions. Inscribed as a World Heritage Site in 2017, Yazd retains its traditional urban fabric, largely escaping modernization (ICOMOS, 2017, p.125). Its governance strategies were outlined in the nomination documents. The Action Plan, prepared by ICCHTO (Iran's Cultural Heritage Handicrafts and Tourism Organization), promotes a collaborative approach between national institutions, local authorities, traditional organizations and residents, recently commended by UNESCO (UNESCO, 2023, p.3).

Fig. 2 – *Stakeholders visit during IWEA training workshop, February 2019* (CRAterre, T. Joffroy).

In practice, this collaboration took shape through co-creation workshops (Fig. 2), meetings, and local conservation campaigns (ICHTO, 2017, p.31-34). This participatory strategy allows for a pragmatic management structure. Dr. Mohammad Talebian, former director of ICHTO, emphasized the necessity of blending centralized oversight

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with local custodianship: "The institution collaborates with municipalities and the locals as a control tool, controlling *[monitoring]* the heritage that's the purpose" (Dr. Talebian, personal communication, Jan. 2025). A practical example of this community-based monitoring is a WhatsApp channel where residents report potential risks to heritage sites. Majid Hajmirbaba, a scholar at CRAterre, described its role: "There is a WhatsApp channel to send photos and denounce inappropriate interventions […] there is also a technical bureau to help inhabitants" (M. Hajmirbaba, personal communication, Jan. 2024).

While such peer-surveillance can raise ethical concerns, it heightens heritage awareness. Beyond monitoring, Iran's heritage governance encourages local stakeholder involvement. Dr. Talebian referenced the case of Tabriz Bazaar, where local merchants directly contributed to restoration efforts. This model, in Yazd, led to the formation of craftsmen teams to train residents, fostering skill transmission and community engagement.

A key distinction between Yazd and Djenné lies in the recognition of customary institutions. Yazd's local *waqf* plays an active role in preservation. *Waqf*s, or religious endowments, hold property in trust for charitable purposes, frequently including heritage buildings. Their role extends beyond property ownership to financing restoration projects. As Dr. Talebian explained: "In a lot of places in Iran where there is a system of *waqf*, they pay the budget because they have the trust foundation for a restoration project in the *waqf* area." (Dr. Talebian, personal communication, Jan. 2025)

This framework strengthens local monitoring structures, ensuring the integration of religious and civic bodies in heritage management. Yazd shows how social and cultural dynamics influence urban conservation strategies. Traditional institutions, local universities, and community groups are active participants in decision-making. This inclusion not only preserves heritage but also fosters awareness among residents: in 2019, 40% of residents believed they should share responsibility for heritage conservation with local authorities (Nasrolahi et al., 2019, p.1745). Ultimately, the Yazd model shows the importance of acknowledging customary techniques by involving the stakeholders who uphold them.

6. Lyon, France: controlled animation of governance practices

The third case study is the French city of Lyon. Its architectural heritage includes a remarkable tradition of earthen construction, which is deeply tied to the city's history and identity. Today, districts like Croix-Rousse and Saint-Just, part of Lyon's World Heritage area, exemplify this heritage, with a high concentration of earthen buildings. Unfortunately, despite academic efforts, earthen architecture remains under recognized in Lyon. The city's 1998 UNESCO nomination dossier overlooked this heritage entirely, prioritizing monumental structures and historic neighborhoods instead.

The 2013 UNESCO MP for Lyon similarly failed to address earthen architecture, offering no specific preservation initiatives. Only in the 2018 *Plan Local d'Urbanisme et Habitat* was earth acknowledged, with guidelines for interventions limited to visible façade (Ville de Lyon, 2018). This lack of comprehensive recognition highlights a deeper issue: both residents and public administrators remain largely unaware of the value of these constructions. Without adequate tools for their preservation, Lyon's earthen architectural heritage continues to be at risk. In Lyon's case, it emerges how the involvement and the responsibilisation of the local community is a recommendation and a necessity to guarantee earthen heritage preservation. Emmanuel Mille, who completed a doctorate at CRAterre, stated: "All the risk factors come from unfamiliarity [on earthen buildings] by actors, inhabitants and users" (E. Mille, personal communication, Feb. 2024)

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A first shift in this tendency can be seen after 2016, when the international congress on earthen architecture, *Terra2016*, was hosted in the city. A large *inventaire participatif* was carried out: local residents were asked, through an online questionnaire, to actively locate and map the earthen buildings of Lyon, effectively conducting a census that listed more than 100 within the historical city (Mille, 2023, p. 114-119).

After some years, earthen heritage recognition and community involvement were jointly addressed in the most recent MP of the city, adopted in 2024. The document states that "heritage is a collective responsibility" (Ville de Lyon, 2024, p. 100) and devotes an entire strategic axis of the Plan towards dynamize governance meaning a differentiation of governance practices: a stronger inter-institutional dialogue, and a collaborative network of actors, users and stakeholders. On paper, the actions seem ambitious and well-oriented, but none has been carried out yet, probably due to the novelty of the Plan. Moreover, as expected in the western, European context, these actions follow a vertical axis, from the central institution towards the local residents and associations, in which the first maintains a managerial, directive role.

7. Comparative Analysis: Key Factors in Community Engagement

The synthesis of findings from the case studies allow a comparison of participatory strategies, levels of community involvement, and the effectiveness of implemented measures.

In fact, the usage of a similar comparison tool, the Management Plan, allows to stress on similarities and to identify corrective factors. A MP evaluation tool exists, and it is provided by UNESCO in its Resource Manual "*Enhancing our Heritage Toolkit 2.0*". This paper will take into account the directives and the guidelines of this document in three main levels (Table 1): the institutional frameworks and systems; the involvement, the collaboration and the coordination between right-holders; the openness to inputs. The heritage management systems in Djenné, Yazd, and Lyon share a centralized, top-down structure.

Each country's Ministry of Culture oversees conservation through local branches: Djenné's Cultural Mission, Yazd's ICCHTO office, and Lyon's multiple institutional layers (Ministry, Region, Prefecture, Municipality). This high level of institutionalization limits horizontal collaboration (Sokka et al., 2021). A key comparison factor is the involvement of local communities and non-institutional stakeholders, which is theoretically encouraged in MPs but faces cultural and economic barriers. Another factor is the MP adaptability to integrate institutional actors, civic society, and customary practices.

In Djenné, international institutions and foreign governments, such as the Aga Khan Trust, the World Monuments Fund, and missions from Italy, Germany, and the Netherlands, are active financial and technical partners (Sacko, 2021). However, the local community plays only a passive role, limited to awareness campaigns, despite being the

Table 1 – *Management comparison table* (Authors, 2024).

WH city	frameworks and systems	present collaboration	openness and potential
Djenné	vertical (Ministère de la Culture, DNPC, Mission Culturel)	international figures (Aga Khan, World Monument Funds, foreign missions)	masons' corporation (*barey ton*), customary institutions (*chéfferie*)
Yazd	vertical (Ministry of Culture, ICCHTO local, on-site branch)	local bodies and academia, religious trusts (*waqf*)	property owners, users of the buildings and local population
Lyon	vertical (Ministère de la Culture, Préfecture, Métropole, Ville de Lyon)	institutional and technical bodies, museums and foundations, tourism bodies	local population (*conseils du quartier),* civic society associations and academia

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main actor in traditional conservation. The masons' corporation is responsible for the customary *crépissage* of the Great Mosque, but this practice is often ignored or replaced by standardized, externally funded interventions. A major example is the Aga Khan Trust's 2006 restoration of the mosque, which sparked controversy as locals felt disconnected from their own heritage (Joy, 2012). Integrating customary conservation methods into management plans presents an opportunity to recognize the role of resident-led initiatives which could enhance earthen heritage preservation.

In Yazd, the collaboration is on a higher degree, as ICHTO is actively searching relationships with local institutions and universities. In several other cases in Iran ICHTO developed a relation also with private entities and local businesses: in the Bazaar of Tabriz, the very own bazaarists became interest-holders and funders of part of the restoration. In Yazd, such a relation can be beneficial in raising awareness and capaciting local business owners, especially since the city is starting to feel the pressure of touristification (Rastegar, 2021): a new attitude towards heritage can mitigate tourism transformative pressure over the historic city.

Finally, in Lyon, the MP is included in a much larger, infra-departmental planification tool. Doing this, the Plan addresses effectively the UNESCO recommendations for the holistic approach of Historic Urban Landscape. The Plan was redacted in a joint team involving institutional and technical bodies at different levels, local foundations, cultural resources and tourism bodies. The great absent of the Plan is indeed the local community: a potential that can be expressed, as the *conseils du quartier* (district associations) and the civic society are a large part of the interest-holders. At the same time, their inclusion can implement a larger sensitisation towards earthen heritage recognition. This role can be also undertaken by academia, which can play an active part in disseminating and knowledge-sharing.

8. Conclusions: Recommendations for Broader Preventive Conservation

The evaluation of the results achieved by each city in terms of heritage preservation and community engagement highlights some common elements and some discrepancies that can be summed up in recommendations for preventive conservation. In fact, this strategy of heritage care is probably the most suitable for earthen heritage (Joffroy 2012), as it reduces the need for larger restoration interventions. Earthen heritage, with its intrinsic fragilities, need care, sometimes directly by the users: most of the damage is caused by inappropriate interventions and a lack of ordinary maintenance. This is why the local community should be at the centre of awareness raising and collaborative campaigns, to reduce the risk of damages and the occurrence of threats. Awareness raising helps preserve not only the physical building, but also the technical, traditional and cultural know-how that led to the construction of these architectures and that can promote their conservation. It is necessary to preserve both the material aspects and immaterial practices, inseparable in earthen heritage.

There is, of course, a larger and more complex discussion of the durability of actions proposed in MPs and their impact on urban heritage landscape preservation. Local communities' knowledge and expertise are often sidelined in practice, and it remains challenging to rely solely on local populations for WH preservation. The central issue, therefore, is to find the right balance between community and institutions (Joffroy, Ould Sidi, 2005) which requires time, attentive listening, careful observation, and collective reflection: elements that are often lacking.

Recommendations for enhancing community engagement and promoting participatory conservation strategies can be drafted. Inputs from local communities lead to an horizontal relationship and the identification and involvement of right-holders, in order to avoid conflicts and to provide a plurality of conservation

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practices. Academia should take an active and central role in collaborating with the institutions and in recognizing customary conservation activities that should not be deemed "inadequate". Finally, the HUL approach should be the background of the whole Plan. Lessons learned from the three cities can inform future WH properties management plans and global practices by developing insights into the role of community engagement and fostering the long-term sustainability of urban heritage.

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The Illusion of Heritage: Critiquing Pseudo-Earthen Vernacular Architecture in Qatar

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Abstract

Qatar has recently become a hotspot for rapid urban development, featuring architectural projects that often incorporate curated elements of heritage. This paper critically explores the rise of "pseudo vernacular" architecture in the country, where traditional design motifs are superficially repurposed to create developments resembling themed attractions. These spaces, while aesthetically impressive, raise concerns about authenticity, cultural representation, and the commodification of heritage. Although the use of traditional motifs in modern construction may seem like an effort to celebrate local identity, a deeper analysis reveals a shallow engagement with Qatari cultural complexities. The "pseudo vernacular" architecture in developments such as the Souq Waqif and Souq Al Wakra creates an illusory sense of nostalgia that appeals to tourists and affluent residents. However, these spaces often detach themselves from the historical and social realities of genuine traditional architecture, risking the erosion of Qatar's authentic cultural heritage. As Qatar aims to position itself as a cultural hub in the Gulf region, this preference for spectacle invites scrutiny regarding its long-term impact on collective memory and national identity. By interrogating the motivations behind these developments, the paper advocates for a shift toward architectural practices that genuinely reflect and preserve cultural identity. It emphasizes the need for a more thoughtful engagement with heritage that fosters meaningful connections between people, places, and history, moving beyond commercial spectacle to achieve lasting cultural authenticity.

Keywords: *pseudo vernacular architecture; heritage commodification; cultural identity, architectural authenticity, Qatar urban development*

1. Introduction

The rapid urban development of Qatar has witnessed a surge in the incorporation of heritage elements within contemporary architectural projects. This trend, often described as "pseudo-vernacular" architecture, raises critical questions regarding the authenticity, representation, and potential commodification of Qatari cultural heritage. While seemingly celebrating tradition, these projects often prioritize spectacle and visual appeal over a genuine engagement with the complexities of Qatari identity, potentially leading to a superficial understanding of cultural heritage. This dynamic is further complicated by Qatar's ambition to position itself as a cultural hub in the Gulf region, a goal that arguably incentivizes visually striking projects that cater to tourist and affluent resident expectations.

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(Al-Mohannadi et al., 2020) emphasizes the importance of socio-cultural factors, such as privacy, gender segregation, and hospitality, in shaping the spatial form of Islamic residential architecture. In her research (Marthya et al., 2021) examines the efforts to mitigate the effects of urbanization on valuable historical heritage sites, underscoring the need for a more thoughtful approach to development that fosters meaningful connections between people, places, and history. The existing literature sheds light on the forces at play. (Fetais & Gharib, 2020) explored how heritage regeneration can contribute to economic diversification in Qatar, emphasizing the importance of maintaining local cultural identity.

(Alattar et al., 2021) examines the tension between cultural and economic forces in historic cities, stressing the need for integrating both to sustain place identity in an increasingly globalized world. Additionally, the process of "globalizing the local and localizing the global" is traced in the urban development of the Arab Gulf region, reflecting the efforts to introduce global architectural influences through reproducing internationally celebrated spaces underscoring the efforts to "bring the world" to these states through the reproduction and duplication of internationally celebrated architectural sites and spaces (Oukhzame & Stasiowski, 2021).

The development of spaces such as Souq Waqif, in downtown Doha and Souq Al Wakra, in Wakra, Qatar, serves as a prime example of this phenomenon. While incorporating traditional design motifs, these projects risk detaching themselves from the historical and social realities of authentic vernacular architecture. This curated nostalgia, while aesthetically pleasing, can lead to a diluted and potentially misrepresented cultural narrative. Scholars like (Boussaa, 2021) emphasize the importance of historical context in cultural preservation, suggesting that such projects, while visually appealing, may fall short of genuine cultural sustainability. The pressure to conform to globalized aesthetics while preserving local traditions creates a tension that can manifest in the commodification of cultural heritage.

This paper argues that the rise of "pseudo-vernacular" architecture in Qatar is driven by a complex interplay of governmental policies, economic ambitions, and the desire for international recognition. By examining these factors, this paper seeks to interrogate the impact of these curated heritage projects on the preservation of authentic Qatari cultural identity and the potential risks of cultural commodification. It will draw upon existing scholarship on cultural heritage management in Qatar , vernacular architecture (Eddisford & Carter, 2017), and the narratives of nationalism in cultural production (Freer & Kherfi, 2020) to provide a nuanced understanding of this complex phenomenon. Ultimately, this paper advocates for a shift towards architectural practices that genuinely reflect and preserve Qatar's cultural identity. It emphasizes the need to move beyond commercial spectacle and achieve lasting cultural authenticity, which is crucial in Qatar's pursuit of becoming a cultural hub in the Gulf region.

1.2. Markets (*Souqs*)

Markets have always been important centers of trade and interaction since the beginning of the creation of urban centers. The cities of the Islamic world have always been known for their thriving *souqs* (bazars), the names of Marrakesh, Cairo or Isfahan recall busy lanes full of colorful and aromatic merchandise and vendors moving here and there to attract their customers. The markets were not exclusive to the major cities of the Islamic world, as even small towns had their markets, whether permanent ones or held on weekly basis.

It is important to study *souqs* as they act as reservoirs of the cultural heritage and the social identity of the people who live, work, and shop

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in them. They also offer an understanding of the collective spirit of the place, the characteristics of a place that make it a destination for people to visit and linger in, wherever in the world. Thus, *souqs* could be considered public realm models designed and planned to attract diverse users, such as citizens and residents, retailers and shoppers, and regional and international tourists (Khan et al., 2021).

1.3. Definitions

Fake Vernacular Architecture refers to the imitation of traditional regional styles in modern construction, often prioritizing aesthetics over cultural, functional, or environmental considerations (Kavas, 2015). While it can create a nostalgic appeal, critics argue it lacks sustainability and historical relevance, potentially misrepresenting authentic architectural heritage. Some scholars suggest that, when done thoughtfully, it can contribute to cultural continuity in urban landscapes (Zwerger, 2019).

Heritage Commodification which involves transforming cultural heritage into commercial products, particularly in tourism and entertainment (Hooper & Lennon, 2017). While this process can promote cultural awareness and economic benefits, it may also distort historical narratives and compromise authenticity (Svidén et al., 1994). Examples include mass-produced traditional crafts or performances staged purely for spectacle (Craith, 2007). Scholars emphasize the need for responsible heritage management that balances economic interests with cultural preservation (Craith, 2007; Gill-Robinson, 2007).

Architectural Authenticity focuses on maintaining the historical and cultural integrity of buildings by preserving original designs, materials, and construction techniques (Jokilehto, 2002). The debate on authenticity extends to renovations and modern adaptations, with some arguing for strict preservation and others advocating for evolving architecture that respects tradition while adapting to contemporary needs (Djabarouti, 2024; Jokilehto, 2002). This balance is crucial in architectural conservation and adaptive reuse discussions (Weiler & Gutschow, 2017).

2. Methodology

2.1. Case Study Selection

Two examples of "pseudo vernacular" architecture in Qatar, Souq Waqif and Souq Al Wakra, serve as case studies. These sites were chosen due to their visibility, popularity, and representation of the trend of repurposing traditional design motifs in contemporary urban developments. Their selection allows for an in-depth examination of how "pseudo vernacular" architecture manifests in physical spaces and its impact on cultural representation.

2.2. Data Collection

2.2.1. Site Visits and Observation

Direct observation of the selected sites to document the architectural features, spatial organization, and overall atmosphere. This includes photographic documentation of the built environment and the activities within these spaces.

2.2.2. Literature Review

A comprehensive investigation of existing literature on Qatari architecture, urban development, cultural heritage, and tourism to contextualize the analysis within broader academic and policy discussions.

2.3. Data Analysis

The collected data was analyzed using critical discourse analysis. This method examined the symbols and narratives employed in the design and promotion of these "pseudo vernacular" projects to uncover underlying power dynamics, cultural representations, and ideological assumptions.

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The analysis focused on how these spaces construct and convey specific meanings about Qatari culture and heritage. This involved analyzing how traditional architectural elements are recontextualized and commodified within these developments.

3. Case study description

3.1. Souq Waqif

Souq Waqif is Qatar's most significant heritage site today (Fig. 1). The name, meaning "standing market" in Arabic, reflects how merchants once sold goods while standing. Located along Wadi Musherib, it was historically accessible by boats from the Gulf. However, land reclamation in the late 1950s and early 1960s for the Doha Corniche shifted the coastline 335 meters northward, altering its connection to the waterfront.

Dating back to the late 19th and early 20th centuries (Khan et al., 2021), the *souq* declined in the 1990s as Qatar's prosperity grew. A devastating fire in 2003 led to a government-led restoration project in 2006 to preserve its architectural and historical character. Initially, international experts proposed designs, but the Emir of Qatar, Sheikh Hamad bin Khalifa Al Thani, was dissatisfied. Instead, Qatari artist Mohamed Ali Abdullah was entrusted with the project, using artistic mediums and field research to capture the *souq's* essence (Mostafavi, 2011).

Fig.1 – *The main spine of Souq Waqif.*

The restoration involved demolishing modern buildings, replacing metal roofs with traditional dangeal wood and bamboo, and using clay and straw for insulation (Mostafavi, 2011). Underground parking replaced surface lots to enhance the pedestrian experience.

Unlike the intricate layouts of other Islamic *souqs*, Souq Waqif stands out as Doha's only open-air public shopping space, offering a pedestrian-friendly environment for dining and retail. It was shortlisted for the Aga Khan Award (2008–2010) and praised for authentically reviving Doha's heritage (Salama & El-Ashmouni, 2020).

However, with its nostalgic aesthetic and abundance of restaurants and cafés, some perceive the *souq* as a tourist trap or a Disney version of Qatar's past or even more of a tourist attraction than a true reflection of Qatar's past.

3.2. Souq Al Wakra

Souq Al Wakra, meaning "the bird's nest marketplace" in Arabic, is also known as Al Wakrah Heritage Village. Located 19 km south of Doha along the beachfront, it is a reconstructed traditional marketplace inspired by the successful rehabilitation of Souq Waqif.

In 2008, the government initiated a plan to rebuild a marketplace on the ruins of old Al Wakra, aiming to recreate the original fishing village's atmosphere and architecture while integrating modern amenities (Khan et al., 2021). The project, covering nearly 625,000 square meters, was inaugurated in 2016.

As the only heritage market in Qatar overlooking the seashore, Souq Al Wakra features replica dhows anchored along its shore. Unlike the compact Souq Waqif, its linear north-south layout consists of five main thoroughfares running perpendicular to the waterfront, dividing the *souq* into superblocks with narrow, winding pathways that mimic historic Arab settlements.

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Fig.2 – *A facade of a building showing traditional architectural elements in Souq Al Wakra.*

Modern planning principles guided the *souq's* land use, clustering similar functions into distinct zones: hotels are located at the northern and southern edges, restaurants and cafés line the waterfront, and retail shops are concentrated in the core. The design emulates a traditional Qatari fishing village with low-rise structures of two to three floors, narrow alleyways formed by courtyard houses, and traditional materials like natural stone and wood (Fig. 2). These passages also provide shade, creating a more comfortable microclimate (Fig. 3). Unlike Souq Waqif, which relies on underground parking, Souq Al Wakra offers ample surface parking.

Fig. 3 – *One of the courtyards surrounded by shops in Souq Al Wakra, most of them were not operating.*

4. Findings

From authors' personal experience and having visited both *souqs* several times at different timings of the day and night and at different seasons, it is possible to confidently assess their popularity, and attractiveness to visitors in addition to the success of "looking" authentic, traditional or historical. Souq Waqif, is considered the most successful and most visited tourist attraction in Qatar, it is lively day and night, and even during the hottest months, it is still visited in the evening (Fig. 4). Many factors could have played a role in its success and popularity among tourists:

- The central location in downtown Doha
- Its proximity to other landmarks and tourist attractions (the Museum of Islamic Art, Qatar National Museum, the Corniche, Musherib neighborhood and its museums).
- The plethora of restaurants with outdoor seating, which is not a common thing in Doha.
- The abundance of souvenir shops.
- The lively atmosphere created by the spreading of goods in front of their shops, the aromas of spices, grilled food, and hookah, and the calling of some of the merchants to attract buyers.
- The strong and continuous marketing campaigns that propagate the *souq* as the country's main attraction.

In addition to all of the above-mentioned factors, the picturesque facades and lanes of the *souq* are appealing to visitors, and can be described as "Instagrammable," recalling other *souqs* of the Islamic world like Aleppo, Cairo or Fes. However, all of this is fabricated, successful, yes, but just as any stage setting is well made and can evoke the needed charm and ambience, but it will always be a stage setting.

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Fig. 4 – *Souq Waqif in the evenings busy with locals and visitors.*

There is no doubt that the layout of the *souq* is well-designed to create passageways with different widths and angles to generate a sense of exploration. The block units were varied enough where the fine grain was concentrated in the middle while the coarse grain was located at the peripheries. The inspiration seems to be from the *souqs* of the major cities of the Islamic World, as Doha or Qatar had never such a dense concentration of shops, workshops and hotels at any period of its history (Khan et al., 2021). The buildings followed the charachteristics of traditional architecture, with a variety of arches and other elaborate architectural elements, such as carved doors and pierced gypsum window grills. These elements could be seen in other old or "historic" significant buildings in the Gulf area, but not in any marketplace in Qatar or the whole region.

The dense clustering of units, the architectural elements and the decorative details in addition to the scale of Souq Waqif, made it a well-designed new project with a program that imagines: "What if Doha was prosperous and thriving in the old days, how would its *souq* look like?"

Souq Al Wakra does not have the same popularity of Souq Waqif; it is rarely busy, and most of its shops and lanes seem deserted. Only the stretch of restaurants and coffee shops overlooking the waterfront is busy, as many customers prefer to have their meals or drinks overlooking the beach. The completely reconstructed Souq Al Wakra depended on a "traditional" fishing village layout, where courtyard houses would be clustered in blocks, and passageways would separate these blocks and create links to the waterfront. This courtyard housing typology was altered to create a new

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typology or a typology that does not have any historical precedent neither in Qatar nor the region. The designers used the rooms of the courtyard houses as shops, connected some houses to create bigger blocks, and even removed some walls outlining the courtyards to create small piazzas or squares. The result is pleasing and interesting if we are looking at Souq Al Wakra as a new commercial project, one that offers open-air shopping and dinning experiences along narrow lanes and clusters of courtyard houses. But if Souq Al Wakra is to be labeled as a "traditional" or an "old" *souq*, then such claims must be questioned and modified. Al Wakra or any other fishing settlement never had such a *souq*, neither in its scale, number of shops, or even layout.

Creating a *souq* inspired by the *souqs* of the Islamic world and trying to use local traditional architectural and artistic elements can be a good approach in contrast to the airconditioned megamalls that all look similar and do not offer the customers an outdoor atmosphere. Yet, claiming that these "new projects" are the restoration or revitalization of old *souqs* is not a genuine or correct approach to dealing with the historical urban fabric of these settlements.

5. Discussion

It is noteworthy that the popularity and success of Souq Waqif as a major tourist destination, and to a lesser extent of Souq Al Wakra, allure architects and developers to ignore the fact that these are recreations of imagined *souqs*. Thus, both *souqs*- with varying degrees- could be labeled as "fabricated heritage villages" that became very popular in several cities of the Gulf region. It is crucial to respect the historic, socio-economic and architectural context of whatever building or neighbourhood that is being restored, but creating such elaborate settings for "historical" sites should not fall under the categories of "restoration" or "revitalization". There is a difference between the process of adaptive reuse of a building or a cluster of buildings and fabricating a new reality of a place and claiming that it had historical roots (Fig. 5). The buildings of both Souq Waqif and Souq Al Wakra may look similar to examples of Qatari vernacular architecture, but their cores do not relate to the processes and decisions that led to the creation of vernacular settlements. Both projects were designed, and decisions were taken by architects and developers based on the need to create tourist attractions or sites that could be labeled as ones reflecting the cultural heritage of the country. Thus, the vernacular architectural and artistic elements were added as a cosmetic layer to these projects. The layout, architecture and artistic details of both *souqs* could be seen as "pseudo vernacular" a process in which heritage could be fabricated with specific sizes, colors and designs to suit the required order, a process similar to the fashion industry. No matter how commercially successful these *souqs* and similar projects could be, the danger lies in the fact that after a few decades, the new generations will consider that these structures are the "original" historical ones. The authors are not looking at attempts of revitalization of dilapidated old sites and buildings, but here is a very bold trial to fabricate buildings and settlements that never existed in such layouts, architectural language, scale, and artistic detailing.

Fig. 5 – *A building housing a movie theatre in Souq Waqif is adorned by traditional architectural elements.*

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6. Conclusion

This paper concluded that the rise of "pseudo vernacular" architecture in Qatar represents a missed opportunity to genuinely reflect and preserve the country's cultural heritage. Instead of creating a false sense of nostalgia, architectural practices should strive to foster meaningful connections between people, places, and history, moving beyond commercial spectacle to achieve lasting cultural authenticity.

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Bioclimatic Enhancement of a Low-cost Earthen Dwelling in Niger Through Comfort Optimisation and Local Skills-based Technologies

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Abstract

The paper presents the outcomes of research conducted within the framework of the "Urbanisation4Change" project in Niger, implemented between 2021 and 2023 by a consortium coordinated by the CISP Ngo, and funded by the European Union Emergency Trust Fund (EUTF) for Africa under the D.E.S.E.R.T. Programme. The study, carried out by the Politecnico di Torino, focused on the bioclimatic optimisation of an earthen housing prototype, employing passive architectural strategies and technologies tailored to the specific social, cultural, and economic context. The prototype, proposed by CISP, was designed for a new settlement intended to accommodate migrants and local populations with limited access to housing on the outskirts of the city of Agadez. Following an extensive review of the literature and a detailed analysis of the climatic and environmental conditions in Agadez, a set of passive bioclimatic strategies aligned with vernacular construction practices was identified. By means of an adaptive thermal simulation model, the indoor comfort conditions of the housing prototype were assessed, and the impact of each enhancement strategy was systematically evaluated. Subsequently, multiple scenarios were elaborated, combining the most effective strategies to maximise improvements in indoor thermal comfort. Furthermore, a field investigation into the availability of local construction materials and artisanal skills enabled the validation of the feasibility of the selected strategies, as indicated by the simulation outcomes. The identified strategies were then developed to the technological scale, actively involving local artisans in the design and implementation processes. As a result, prototypes for two of the three technologies were successfully produced on-site.

Keywords: *earth construction; bioclimatic strategies; migrations; appropriate technologies; low-cost housing*

1. Introduction

According to data provided by UNDP and OPHI (2024), although referring to 2012, Niger is rated as the poorest country in Sub-Saharan Africa, where the number of people living in extreme poverty is expected to further increase in the coming years (World Bank Group, n.a.). The region of Agadez, the ancient capital of the Country, lies along one of the main migratory routes to North Africa and Europe. The high number of migrants over the past 15 years has been among the main causes of the dramatic

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growth of local population (World Bank Group, n.a.). Between 2021 and 2023, within the framework of the D.E.S.E.R.T programme, coordinated by the Italian Agency for Development Cooperation (AICS) and funded by the EU Trust Fund for Africa, the CISP Ngo implemented the *Urbanisation 4 Change project (U4C) - Socio-economic inclusion in Agadez between principles, resources and local needs through earthen architecture universal knowledge and traditions*.

The specific objective of the project was to plan and build a new settlement on the outskirts of the city, providing 350 affordable 25 m^2 earthen housing units for low-income residents, thus addressing one of the main causes of poverty in the region (Adabre et al., 2021). The project also provided basic urban services and offered training opportunities for local workers in earthen construction techniques.

The dwelling type developed by CISP is organized in two contiguous 3x3 m rooms, within 250 m^2 plots differently oriented in the master plan. Only single-sided ventilation is permitted. The main structure consists of 30 cm thick *Banco* masonry, supporting two vaulted roofs (Fig. 1). *Banco* is a local traditional construction technique employing handmade earth blocks dried in the sun (Taton, 1981). The 15 cm thick vaults are built with stabilized compressed earth blocks (CEBs). Walls and vaults are plastered with an earth-based coating stabilized with cement.

In recent decades, traditional materials and technologies have been progressively replaced by concrete and other construction methods, which are unsuitable for the hot-arid local climate (FAO). Thus, the use of earth construction techniques aims to foster renewed interest in affordable traditional technologies, better adapted to the local context. The Agadez region features a hot desert climate with significant day/night temperature variations, a warmer season with high temperatures, often reaching 40°C from April to July, and a cooler season, from November to February, with average temperatures around 13 °C (Weather Spark). Sandstorms are frequent during the dry season, and heatwaves are expected to become more intense in the coming years, according to IPCC (2022). Rainfall is generally low, but severe flash floods may occur between July and September (Weather Spark).

The research conducted by the Politecnico di Torino aimed to identify appropriate passive cooling strategies, replicable by local, low-cost labor, to optimize thermal comfort in the earthen dwellings proposed by CISP.

2. Methodology

The research framework was defined through a holistic approach, including: a preliminary study of Agadez's climatic conditions; the identification of appropriate passive strategies to be potentially implemented, based on a literature review and a study of the vernacular architecture; a field assessment of market-available building

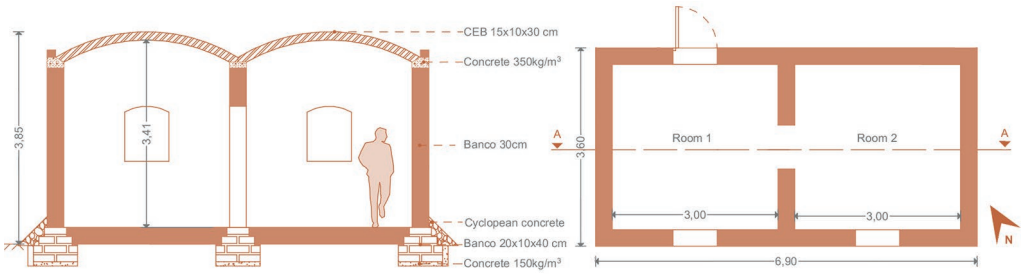

Fig. 1 – *CISP Dwelling section and plan* (adapted from Gualdrón-Frias, 2024).

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materials and craftsmanship skills; the development of technological solutions derived from the identified passive strategies, involving local artisans; on-site prototyping of a selection of the proposed technological solutions; and a thermal simulation campaign to optimize indoor thermal comfort in the dwellings through the proposed strategies.

3. Defining appropriate passive strategies

In order to enhance the thermal comfort of building occupants, a set of passive strategies was defined through an analysis of the bioclimatic behaviour of local vernacular architecture, a literature review, and validation using the Climate Consultant software.

3.1. Bioclimatic behaviour of Agadez vernacular architecture

The bioclimatic behaviour of local vernacular architecture was analysed through a literature review and a field study conducted in Agadez.

A compact building layout organized around inner courtyards, providing high levels of privacy and activating a combination of passive cooling mechanisms for indoor thermal control (Moore, 1993), has been widely documented in the scientific literature (Abiodun & Damilola, 2016; Umar et al., 2019) and confirmed on-site.

High thermal inertia is ensured by a 45-60 cm Banco block masonry walls (Zhang & Yusuf, 2018) and compacted earth flat roofs and floors, supported by wooden structures (Umar et al., 2019).

Night ventilation of thermal masses and convective air movement, fostered by large openings towards the courtyard (Zhang & Yusuf, 2018), promote heat dissipation, while minimization of solar gains is achieved through small openings towards the street and by shading the facades and the courtyard, using surrounding buildings and the built form itself.

3.2. Passive strategies appropriate to the local cultural and climatic context

The use of high thermal mass in the building envelope, shading, and enhanced night-time natural ventilation are among the most appropriate passive cooling strategies suggested by the Climate Consultant tool for hot-arid regions.

Solar and heat control: Given the high solar radiation in tropical and sub-tropical climates, coating external roof surfaces with bright colours (Oropeza-Perez & Østergaard, 2018) and improving the thermal performance of roof systems may reduce overheating risks (Elaouzy & El Fadar, 2022). Shading systems can reduce solar gains on exposed facades (Manzano-Agugliaro et al., 2015), while porches or patios can provide transitional spaces with moderated outdoor microclimates (Moore, 1993).

Thermal inertia: In hot-arid climates characterized by significant day/night temperature differences, high thermal mass enables heat storage during the day and its release at night, with subsequent dissipation through ventilation (Kitio et al., 2017).

Heat dissipation: Depending on occupants' window management, daytime cross-ventilation may offer effective cooling when outdoor temperatures are lower than indoor ones (Oropeza-Perez & Østergaard, 2018). Night ventilation, cooling the building structure and dissipating heat accumulated by thermal masses, may be even more effective in arid climates (Hu et al., 2023). Additionally, ventilated roof systems can effectively dissipate part of the heat transferred through the external surface (Neila González, 2004) and protect from occasional heavy rainfall.

An initial campaign of thermal simulations identified natural ventilation, thermal mass flush cooling, openings and facades shading, ventilated or thermally improved roof systems,

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and enhanced envelope thermal inertia as the most effective strategies for thermal comfort optimization. Final optimization results are discussed in Chapter 7.

4. Resources availability

A field survey enabled a preliminary assessment of the materials and artisanal skills available for the design and construction of the proposed technological solutions.

4.1. Materials available on the local market

The use of wood was excluded due to its limited availability in the region. The availability of steel building components, primarily for windows frames and roof structures was investigated among the largest wholesalers in the city, who regularly supply local artisans and small providers. Reinforced steel bars, 12 m in length and ranging from φ 6-16, were available at 60,000-65,000 FCA (90-98 €, as of 2023). Corrugated metal sheets were found in limited size (75x100 cm, 2.7-6.3 mm thickness) at 4.9-10.5 € (2023) per piece.

Earth is abundant and was deemed suitable for the production of blocks to enhance the thermal inertia of the building envelope and for the fabrication of shading elements. Moreover, its use would allow the engagement of local labour, trained by CISP in earthen construction techniques.

4.2. Available artisanal skills

Following field research conducted in the Agadez area, local artisans were engaged in the production of steel elements and building components intended to improve the thermal performance of roofs.

A local steel craftsman, already engaged in the U4C project, was involved in the design and fabrication of vents frames and roof trusses to enhance indoor and attic ventilation. Discussions were also held with a pottery artisan regarding the production of components for an air gap system integrated into the vault, inspired by the Sangath vaults designed by B.V. Doshi (Jalia, 2017). The artisan's production process involves crafting pots using an earth-based mixture blended with donkey dung, firing them for 4 hours in an open-air kiln powered by cow dung, and subsequently drying them for 36 hours.

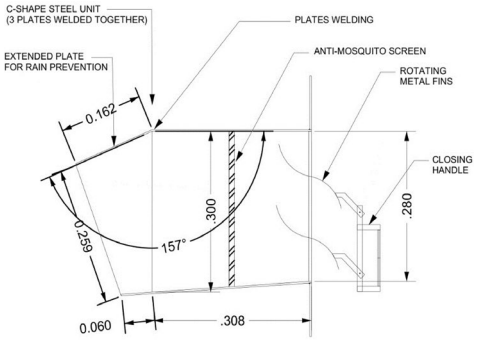

Fig. 2 – *Vents frame* (Arzjani & Baghirova, 2023).

5. Passive strategies technological development

Three passive strategies have been developed through two Master's thesis at the Politecnico di Torino (Arzjani & Baghirova, 2023; Gualdrón-Frias, 2024): the design of steel-framed vents to enhance natural ventilation; the development of an enhanced vaulted roofing system incorporating an air gap and reflective coating; the creation of a ventilated roof supported by steel trusses with a corrugated metal sheet finishing.

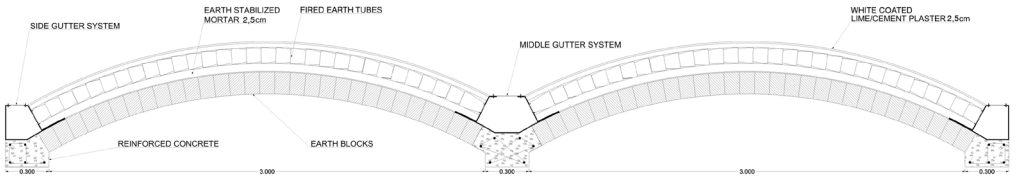

Fig. 3 – *Enhanced vault roof system with fired earth tubes air gap*. (adapted from Arzjani & Baghirova, 2023).

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5.1. Air vents for enhanced natural ventilation

A 30x30 cm vent frame (Fig. 2) was designed to allow installation even after the building's completion. The upper external flange is inclined to provide protection from solar radiation and rainfall. Internally, two adjustable slats enable occupants to direct airflow towards themselves or to close the vent during storms; a welded mosquito net frame prevents insect intrusion. A price of 12,000 CFA was agreed with the local steel artisan.

5.2. Enhanced vaulted roof with air gap

To minimize heat transmission into the interior, a system of fired earth pots assembled into contiguous arches - providing an air gap between the vault's extrados and the CEB structure - was designed (Fig. 3).

Through thermal simulations, the optimal pot diameter was determined to be 14 cm. The pot arches rest on a 2.5 cm thick earth-based plaster layer applied over the vault, enhancing its thermal inertia. A white-coated cement plaster finishing further improves solar reflectance. Approximately 1,100 pots are estimated to cover each vault, and an agreed price for an initial installation test was set at 400 CFA (approximately 0.60 €, in 2023) per pot, totaling 880,000 CFA (approximately 1,320 €, in 2023) per roof. The cost is expected to decrease with larger-scale production.

5.3. Ventilated double roof system

The ventilated double roof system was designed to simultaneously dissipate part of the heat transmitted through the roof layers and to protect the vault from weathering.

The structure is modular and disassemblable, designed according to the size constraints of the corrugated metal sheets size available on the local market.

Truss girders, made of welded φ 16 reinforced steel bars, are connected to the vault's ring beam via tubular steel elements (Fig. 4).

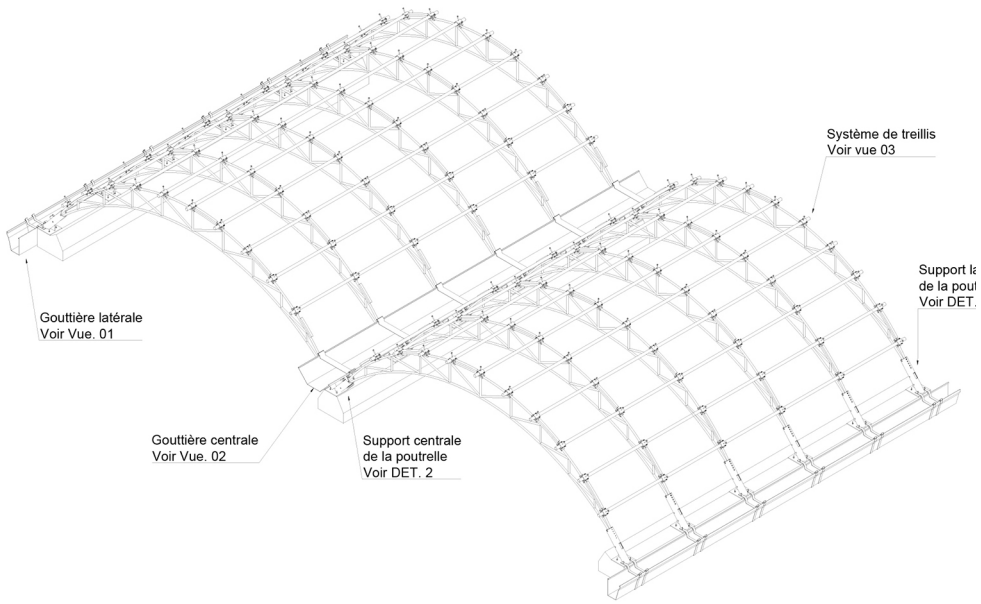

Fig. 4 – *Ventilated roof structure* (Arzjani & Baghirova, 2023).

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6. Production and installation test

The co-design activities carried out in collaboration with local artisans led to the production of vent frames for enhanced indoor natural ventilation (Fig. 5) and the development of pottery prototypes for the vault air gap system. Additionally, an installation test of the pottery arches was conducted.

6.1. Fired earth tubes adaptation workshop and installation test

During a hands-on workshop, the traditional artisan pots were redesigned into regular conical tubes (Fig. 6) to facilitate their assembly into arches atop the building vaults. Initially, the diameters of the tube ends were set at 8 cm and 5 cm, following the precedent of Jalia (2017). They were later increased to 14 cm to optimize thermal comfort. A total of 27 fired earth tubes were produced for an installation test on the vault of a dwelling (Fig. 7). The test involved two artisans responsible for producing a stabilized earth-based mortar and two artisans for the assembly and installation of the tubes.

7. Thermal simulation

Dynamic thermal simulations were conducted using EnergyPlus software to evaluate indoor operative temperature conditions across various building design alternatives and operational scenarios. Different incremental improvements were simulated and combined to achieve optimal indoor comfort conditions, as illustrated in Fig. 8. The ventilated double roof system was proposed as an alternative to the enhanced vault system, demonstrating comparable performance in the thermal simulations. The key performance indicator used to compare simulation results was the percentage of time during which the indoor operative temperature exceeded the acceptability limits, according to the adaptive comfort model defined in ANSI/ASHRAE Standard 55-2023. Two comfort bands were considered: 80% acceptability (for typical applications) and 90% acceptability (for high-comfort standard).

Fig. 5 – *Vents frame prototype* (ph. R. Pennacchio).

Fig. 6 – *Fired earth tubes workshop* (ph. R. Pennacchio).

Fig. 7 – *Earth tubes installation test* (ph. R. Pennacchio).

The model is applicable exclusively to naturally conditioned space (without mechanical heating or cooling), for moderate metabolic rates (1.0-1.3 met), and when occupants are able to adapt their clothing within a range of 0.5-1.0 clo.

7.1. Simulation results

The results of the dynamic thermal simulations are presented in Fig. 9. Non-optimised and optimised design scenarios were compared for different building uses: a) Bedroom and Living space (BL) and b) Residential unit with kitchen (R+K). Table 1 summarizes the significant reduction in overheating hours achieved through the improved design strategies. Overall, the results demonstrate that passive design measures can enable indoor thermal comfort without the

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Table 1 – *Maximum indoor operative temperature and Percentage of overheating hours according with ASHRAE 55 standard* (Authors, 2024).

Configuration	Max. operative T [°C]	Overheating h percent. (80% acceptability limit)	Overheating h percent. (90% acceptability limit)
BL Non optimised	34.5	17.0%	34.3%
BL Optimised	32.1	0.0%	0.2%
R+K Non-optimised	35.7	39.1%	51.4%
R+K Optimised	33.2	0.4%	8.8%

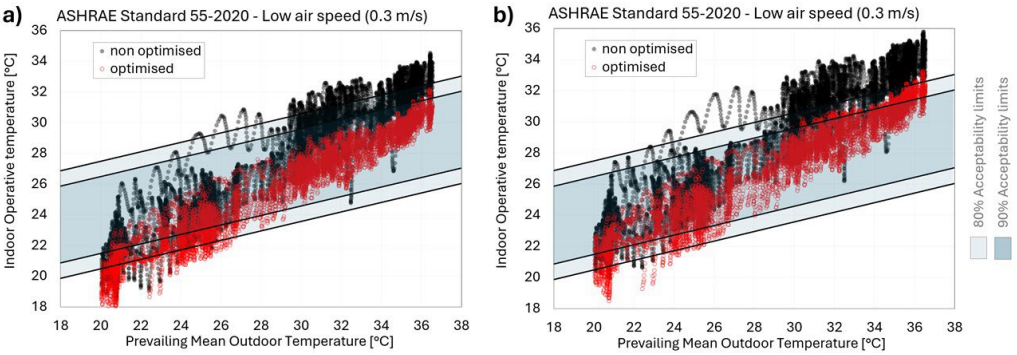

Fig. 9 – *Indoor operative temperature as prevailing mean outdoor temperature function (10 days) for optimised (Fig.8 steps) and non optimised building design and operation: a) (BL); b) (R+K)* (Authors, 2024).

need for mechanical cooling systems. Moreover, an approximate 2.5 °C decrease in maximum indoor operative temperatures was observed for both BL and R+K configurations.

8. Conclusions

Within the framework of the U4C project, this research has demonstrated the potential to optimize thermal comfort in the affordable earthen dwelling proposed by CISP, through the application of passive strategies supported by simple construction technologies and the use of locally available materials and resources. The involvement of local artisans in the design and production of building components contributed to the replicability of the proposed technologies and holds the potential to stimulate the local economy. Among the technologies developed, the ventilation frames for enhanced indoor natural ventilation and the fired earth tubes for improving the thermal performance of vaulted roofs showed particularly promising results in terms of constructability during the prototyping workshops. Furthermore, these components are designed to be installed both during construction and as part of future retrofit interventions, providing flexibility for future upgrades.

However, it must be noted that some of the proposed technologies—such as the enhanced envelope thermal inertia, the improved roof air gap system, and the ventilated double roof—could have a non-negligible impact on the overall construction costs of low-income housing models, such as those promoted by CISP. Further research into the scalability and economic feasibility of the proposed solutions is therefore recommended.

Acknowledgements

The authors acknowledge the support of CISP and its staff in Niger. We also thank Master's students Sepher Arzjani, Aynur Baghirova and Laura Gualdrón-Frias (Politecnico di Torino) for their contributions to the research.

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Earthen Construction, a Question of Permanence

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Abstract

The "Confédération de la Construction en Terre Crue" is a French non-profit association, representative of the different categories of players involved in earthen construction. In 2020, the "Confédération" published the "Guide des bonnes pratiques de la construction en terre crue" (Collectif - CONF terre 2020), the first step "normative" text for French construction, and nowadays conducts research through workshops and a variety of actions. Its initial research work highlights the obstacles to the development of this practice, whether regulatory, normative or related to the skill levels of professionals in the sector. In this paper, the "Confédération" is presenting three of its most recent works in order to share and cross-fertilize, with other European researchers, the advancement in our research and actions in favour of permanent earthen construction, from yesterday, today and tomorrow: the Projet National Terre, PN Terre, a nationwide research project aimed at removing the main obstacles to the deployment of earthen construction on a larger scale; the prefiguration of a participatory guarantee system, PGS, for earthen builders and actors, a participative, non-commercial system based on peer assessment for the recognition of skilled workers; ongoing efforts to have the know-how of those involved in earthen construction recognized as part of humanity's intangible cultural heritage, in France at first and then internationally.

Keywords: *common-good; craftsmanship; earthen building; norm and standardization; participatory guarantee system PGS; UNESCO intangible cultural heritage ICH*

1. Introduction

In France, ten structures and associations of earthen construction professionals, on a national or regional scale, have joined forces since 2018 to form the "Confédération de la Construction en Terre Crue" (https://conf-terrecrue.org/). This non-profit organization aims to: federate and represent earthen construction professionals, promote and defend earthen construction, and support and contribute to earthen construction research activities.

This Confederation operates on a collegial basis. Actions are carried out in workshops, that are open to every member of the organisations forming the Confederation. Among other things, the Confederation's work focuses on enabling vernacular earthen construction techniques to be more easily used in new construction and heritage maintenance. In other words, the fields of study do not stop at materials, workmanship or know-how of the past, but are part of a continuum, as a present-day necessity: "How to settle on Earth" (Friedman, 1976) is a permanent question.

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The Confederation was founded in response to a tendency to "standardize" earthen construction. In France, many of the particularities of earthen construction and vernacular building in general are "outside the norm" of the current framework of the construction sector. This situation makes them extremely difficult to use (Calame 1987) outside the framework of renovations on old buildings dating from before 1948. Nevertheless, the Confederation's normative approach does not go in the direction of conventional standardization of construction products. The Confederation is committed to the recognition of these practices, which transform a diversity of raw materials into building materials while preserving vernacular construction skills, the common good, and environmental and social resources. It is committed to ensuring that these specific features are recognized as standards adapted to contemporary challenges.

A first step towards this "standardization" was taken with the publication in 2020 of a reference text recognized by the entire profession: the "Guide des bonnes pratiques de la construction en terre crue". The aim of this text was to transpose from the spoken word to the written word the habits and needs of the French earth construction system taken as a whole, old and new. This Guide is now recognized as a first step reference by the construction sector i.e., by builders, designers and the insurance system. This article will develop three of the Confederation's actions on the subject of contemporary transposition to the written of vernacular building cultures.

- Firstly, we present the Projet National Terre (PNTerre), a research program supported by the French government, which takes place in a university setting, integrating practitioners in broad participatory research.
- The Confederation is also considering a Participatory Guarantee System (PGS) that would guarantee the right relationship between the quality of workmanship, the transmission of know-how and all the activities induced by the act of building, while ensuring the preservation of resources.
- In the third part, attention is drawn to the desire to have the skills and know-how of earth building, as described in the Guide des Bonnes Pratiques, listed as an Intangible Cultural Heritage by UNESCO.

2. The Projet National Terre

In France, "National Research Projects" are programs designed to promote collaborative applied research projects and full-scale experimentation aimed at increasing knowledge and improving practices, tools and methods in the French civil engineering economic sector. Financially supported by the French Ministry of Ecological Transition[1], these projects bring together public and private research laboratories, design and construction companies, architecture schools and heritage institutions, such as the National FastCarb Project (PN Fast Carb, 2020) on low-carbon concretes. In other words, the results of these projects are reflected in the publication of collections of recommendations and methodological guides, which are intended to contribute to the updating of technical guidelines and standards. Initiated in 2017 by a group of earth construction researchers and practitioners, the Projet National Terre was built around one ambition: to make earth a major contributor to the ecological transition of the construction sector in France by drawing scientific lessons from built heritage in order to apply them to contemporary construction. Today, it brings together over 100 members.

[1] Ministère de la Transition écologique, de l'Énergie, du Climat et de la Prévention des risques.

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The first step was to draw up a charter or set of rules (PNTerre 2017) that reflects the desire to stay as close as possible to vernacular construction and to pay attention to the social, environmental and economic impacts of future constructions. The studies focus exclusively on earth, used with no added binders. The research projects financed or accredited under the PNTerre program promote on-site building skills (with few or no industrial processes), low-carbon projects that maintain the reversibility of construction, and products whose composition is known and free of rights.

The second step in 2019 was to carry out a literature review on all the topics covered (earth building socio-culture, environmental impacts, mechanical and hygrothermal properties, fire safety, worksite testing), and to draw up a research program covering the needs to be met for the sector in the short and longer term, as well as the means envisaged to meet them (PNTerre, 2019).

Projects in progress over the next two or three years include: structural characterization of load-bearing cob structures based on examples from Brittany's heritage (Fig.1); dimensioning of rammed earth structures in Auvergne-Rhône-Alpes; fire behaviour of earth walls; sociological study of heritage renovation sites to gain a better understanding of the transmission of know-how.

The expected scientific and technical results include changing regulations, so that multi-storey buildings in load-bearing adobe or brick partitions in social housing are made possible again. While we await the technical results of the research, we have noticed another result of this project: the opening of dialogue and cooperation between university researchers carrying out laboratory research on earth samples, and the craftsmen and women working on site, far from the academic world. For example, during the construction of a new elementary school in Mordelles, Brittany, applied research was carried out on an in situ seismic risk test, on acoustics between classrooms, as well as on the interactions between the different participants: town council, the architects, the engineers and the masons.

3. Recognizing skilled workers, an ongoing need

In this section, we return to the need to recognize craftsmen in the field of vernacular construction: how Participatory Guarantee Systems (PGS), as defined by the IFOAM[2], are a means to this end.

We will then present the basic principles of the PGS being developed by the Earth Confederation.

3.1. Context

Earthen construction belongs to the realm of vernacular architecture and relies on the mastery of a wide range of skills. “Maintaining and looking after our built heritage means knowing how to do things and being able to pass them on. The absence of this maintenance leads to the loss of this built heritage”. (Chevallier, 1991).

One of the Confederation's aims is to promote and defend earthen construction. Preserving heritage also means learning from the past to improve practices and meet the building needs of today and tomorrow. Achieving this objective implies maintaining know-how, passing it on and improving it (Chevallier, 1991).

Finding competent professionals is a recurring need for project owners concerned about preserving their heritage and the quality of the construction work. They need to find and contact these professionals. Directories of professionals who possess this know-how have always been

[2] IFOAM, International Federation of Organic Agriculture Movements

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used (Calame, 1988). In 2003, the “Maisons Paysannes de France” association published a national survey and census of professionals chosen in the field of rural built heritage, by theme, which included professionals in earthen construction.

At present, there are many different attempts to distinguish professionals. To navigate this, the “Confédération de l'Artisanat et des Petites Entreprises du Bâtiment” or “CAPEB” has published a summary of all the guarantees, acronyms, designations, certifications, etc. that exist in France (CAPEB Grand Paris 2019).

Among these qualifiers, we are seeing a new concept emerging in building environmental quality, based on a participative guarantee system or PGS (DRIEAT IDF 2021 p.35).

3.2. Peer-certified labels or participatory guarantee systems: PGS

The PGS concept was theorized and put into practice within IFOAM as early as 2008 (May 2019), “Participatory Guarantee Systems (PGS) are quality assurance systems with a local focus. They certify producers by relying on the active participation of stakeholders and are based on trust, social networks and knowledge exchange” (IFOAM - Organics International, 2008).

It is a certification system that provides a guarantee of continuous improvement by those who practice this profession for their mutual benefit, while preserving the resources or common goods of Humanity. It is an open, horizontal and transparent process. This model of governance is based on the theory of the commons and its applications (Ostrom, 1999).

Fig. 1 – *Projet Bauges Porteuses – Pn Terre-2025* (Authors, 2025).

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Participatory guarantee systems (PGS), labels or endorsements certified by peers, are increasingly visible in the field of food and fair trade. The French association “Nature & Progrès” was a forerunner of what would later become the organic farming movement, drafting its first specifications in 1972.

Other sectors of activity have also adopted this model of governance, such as intellectual data in research, or free software in information technology.

From the outset, these PGSs aroused the curiosity of intellectuals, self-builders and craftsmen in favour of vernacular construction, though without ever achieving the equivalent success or recognition of the “BIO” (organic food) certification.

In the building sector, a PGS was launched in 2009: this is when the BDM (Bâtiment Durable Méditerranéen) approach became operational. It includes a self-assessment framework covering environmental, social and economic aspects, as well as a human and technical support system for all those involved in the project, and a final validation of the performance level achieved by the building by an inter-professional commission (Buick 2012). This system is now being rolled out in other regions: Bâtiments Durables Occitanie (BDO), Bâtiments Durables Franciliens (BDF)EKOPOLIS in Île de France.

In contrast to the IFOAM's definition of PGS, BDM and its successors have chosen to certify buildings, not the construction professionals involved. Buildings are assessed in their entirety, in terms of their environmental impact over their complete life cycle. These labels or participatory certifications are difficult to compare, as they do not relate to the same objects.

3.3. The project for a peer-certified label for earth constructors

Following the publication of the “Guide des bonnes pratiques de la construction en terre crue” in 2018-2020, a forward-looking workshop was formed within the Confederation on the subject of participatory guarantee systems (PGS). In the light of the COMPAIRS[3] studies from 2020 to 2023 and the analysis of pre-existing PGSs in the building sector, the Confederation workshop has been able to define its own project. Initially, it intends to address the need for skill recognition and knowledge transmission. We can see that a double shift needs to take place. One that comes from an understanding of the materials, their characteristics and the results achieved (based on research carried out at “Projet National Terre”), and the other from participative certification, an organization that certifies that the company or individual has the skills to achieve on site the results achieved in the laboratory. This participatory certification or peer-certified label project has several goals:

- structure the profession, allowing a better knowledge of the profession from within and without,
- improve, disseminate and transmit practices and know-how, through initial and continuing training and all forms of knowledge dissemination,
- revise and update the standard-setting reference text: “Guide de bonnes pratiques de la construction en terre crue” (Confédération de la Construction en Terre Crue, 2020),
- gain the confidence of all those involved in the building industry, particularly technical control and insurance companies, in earthen construction.

[3] https://certification-participative.org/le-projet-compairs/

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4. Earthen construction know-how, Intangible Heritage of Humanity

In France, as in many other countries around the world, building with earth involves a wide range of skills, from the selection and preparation of local earth to its use in built structures. Despite the evolution of laying techniques and the mechanization of some tools, these skills are characterized by a high degree of permanence, requiring many years of practice to master. According to UNESCO:

> "Intangible cultural heritage means the practices, representations, expressions, knowledge and skills... that communities (...)recognized by communities (...) as part of their cultural heritage (...) transmitted from generation to generation (...) constantly recreated by communities and groups according to their environment, their interaction with nature and their history, and providing them with a sense of identity and continuity, thus helping to promote respect for cultural diversity and human creativity" (UNESCO, 2003).

Throughout France, both in the metropolitan and overseas regions, the cultural community of earthen construction, which has existed for centuries, has all but disappeared. It is no longer precisely defined as "passing on a heritage from generation to generation, providing a sense of identity and continuity". However, know-how has not disappeared, even though it has declined since the Second World War, partly due to the death of many craftsmen on the battlefields, and partly due to the industrialization of construction. Over the last forty years, and particularly over the last ten, they have been revived and updated by professionals and residents who practice earthen construction and contribute to studying, highlighting and improving recognition of this know-how. Today, building with earth is more than just the act of making structures with a clay-based material. It's also a state of mind specific to a community of craftsmen and practitioners who have made a name for themselves in the construction industry. The "Confédération"'s application for earthen construction to be listed as an intangible cultural heritage site under the UNESCO Convention is based on this community of practitioners.

The aim is to make an inventory of the specific skills involved in earth building, understand their vitality and how they are passed on, identify the threats and risks they face, and identify the ways in which they can be safeguarded and enhanced, either currently or in the future.

4.1. Inventory of skills

Knowing the skills and know-how of our craftsmen and craftswomen requires a thorough understanding of the heritage they have built up. Inventories have already been carried out in the regions, some by government departments, others by the regions themselves (Midi-Quercy; Nord-Pas de Calais); surveys carried out as part of university theses and dissertations (Bassin Lyonnais, Isère, Bresse, Ain, Champagne, Rennes, etc.); the inventory launched by the Gustave Eiffel University in Nantes on the sustainability of earthen construction techniques (Brittany, Pays de la Loire, Champagne, Limagne, Occitanie). There is also a national inventory project, as well as three inventories of contemporary earthen architecture. Further studies are planned to cover the entire country.

4.2. Methods of learning and transmission

Earthen construction practices are based on specific knowledge and know-how different to those usually required to design and build with standardized and industrialized materials. They are transmitted in different ways: on-site in a company; in continuing education; in participatory construction sites or educational construction sites. Transmission is based on teaching traditional techniques, based on the observation of heritage for inspiration, even when the goal is to find new ways of doing things.

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4.3. Threats and risks

Among the threats and risks weighing on the know-how linked to earthen heritage, the loss of culture in the broad sense, among the general public on the one hand, and among the inhabitants of earth houses on the other, as well as the loss of contact with the earth material, lead to disqualifying representations, and to a lack of skill transmission.

The invisibility of earth as a building material is due to social representations which, in France as in many other countries (this is one of the "discourses" of colonization), equate earth houses with poverty and squalor, or with obsolete knowledge. The bad reputation of the material is conveyed by conventional building professionals and residents who suffer and cause damage, due to a lack of knowledge of the properties of the material to the point of making it lose its thermal and plastic assets, thus giving it the status of "bad" material." (Pecquet & Pruvost, 2019). This lack of knowledge leads to inappropriate rehabilitation and renovation practices by residents and professionals with the use of inadequate materials and techniques, but also incorrect practices in new construction. In addition to this lack of knowledge of built heritage and the lessons that could be learned from it, there are other factors such as the trend towards standardization of traditional know-how on the model of industrial materials through the growing demand for reference texts to justify the performance of these techniques, installation and insurability difficulties for craftsmen due to regulatory constraints. Another factor is urbanization, which causes the disappearance of village communities which participated in the collective maintenance of earth structures.

4.3. Safeguard measures

Safeguarding measures consist of regulatory actions aimed at the building profession. They also aim to give visibility to this know-how and to the earthen built heritage, so that building professionals, but also the population, can re-appropriate this heritage. They are of several types:

4.4.1. Reference texts

These texts are written by professionals in earthen construction and published: Treatise on earthen construction; Guide to good practices; Professional rules for renderings on earth supports; Standard on earth bricks; Glossary and lexicon of earthen construction.

4.4.2. Training actions

A collaboration with national training authorities; the drafting of professional references at European level and dissemination in existing national references; different programs in architecture and engineering schools; regional introductory projects for the restoration of earth buildings, open to all.

4.4.3. Actions for main public

Many expositions, conferences and regional festivals are accessible to the general public.

4.4.4. Public recognition

The French State has been funding actions to structure the sector since 2012. Many projects are supported by the Regions and local authorities. In 2020 a national professional diploma for earth masons was created. Earth as a geo-sourced material was reintroduced into the curriculum of the C.A.P. (Professional Aptitude Certificate) for masonry. A new C.A.P. was introduced for half-timbered construction. All these initiatives are bearing fruit. However, they are still insufficient for earth building to become a common construction technique again. All the risks and the difficulty of safeguarding and promoting this know-how encourage us to request its registration as Intangible Cultural Heritage with UNESCO, because the urgency is great, given the disregard in which earthen construction heritage finds itself today.

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Since this type of construction is practised in all latitudes, it could be defined as a universal example of the interaction of human with nature, a universal art of building with local, organic and geo-sourced materials.

We hope that this Conference will be an opportunity to create links with other countries, which could undertake the same approach, first with their government, to then join in a common recognition by UNESCO of this vernacular heritage in earth.

5. Conclusions

The challenges of heritage preservation and in particular the transition between vernacular architecture and contemporary construction can be addressed by different types of organization: States at different national, regional and local levels, but also educational organizations (Universities) or cultural dissemination organizations (Museums). These issues can also be supported by private entities defending quite divergent goals. In this contribution we have tried to show the values and actions supported by a federation of regional and national associations representing, for the most part, artisanal companies in earthen construction. What emerges is a renewal and an interpretation of traditional techniques for their application in contemporary architecture, not from a formal and nostalgic point of view, but on the contrary in the sense of a living heritage anchored in building skills and knowledge, trust between peers, and extended to the scientific community.

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Traditional Architecture and Urbanism of Veraguas, Panama, in a Globalized Reality

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Topic: T4.4. Reinterpretation of traditional techniques for their application in contemporary architecture

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Abstract

The Republic of Panama is home to a rich architectural heritage that has progressively developed throughout history, forging a unique identity in each region. This heritage had remained steadfast for more than 200 years, especially in rural areas, where vernacular architecture became a way of life and a means of coexistence for the small communities that inhabited these regions. However, in recent decades, the advancement of globalization has promoted the use of foreign materials and designs, threatening to dilute this cultural identity. The research focuses on analyzing this phenomenon in the rural areas of the province of Veraguas, where this native spirit is still preserved. It examines the history and the main architectural and urban typologies characteristic of the region, which flourished between 1860 and 1945, as well as their advantages, benefits, and adaptability to the present day. Through a housing inventory conducted in the province, three main typologies were identified: Quincha, Adobe Brick, and Caña Blanca or Vegetal Housing. Consequently, a set of regulations was proposed for social housing developments in rural areas, promoting the formalization of these constructions. Based on international guidelines, two mixed typologies were proposed, combining traditional methods with modern advancements to enhance the structural characteristics of traditional typologies. Finally, a comprehensive urban structure was designed, incorporating buildings of various types and uses as an example of the correct application of the strategies proposed in this research. In conclusion, this study revealed the urgent need to protect and revitalize traditional constructions in the rural areas of Panama, proposing solutions that integrate local building practices with new possibilities adapted to current conditions.

Keywords: *tradition; sustainability; cultural heritage; construction; rural population*

1. Introduction

Globalization has profoundly transformed social, economic, and cultural dynamics, facilitating access to technology and information, but also leading to the homogenization of lifestyles. This influence has weakened local cultural expressions, particularly in architecture, where foreign models have displaced traditional construction forms adapted to the environment and the identity of each region.

In this context, the province of Veraguas, located in the heart of Panama, serves as a key reference. With more than 500 years of history and a strong cultural tradition, Veraguas has preserved many of its customs, both in religious practices and in the everyday life of its people. Since its establishment as a province in 1560, it has been the setting for a way of life deeply connected to community, land, and the material expressions of dwelling.

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The vernacular architecture in Veraguas—constructed using local resources such as earth, cane, wood, and palm—responds not only to climatic and geographical conditions but also reflects the social structure and collective mindset of its inhabitants. However, in recent decades, this architecture has been displaced by standardized solutions promoted from urban centers, which often disregard the realities of rural areas. As Arias Martínez (1981) warned, these new housing solutions tend to overlook native materials, creating dependency and weakening the appreciation for local culture.

Given this issue, it is crucial to rethink housing development models in rural areas. This study aims to analyze the traditional architectural typologies of Veraguas and their urban context, to propose strategies for reinterpreting sustainably within the current reality, strengthening cultural identity and improving the quality of life of its inhabitants.

Fig. 1 – *Last "quincha" house in downtown Santiago* (Aponte, 2022).

Fig. 2 – *Typical 21st-century Panamanian house, constructed after the demolition of the previous house* (Aponte, 2023).

2. Concepts and definitions

2.1. Traditional architecture in Veraguas

Traditional Panamanian architecture extends across the national territory and varies regionally. Despite using similar materials, each area adapted specific strategies to respond to its unique climatic and geographical conditions. As a result, this architecture became deeply intertwined with the sociocultural reality of its inhabitants.

This is how the architecture of the Province of Veraguas was shaped—not designed to represent specific eras, nor dependent on architects; rather, it was molded by the people themselves as a reflection of their way of life.

Fig. 3 – Mud plastering assembly carried out in Veraguas (Aguilar, 2022).

2.2. Characteristics and typologies

For the purposes of this study, the representative homes of Veraguas will be those identified in the Rural Spaces Characterization Report by ECLAC. The construction systems of these dwellings are understood as direct responses to the needs and opportunities presented by their surrounding environment. The focus will be on homes developed between 1860 and 1945—a period during which these construction methods reached their peak and their defining features became fully established. The main systems are described below:

- **Quincha**: "Quincha is a traditional technique for building walls, consisting of a wooden framework filled with plastic earth (mud) mixed with plant fibers. Given the presence of

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different materials, it is classified as a mixed construction system" (Jorquera, 2015, p. 10). The quincha house can be considered the most widespread throughout the region, as evidence of its development can be found in all districts.

Fig. 4 – *Quincha house with zinc roofing* (Aponte, 2022).

- **Adobe Brick**: Adobe brick homes emerged after quincha homes. However, according to local testimonies, they did not replace quincha construction but rather offered an additional option at the time. The bricks were made from a mixture of mud and straw (sometimes sand in coastal or river areas). These bricks were molded and dried in the sun for several days or weeks. In some communities, artisanal kilns were built to fire the bricks, a process that increased their durability and resistance to moisture. While less common than sun-drying, this method was particularly useful in regions with higher rainfall or where greater structural longevity was desired.
- **Vegetal**: The vegetal house, as its name suggests, is constructed entirely from materials sourced from the endemic vegetation of the region. The first type, which could be considered the most widespread, was the "penca" house, characterized by a roof made of dry palm leaves and walls made from bamboo or wood. The second type developed in more specific areas, such as the **Santa Fe** region, where "caña blanca" houses are found, easily recognizable by their yellowish cane walls.

2.3. Social housing projects in Panama

Panama's investment in support programs for individuals, groups, and sectors at risk has increased significantly over the past decade. The growing allocation of state funds to ensure a dignified standard of living for all citizens extends beyond direct economic subsidies to include investment in the strategic planning of development projects.

A representative example is the "Techos de Esperanza" program, which provides 41 m² houses built with metal structures and prefabricated panels (RBS) or concrete blocks. According to the budget execution report from the Ministry of Housing and Territorial Planning (MIVIOT), more than 46,219 housing solutions have been delivered nationwide.

2.4. Relationship between housing and life

Modern society, particularly in urban areas, has progressively lost its connection with customs, traditions, and the sense of community life. Over time, it has succumbed to individualism, and homes have been designed as "fortresses" that keep family members inside and hinder any connection with others. This is not the case in rural areas of the country, where these customs, traditions, and ways of thinking remain alive.

The importance of this reflection lies in recognizing that the lifestyle of the inhabitants of these rural areas cannot be compared to that of the city, not only due to economic or social differences but also because of a profound shift in ideology and thought shaped by their upbringing.

This aspect may be the most significant part of this research, as it is here where social housing projects alarmingly fail in their efforts to promote quality infrastructure. They export models that do not adapt to the specific needs and, therefore, to the way of life of these people.

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3. Characteristics of the province of Veraguas

3.1. Location and area

The province of Veraguas is located in the center of Panama, extending from the Atlantic Ocean to the Pacific. It borders all the provinces of the isthmus, except Darién, Bocas del Toro, and Panama. Its surface area is 10,629 km², according to the Environmental Atlas of the Republic of Panama (2010).

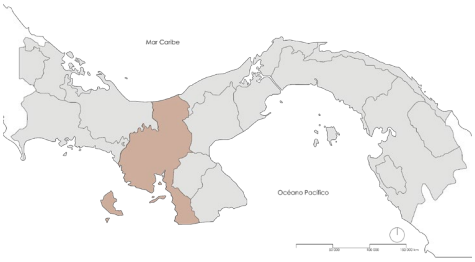

Fig. 5 – *Location of Veraguas Province in the Republic of Panama* (Aponte, 2022).

3.2. Political administrative division

Veraguas is divided into twelve districts, each with diverse physical, social, and economic conditions. Santiago serves as the economic center; Atalaya stands out for its religious traditions; Calobre, La Mesa, Cañazas, Las Palmas, and Soná rely on agriculture and livestock; Santa Fe and Mariato have tourism potential; Montijo is known for its fishing and handicrafts; and San Francisco and Río de Jesús combine historical significance with a diversified rural economy.

4. Characteristics of the population

According to figures from the National Institute of Statistics and Census (INEC), the province of Veraguas has approximately 247,644 inhabitants, with a low population density of 23.4 people per km². It is characterized by its predominantly rural nature, with only 15.8% of the population living in urban areas.

The main economic activity is agriculture and livestock. In 2023, around 19,233 people (18.38% of the active population) were employed in related sectors such as agriculture, fishing, forestry, and hunting.

5. Current overview of architectural heritage in Veraguas

In recent decades, the architectural heritage of the province of Veraguas has experienced a marked decline. According to the *Rural Spaces Characterization Report*, developed by the Economic Commission for Latin America and the Caribbean (CEPAL) in 2015, traditional housing typologies—originally constructed using locally sourced materials—have gradually been replaced by standardized construction methods, including block walls, concrete structures, and zinc roofs. Further insight into the early stages of this transformation can be found in the 1981 thesis *The Rural Habitat of Panama*, which presents relevant data underscoring the replacement of vernacular architecture. As noted:

> The houses or designs provided by the State to rural communities, in addition to disregarding the use of local materials and resources, present the issue that, due to the adoption of urban patterns, they do not align with the economic capacities of the rural community. Instead, they are determined by the tastes and preferences of the users, creating dependency among farmers and diminishing their appreciation for the materials offered by their own environment. (Arias Martínez, 1981, p. 357).

6. Housing inventory

As part of the effort to gather information on the current state of traditional architecture and urbanism in the region, an inventory was carried out in five districts of the province of Veraguas: Cañazas, Calobre, La Mesa, Santa Fe, and Santiago. The selection process prioritized buildings that preserved representative elements of traditional architecture and exhibited

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vernacular construction techniques. A total of 30 homes were documented, with data collected on their state of preservation, year of construction, ownership, individuals involved in the building process, general dimensions, and their positioning within the lot.

Fig. 6 – *Quincha house with zinc roofing* (Aponte, 2022).

Fig. 7 – *White cane house with zinc roofing* (Aponte, 2022).

6.1. Structure of the towns

The rural towns studied to exhibit a similar urban structure, adapted to human needs such as access to water, farming, and animal husbandry, as well as to economic and religious factors. In lowland areas, communities are located on plains, while in mountainous regions they are found on slopes or plateaus.Most settlements feature a central open space known as a *llano*, which is irregular in shape and lacks a specific function, though it is commonly used for recreational purposes. Houses are typically aligned parallel to roads but are set back from both the roadways and property boundaries. Additionally, the presence of nearby rivers or streams influences the organization of the built environment.

6.2. Lot organization

Unlike modern homes, which contain space for all daily activities inside, in these rural towns, activities extend across the farm and are not limited to the main building of the house. The spaces and their organization on the property are explained as follows:

- **Kitchen**: The kitchen is a structure built near the main house. This space is typically constructed with wooden walls and a thatched or zinc roof (in recent decades).
- **Latrine**: Traditionally, this space was an independent, closed wooden structure, containing a hole with a wooden or concrete seat, where people performed their sanitary needs.
- **Showers**: Located next to the latrines, this is a space specifically built for personal hygiene, enclosed for privacy.
- **Pens**: These are small, roofed wooden structures, sometimes elevated off the ground, depending on their use. They are used to confine animals, facilitating their raising and preventing them from escaping or being harmed by predators.

Fig. 8 – *Organization of a Traditional Property in Veraguas* (Arias & Martínez, 1981).

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6.3. Internal organization of the house

Traditional homes are not characterized by a wide variety of internal spaces; in fact, the organization inside is quite simple. The following spaces can be differentiated:

- **Living Room**: The living room serves as the social hub of the house. This space is typically found in traditional quincha homes or adobe brick houses.
- **Dining Room**: This space is rarely used and is commonly found in quincha houses, where small tables, chairs, or stools are placed. Its limited use is due to the fact that in these rural areas, meals are often consumed in less formal spaces, such as the porch or patio.
- **Porch**: The porch is a common space in quincha and adobe brick homes, but it was not usually found in traditional vegetal houses. It is a free and open space located at the front and extending along the entire house.
- **Bedroom**: The bedroom is present in most older constructions. In quincha houses, bedrooms are typically located on the sides of the house, while in vegetal homes, when they are found, they are placed at the rear of the house.

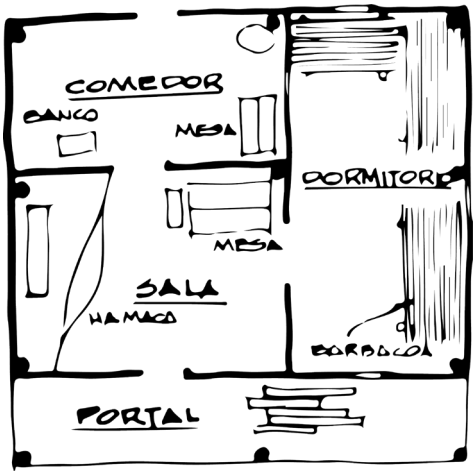

Fig. 9 – *Internal Organization of a Traditional Home in Veraguas* (The Rural Habitat of Panama, 1981).

7. Update of construction systems and urban structure

It is evident that over the years, the needs, quality expectations, and interests of people regarding their homes, even in the most rural areas, remain like those present more than 150 years ago. However, rejecting these construction typologies is not the logical response, as doing so would also mean losing the great advantages that traditional systems offer us.

7.1. References in the Region

This situation has also occurred in other countries in the region, and analyzing this issue in an international context provides us with clues about the strategies we can use to address it.

- For example, in the case of Peru, this situation was evaluated in 1970, which initiated research by the Pontifical Catholic University of Peru with the aim of formalizing construction using these systems. This led to the creation of the Technical Building Standard E.080 Adobe, which covers the use of simple adobe, stabilized adobe, quincha, or similar materials as a unit for masonry construction with these materials, as well as the characteristics, behavior, and design.
- In the case of Chile, the construction of earth is promoted through a series of manuals such as *Building a Rural Quincha House* or *Manual of Improved Quincha*. According to the architects and researchers within Chile's bioconstruction community, the goal of these strategies is to highlight, disseminate, and certify contemporary earth construction techniques, opening new possibilities for the sustainable development of Latin American societies.

8. Proposal

The purpose of this research is not limited to theoretical; the practical implementation of the concepts explained here consists of developing an architectural and urban typology adapted to rural life and based on traditional construction systems.

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Fig. 10 – Reinterpretation of traditional construction typologies in three buildings adapted to the traditional style (Aponte, 2023).

8.1. Urban development regulations

For an objective like this, the current urban development regulations in the Republic of Panama fall short when attempting to emulate rural lifestyles. Achieving this requires a reconsideration of the existing regulations and a focus on specific goals.

These include creating a new designation and coding to distinguish this regulation from the existing ones, reducing net density to foster less populated and more connected urban structures, significantly decreasing the maximum occupancy percentage, and establishing generous setbacks to prevent small and inefficient spaces between homes. Through these strategies, the creation of a regulatory proposal, named "R-RT" or "Traditional Rural Residential," is ultimately achieved.

Fig. 11 – *Urban planning, residential in yellow, commercial in red, recreational and green spaces in green, and infraestructures and public facilities in blue* (Aponte, 2023).

8.2. Architectural Reinterpretation

Once the proposed regulatory framework was established, architectural models were developed to reinterpret traditional typologies and adapt them to a variety of contemporary uses. These proposals combine vernacular techniques—such as the use of *quincha* or adobe—with modern structural enhancements, including concrete or lime foundations and raised plinths to improve durability. The designs feature characteristic elements such as gabled roofs, casement windows, wide front porches, and exposed wooden columns. Productive areas are also incorporated within each plot, including spaces for cultivation and animal husbandry. Ceilings and interior partitions are built using *caña blanca*, preserving local construction methods.

In total, nine buildings were designed: an incremental housing unit, a caretaker's house, a market, a shop, a school, a health center, a religious temple, and a tourist hostel—each tailored to its specific function while preserving the essence of traditional architectural identity.

8.3. Urban reinterpretation

Integrating traditional architecture with modernity is only meaningful when it is accompanied by a reintegration into local culture. This research aims to preserve identity and improve the quality of life in rural areas through urban reinterpretation based on compiled inventory and bibliographic data. The proposal suggests separating residential development from the main road to create greater spatial autonomy, with two vehicular access points for easier entry and exit.

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Table 1 – *Comparative table between Royal Building System and the Quincha system* (Aponte, 2023).

Aspect	Royal Building System (RBS)	Quincha
Materiality	Prefabricated PVC panels reinforced with concrete and steel.	Wood and cane structure, interwoven and coated with mud.
Logistics and transportation	Requires specialized transportation and heavy machinery.	Locally available materials: minimal transportation required.
Construction	Requires specialized technicians and assembly with machinery.	Enables local labor and traditional techniques.
Housing area	41 m²	83 m²
Costs	$17,500	$18,440.84

The layout consists of 51 homes distributed along the perimeter, while urban facilities, such as a school, health centers, and a religious temple, are placed at the center, maintaining the traditional rural structure. A central market is introduced for commercial use, acting as a meeting point and strengthening the community's social fabric. Public spaces are concentrated in the central area and expanded to zones with high value or population density.

9. Cost Study

With the objective of assessing the economic feasibility of the proposed architectural models, a cost study was conducted to evaluate the development of the evolutionary housing model designed earlier. The results show that the investment required to construct a 83m² Quincha home would be approximately $18,440.

In 2017, the national news program TVN reported that “The value of the Techo de Esperanza homes is estimated at $17,500.” These 41-square-meter homes promoted by the Ministry of Housing and Territorial Planning have high costs, requiring specialized labor, heavy machinery, and transportation.

We can assert that investing a similar amount of money to achieve larger homes, which allow for participatory construction, future expansion, annex building, and the preservation of culture, is clearly a much more favorable offer for the country and its residents.

10. Conclusions

A human-scale urban organization centered on social cohesion was identified, highlighting the need to reconsider current development models. Additionally, the traditional architecture and urbanism of Veraguas retain a strong cultural identity and demonstrate effective adaptation to the environment, offering valuable methodological insights for future research.As previously mentioned, this study serves as an action plan, emphasizing the potential for incorporating traditional architecture into government projects and progressively encouraging its widespread recovery.

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Author Index

Alfonso, J., 561
Amer, V., 737
Aponte, C., 513, 833
Arroyo, B., 673

Barada, J., 681
Basset-Salom, L., 633
Bollini, G., 657
Boostani, A., 697
Bosch González, M., 705

Cancino, C., 529
Canivell, J., 545
Canziani, J., 497
Çapeli, L., 585
Carranza, L. M., 545
Carrascosa Moliner, B., 721, 745
Celestino, S., 545
Celina-Sáez, V., 609
Chen, X., 761
Cristini, V., 729
Cutillas-Victoria, B., 545

Dabaieh, M., 455, 809
Dai, S., 761
D'Amore, A., 777
Daneels, A. J. E., 601
De Filippi, F., 817
Dethier, J., 489
Diaz-Santivañez, M., 769

Fantucci, S., 817
Fortea, M., 545
Fratini, F., 585

Gambilongo, L., 641
Garcés Desmaison, M.A., 785
Garcés Rallo, J., 785
García-Soriano, L., 665
Gentilleau, J.M., 825
Germanà, M. L., 777
González, A., 521
Grazzini, R., 697
Guardiola-Víllora, A., 633
Guerra, P., 545
Guerrero, R., 825
Guerrero, L., 673
Guillén Guillamón, I., 609, 625
Gusella, V., 737

Hage, S., 569
Hernández-Salazar, I., 505
Hollerman, S., 569
Hueto-Escobar, A., 199, 407, 665, 689, 1145

Jiang, W. H., 553
Jiang, C., 761
Joffroy, T., 801

Khalil, M., 705

La Spina, V., 231
León, M. A., 545
Liberotti, R., 737
Lico, A., 697
Lorenzón, M., 545
Losa, N., 681
Lourenço, P. B., 641
Luvidi, L., 585

Macchioni, E., 529
Manzano-Fernández, S., 407, 537, 649, 665, 729
Marcus, B., 529
Martínez Díaz, L., 617
Mattone, M., 585, 801
Medialdea, A., 545
Medina Lorente, O., 721
Mendiguchia, F. A., 609,625
Meniku, J., 585
Mileto, C., 25, 319, 407, 577, 665, 1169
Misseri, G., 697
Morocho Jaramillo, D. E., 25, 447, 649

Nicolas, A., 825
Obama, A., 569
Olcese Ortega, J., 785
Olivera, A. R., 521
Osete Cortina, L., 721, 745

Pennacchio, R., 817
Pons Valladares, O., 705
Popot, S., 825

Quintana-Gallardo, A., 609, 625

Rakotomamonjy, B., 801
Rescic, S., 585, 697
Revert, E., 545
Roca Cabedo, M., 745
Rodríguez González, E., 545
Rovero, L., 697

Sáez, E., 497
Sáez, V., 609
Sainz Esteban, A., 785
Sainz Guerra, J. L., 785
Sakr, M., 809
Salcedo, J. C., 545
Sandoval-Gómez, F., 25, 537, 609
Sastre, J. M., 785
Scudellaro, C., 801
Secondo-Maglia, J. G., 609
Shibata, S., 753
Shu, Y., 793
Silva, R. A., 641
Sirera-Cocera, A., 625
Sprega, A., 529

Tomasi, J., 681
Tortajada Montalvá, E., 447, 463, 689, 729

Vegas, F., 199, 319, 407, 447, 577, 665, 689, 1169
Veliz, N., 681
Villaseñor, E. E., 521
Voksh, A., 585

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Weston, A., 713
Wu, YH., 761
Wu, Y., 761

Xie, T. Y., 593
Xu, J. L., 553

Ye, F., 577

Zamora-Marina, E., 609

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