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Experimental evaluation of earthen plasters for the conservation of raw earth heritage in the Piemonte Region - Italy.

Master degree in Architecture for Heritage

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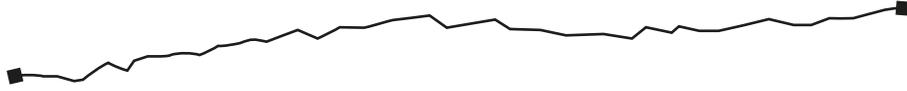
Politecnico di Torino
Faculty of Architecture
Department of Architecture and Design

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2026

A mi madre
A mi padre
A mi hermano

Acknowledgements



At the conclusion of this two-and-a-half-year academic journey, I would like to express my sincere gratitude to my supervisor, Professor Manuela Mattone, who introduced me to the fascinating and, for me, previously unknown field of earthen architecture in Italy, while generously sharing her extensive knowledge. Her patience, guidance, and kindness were fundamental in helping me understand this subject, particularly as a foreign student approaching this context for the first time.

Grazie mille prof!

I would also like to thank everyone who was aware of this project and without hesitation, gave me encouragement and support through their words, as well as my friends and professors in Bogotá D.C., without whom this journey would certainly not have been possible.

Abstract



Experimental evaluation of earthen plasters for the conservation of raw earth heritage in the Piemonte Region - Italy.

The earth has been used during centuries as one of the most common building materials for humans, it has provided shelter since the first settlements and created also cultural landscapes. Even though it has many advantages, such as: low cost, local availability, breathability, and thermal insulation, the earth buildings are fragile and vulnerable to environmental and human being threads leading to a progressive degradation. It has to be taking into account that the conservation of earthen heritage not only safeguards material remains, it also contributes to the transmission of traditional construction knowledge being the base of the “culture of the earth”. This study is focused on the Piemonte region in Italy, recognized for having a rich heritage of earthen buildings. Also, has been one of the regions that have approached this type of heritage from a legal framework.

Some laboratory tests were carried out on eight (8) plasters made with Alessandria’s province earth, where it was possible to identify the plasters’ performance in terms of material compatibility, erosion resistance, adhesion and response to moisture. As a result, it was possible to identify the most suitable plaster that can be used to improve the conservation of earthen constructions while respecting traditional techniques.

Keywords: Earth buildings, earth plasters, earth heritage conservation, Piemonte region, Alessandria, laboratory tests, Geelong Test, Spray Erosion Test, Karsten Tube Test, Shear Test.

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I



Introduction

From its origins the earth has been one of the most common used materials by humans for buildings, this has provided shelter for long periods and on a larger scale than any other material. For almost 10,000 years, with the existence of the first urban settlements¹, raw earth has been present in historical and vernacular building traditions, making that a third of the world's population (around 1.5 billion people) live in buildings made of this material². Compared to masonry, earthen architecture has not a lasting monumental character, many structures have almost completely disappeared, making their traces being barely perceptible in the landscape. However, its architectural features and their preservation is very important, especially for its widespread use and their fragile and ephemeral nature³.

Building with earth has lots of advantages, it involves working with available material whose structural quality depends on its adequate internal cohesion, mainly provided by the presence of clay, acting as a natural binder⁴. This tradition is the origin of many construction systems developed, with some technical variations that reflect the cultural and territorial identity of different geographical contexts. These constructions either monumental, domestic, or rural, can be found in regions of the world where climatic conditions and soil's features (physical and chemical) allow their use, shaping cultural landscapes recognized by earthen architecture⁵.

That is why, earthen architecture constitutes a living testament of history, culture and technical knowledge of cultures, integrating landscape, historical, and technological values. The conservation of this heritage not only implies the material remains but also the transmission of the construction knowledge, considered a base of preserving what is known as the “*culture of the earth*”⁶. However, many of these settlements are now seriously endangered due to the progressive loss of maintenance, abandonment and the replacement of raw earth with materials considered more “modern” or “durable” (most of the times incompatible materials). Also, the inappropriate interventions, such as partial demolitions, have accelerated the processes of deterioration and destruction of these structures⁷.

Very closely linked to heritage and vernacular architecture, earthen plasters play a fundamental role in conservation. Around the mid-1970s, UNESCO recommended the use of traditional techniques in the restoration of cultural monuments and buildings, including the earthen plaster, as a response to the damages caused by the use of incompatible modern materials

1 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 1.

2 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. Introduction.

3 Ibid. Introduction.

4 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 1 – 2.

5 Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 9.

6 Ibid. pp. 20 – 21.

7 Ibid. pp. 20 – 21.

and techniques. This recommendation was subsequently adopted by the Council of Europe in 1985⁸.

Despite its gradual decline in the last decades, the earthen architecture has experienced a new focus of interest in recent years. The attention for the earthen heritage conservations started to be noticed in the late 1960s, following several archaeological campaigns in the Middle East, particularly Iraq, highlighting its vulnerability and high cultural value⁹. Some studies made over the last few decades have demonstrated the advantages of the earth as a building material. Some of the features are: its high availability, low cost, reduced energy consumption during its process and its ability to provide comfortable living spaces, thanks to its breathability and thermal insulation properties¹⁰.

The preservation and transmission of knowledge related to materials, construction techniques and traditional regulations are essential references and starting points, for the development of sustainable modern architecture with low or zero environmental impact¹¹. However, in reality the advance of modern construction techniques has affected the transmission of this knowledge, leading to a lack of maintenance of traditional buildings and the implementation of unsustainable interventions that threaten the integrity of vernacular heritage.

This big problem has addressed the “*Enhance VERnacular EARThen Heritage (EVER EARTH)*” project, which main objective is to analyze the strengths and weaknesses of actions implemented so far to safeguard and promote the reuse of vernacular earthen architecture, also, to propose adaptable intervention methodologies that can be replicated in other contexts. It focuses primarily on the Piedmont region, featured by a rich heritage of earthen architecture and which has been the focus of specific conservation and restoration interventions, not only from work of cultural associations, but also with the regional law 2/2006.

After years of its creation, it is important and useful not only to evaluate the results of the interventions carried out and take advantage on their findings. Also, to study in depth the risks that can affect the land heritage and to outline strategies that can be applied in other contexts and to similar heritages, contributing to the effective conservation and reuse of the architecture and the rural landscape. This, in line with the missions “Digitalization, innovation, competitiveness, culture and tourism” and “Green revolution and ecological transition” of the National Recovery and Resilience Plan.

8 López Pérez, C. (2019). *Revestimientos en tierra en edificaciones patrimoniales en Colombia* (pp. 8 – 19). REVISTA NODO, 12(23), pp. 9.

9 Bartolomucci, C. (2021). *Conservation of earthen architecture: An overview of international guidelines and resolutions*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 23.

10 Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 20 – 21.

11 Ibid. pp. 20 – 21.

This research project led to this present final master's thesis, which main objective is to evaluate the behavior of eight (8) earth plasters, in order to identify, which one is the most suitable for its application to improve the conservation of earth constructions in the Piemonte region.

This master's thesis is developed in three chapters. The first chapter establishes the importance of earth as a building material, beginning with a study of its historical use, geographical distribution and the main construction systems developed from the traditional earthen building methods. It also shows its presence in the Italian context, focusing on the Piemonte region and how it has been approached from the legal framework.

Based on this general context, the second chapter analyzes pathologies and identifies the conservation problems. In order to determine which factors can affect the durability of earthen constructions, providing a context for more effective interventions that respect traditional techniques. Also, it establishes the starting point for planning preventive and corrective conservation without compromising the authenticity of the material.

Finally and as a conclusion, the third chapter details the experimental tests of the plasters under study, identifying which offers the best material compatibility, erosion resistance, good adhesion, and performance when dealing with humidity. Besides, these laboratory tests contribute to the preservation of earthen architecture using scientifically proven methods respecting the original materials.

III

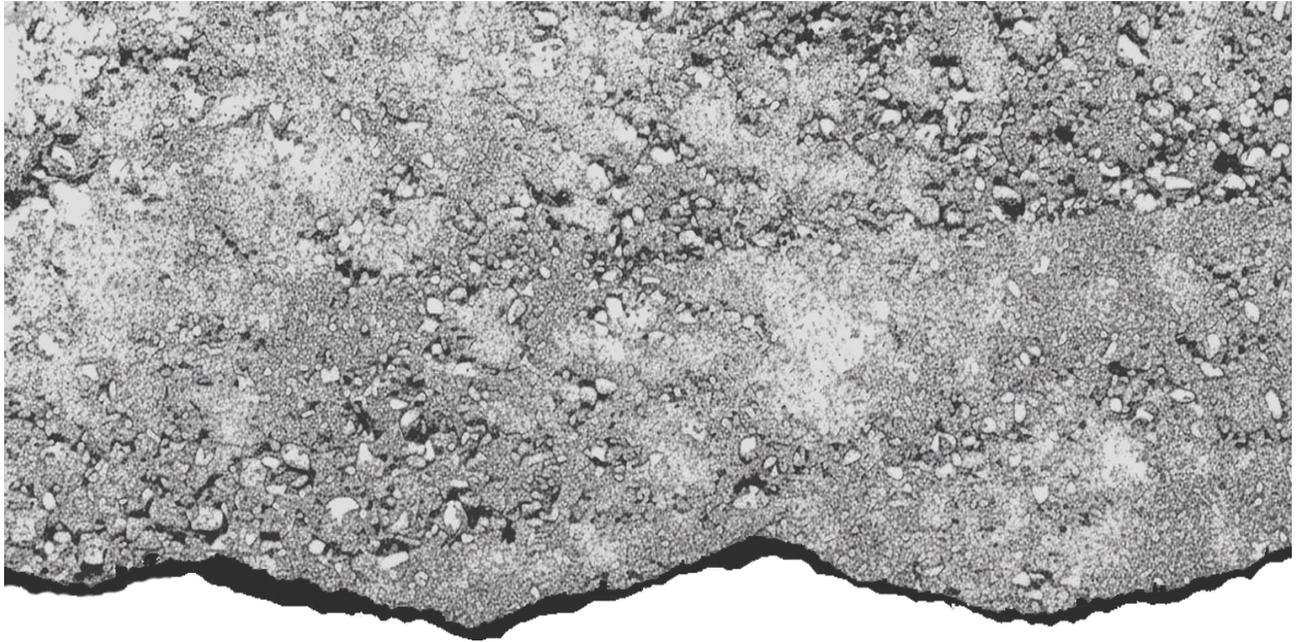


From the traditional
practice to the
experimental research

1

Earthen constructions.

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Earthen constructions.



Celia Neves affirms that earth is one of the oldest building materials used by civilizations. Its presence has been recorded in many constructions since prehistoric times, from vernacular architecture to monumental and representative buildings. However, at the beginning of the second half of the 19th century, the inclusion of industrialized building materials led to an inevitable decline in the use of earth. This material started to be discriminated and put aside in public and private works, thus losing space in the “competition” with the new “aesthetic” and technical standards established by modern materials¹.

In spite of this discrimination, earth remains one of the limited alternatives available for housing populations excluded from the formal housing market, especially in developing countries (especially in rural areas and urban peripheries). Because its use is closely linked to the resistance of primitive building systems to modernity and responds the housing needs of these communities, earth has become a key focus for researchers. The main goal is to advance in the use of this material by recovering and understanding ancestral techniques, as well as developing innovative construction systems characterized by their simplicity, efficiency, and low cost².

Manuela Mattone adds that earthen constructions, whether grand monuments or simple dwellings in rural areas, are found all around the world wherever the soil’s physical and chemical

1 Neves, C., & Faria, O. B. (Org.). (2011). *Técnicas de construcción con tierra*. FEB-UNESP/PROTERRA. pp. 9.

2 Ibid. pp. 9.

properties and the climate allow the use of this material in architecture. The several ways in which earth is used in construction are a direct reflection of the unique cultural identity of each place³.

Therefore, Chapter 1 is structured into three (3) subchapters. These subchapters basically develop the historical, technical-architectural, and legal context needed for a better understanding of earthen constructions.

The Section 1.1 starts addressing the historical context, analyzing the history of earth as a building material, from the first records to nowadays. It was also considered important the explanation of the different existing techniques, being these a key to understand the material's versatility and how many cultures adapted it to their contexts. In section 1.2 is explained the Italian national context, identifying the earthen heritage constructions and so achieving a greater understanding of the territory. Finally, in section 1.3, a study of earthen constructions at the regional level in Piedmont is developed, taking the landscape into account. It was also considered important to include a legal framework, allowing to comprehend how these constructions are approached in regulations and management according to the established authorities.

1.1. Earthen constructions and building techniques.

Earthen architecture proves humanity's capacity to build using local and available resources. Due to its versatility, this material has been used since ancient times, by itself or combined with stone, wood, plaster, lime, or plant fibers. Although today it is often associated with mud huts and contexts of poverty, its importance is widely recognized. Many of the world's oldest buildings were constructed with earth, at least a quarter of the world's population lives in earthen residences, and more than 180 UNESCO World Heritage sites include earthen elements⁴.

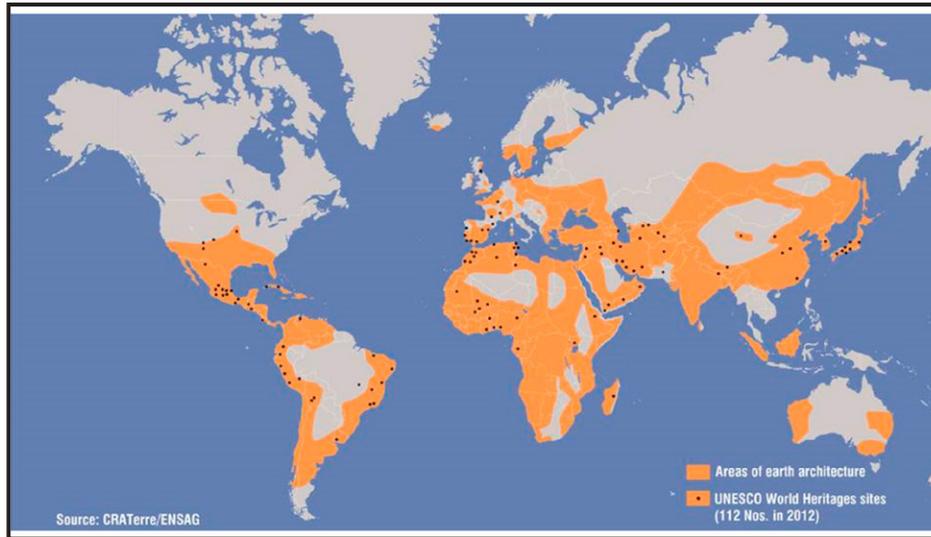
The origin of its use was possibly in order to improve the habitability of protected spaces such as caves, and the transition from nomadic societies to permanent settlements, raising the development of more solid and durable constructions. Due to the historical records, it can be confirmed that the earliest earthen constructions were built along the banks of rivers such as the Tigris, Euphrates, Nile, Indus, and Yellow, where the sandy and clayey soil was mixed with straw. Nowadays, earthen constructions, from vernacular houses to monumental buildings, can be found in Africa, Asia, Europe, and the Americas⁵.

3 Luvidi, L., Fratini, F., Rescic, S., & Zhang, J. (Eds.). (2021). *Past and Present of the Earthen Architectures in China and Italy*. Roma: CNR Edizioni. pp. 11.

4 Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 11.

5 Ibid. pp. 14.

Image 1. Earth constructions around the world



Source: <https://ars.els-cdn.com/content/image/1-s2.0-S1546221820001940-fig-1.jpg>

1.1.1. Diffusion

In Africa, the earliest settlements made of earth, reeds, and interlaced branches date back to 5000 BCE in the Nile Delta, such as Merimde and Fayum. Hand-molded adobe bricks began to be produced around 2900 BCE and were used for monumental buildings, including the large independent adobe structures at Shunet El-Zebib and Nekhen, as well as pyramids discovered in Tamis. Many buildings constructed during the reign of Pharaoh Ramses II (1279–1213 BCE), including the houses of artisans and nobles and temples, were also made of adobe. In North Africa, the succeeding civilizations over time contributed to the diffusion of both adobe and rammed earth (*pisé*) techniques. From the 11th century forward, the expansion of Islamic culture significantly changed the characteristics of urban settlements and led to the construction of a new type of religious building, such as mosques⁶.

The Egyptian civilization is one of the most recognized of the African civilizations, this existed for over three thousand years approximately. Dating back to 5000 BCE, there were the first human settlements in Merimde and Fayum (Nile Delta). The constructions in this zone, were made with reeds and small branches covered with clay or filled with clods of earth. The Nile Valley supplied the main building materials: silt and clay, which were later mixed with desert sand and straw from cultivated grains. Techniques and forms evolved: the northern regions, influenced by later Mediterranean civilizations, contributed to the spread of adobe; in East Africa, influenced by cultures from the Indian Ocean, the “*torchis*” technique was particularly prevalent. With the arrival of Islam in the 6th century, a significant change took place, transforming the appearance

⁶ Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 15.

of ancient African cities through the introduction of mosques. Like that, the mosques of San, Djenné and Mopti (Mali) were an example to the neighboring populations of Nigeria and Burkina Faso⁷.

Image 2. Shunet El - Zebib, Egypt.



Source: https://live.staticflickr.com/8248/8635692826_1a3a340035_b.jpg

Image 3. Mosque of Mopti, Mali.



Source: <https://www.flickr.com/photos/by-chris-g/4957936901/in/album-72157624538486744>

⁷ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 12.

In the middle East, earth was used to build monumental structures, such as the temple cities of Uruk (3200–2800 BCE) and third-millennium BCE sanctuaries, for example, the Euki Temple in Eridu, constructed with unfired bricks without mortar. In Iran, especially in cities like Yazd and Isfahan many historical adobe buildings are preserved, compared to the city of Tous, where rammed earth walls used to surround it. Bam is the largest adobe settlement in the world, unfortunately it collapsed after an earthquake in 2003. In Yemen, since the 18th century, many outstanding buildings were created, such as the Al-Muldher Mosque, it is made of adobe minaret and 53 meters high, it is considered the tallest earthen structure in the world⁸.

Image 4. Pigeon tower - Isfahan, Iran.



Source: <https://www.ismeo.eu/wp-content/uploads/2020/07/02-1024x681.jpg>

Many excavations have helped to show that earth constructions were common since the Neolithic period. Around the year 8000 BCE in Jericho, it can be seen that the circular houses were composed by stone foundations and mud-brick walls, while in Muraybet (Syria), was noticeable that the upper levels were made with adobe walls and had square plans. Between the years 5000 and 3200 BCE, it can be said that monumental earth architecture appeared, for example in Uruk with sanctuaries like the Eanna Temple and in Eridu with the Enki Temple, made with fresh bricks without mortar. In Ur, the houses had two levels and courtyards, and in Mari (Syria), the Isin-Larsa palaces had mud-brick walls. In Babylonia this tradition was conserved with the Ishtar Gate and the Marduk sanctuary tower, being a pioneer of reinforced earth by embedding thick reeds in the brick's masonry. Finally, the Persian architecture moved forward in the earth construction with Persepolis disposing it with columned spaces, galleries, porticoed halls,

⁸ Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 17.

vaults, and domes, used in both monumental and civil buildings⁹.

Image 5. Persepolis, Iran.



Source: <https://media.istockphoto.com/id/512700552/it/foto/tachara-palazzo-di-dario-a-persepolis-iran.jpg>

In Europe, some other earth construction techniques were used: in the north, earth and wood were combined using a timber and mud framework, with rammed earth structures dating back to the 15th century in the United Kingdom and used until the 19th century. However, fired bricks began to replace earth since the 16th century forwards. In the south, adobe and rammed earth predominated, with Sesklo, Greece, dating back 5,300 years, being a main example. It is possible that the Phoenicians introduced the rammed earth technique, which then it was spread to Spain, France, Italy, and Portugal, where it was used in walls, monumental palaces, historic centers, and vernacular rural buildings¹⁰.

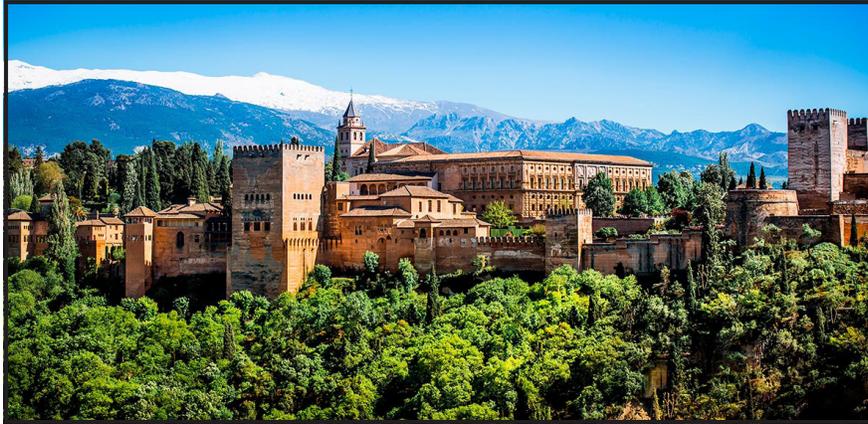
It is registered that around 6.000 years dated back are the oldest earthen settlements in Europe. Around the Aegean Sea, specifically in Thessaly, the earliest communities used to mix earth and wood. However, the Dorian invasions made that the mudbrick blocks started to be replaced by stone blocks in fortifications. The Minoans in the island of Crete, built palaces in Knossos and Phaistos using rammed earth, tufa, gypsum, marble, and wood. Meanwhile, mudbricks and clay bricks were still used in Athens and Smyrna, and in Rome, the first huts of wood and earth evolved into houses and public buildings made of mudbricks, replaced after by tufa, marble, and travertine during the imperial period. The mudbricks remained to be the primary material for modest houses until the reign of Emperor Augustus. In Mediterranean Gaul, Greeks and Carthaginians influences introduced adobe bricks, although Cisalpine Gaul had long used earth in rural and urban construction, as seen in Lyon with its rustic masonry of brick, wood, and

⁹ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 13.

¹⁰ Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 17 - 18.

timber framing. The earth construction had place until the 1950s, when post-World War II material shortages created its renewed use. Finally, in Germany systematized earth construction techniques, building thousands of houses and training specialists, and today, rising energy costs have revived interest in earthen construction¹¹.

Image 6. La Alhambra - Spain.



Source: <https://tripgranada.com/wp-content/uploads/2023/10/que-es-la-alhambra-de-granada.jpg>

Image 7. Knossos Palace columns - Greece.



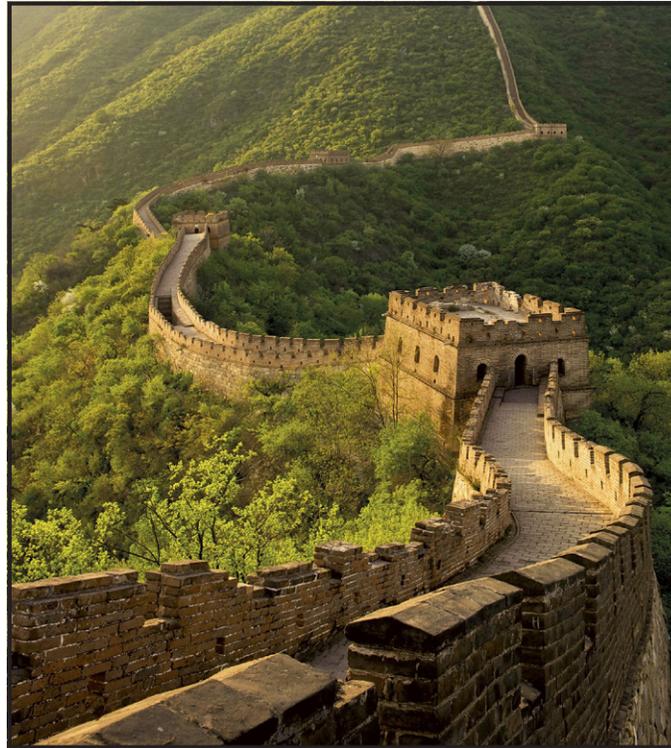
Source: <https://adventureswithsarah.net/wp-content/uploads/2024/01/knossos-palace-columns.jpg>

In Asia, earth was widely used for walls and residential buildings. In China, the earliest rammed earth walls date back to the Qin dynasty (221–206 BCE), with the Great Wall being the most

¹¹ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 10.

notable example. These structures were restored by the Han and Jin dynasties, however some few original sections remain¹².

Image 8. Great wall - China.



Source: https://content-historia.nationalgeographic.com.es/medio/2014/06/12/china2_1787x2000.jpg

In parallel, during the same time period of the Mesopotamian cities of Ur and Babylon, many cities in India located along the Indus River like: Kalibangan, Mohenjo-daro, and Harappa, were using mudbrick for the construction of their fortified walls. Also, the urban design was noticed by the houses settled around courtyards and streets paved with fired bricks. In China, the earthen building tradition had different ways: mudbrick blocks became a standard material for urban architecture since the Han dynasty forward. Other techniques, such as wood and mud mortar, bauge, and rammed earth, were use for centuries, including the Three Kingdoms and Ming periods. The fortified settlements of Fujian, with their circular or square structures organized around central plazas, many of these settlements survived or were replicated until the 1990s¹³.

¹² Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 17.

¹³ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 14.

Image 9. Mohenjo - daro, Pakistan.

Source: <https://i.dawn.com/primary/2022/12/301125068c4d944.jpg>

In the American continent, earthen construction was spread widely from north to south. In Mexico and the southern part of the United States, native populations used adobe for their houses, while the Aztecs reserved stone for monumental buildings. European colonizers adopted these techniques in the construction of missions and forts, such as Tomacacori, Guevavi, and Calabazas in Arizona (1691) and later, the U.S. Army used them for Fort Union and Fort Selden. The rammed-earth technique, introduced by German immigrants, was spread to places like Washington, Mount Vernon, Trenton, and Canada¹⁴.

In the United States, Indigenous and Spanish building traditions remained alive in California, New Mexico, and neighboring states until the 20th century, having stylistic revivals and renewed interest after the 1973 energy crisis, which sparked a renaissance of earthen architecture¹⁵.

In Central America, between 1200 and 1300 BCE, early civilizations built urban centers with houses made of earth and wood, while the use of mudbrick appeared between 500 BCE and 600 CE. In the 12th century, the Aztecs built Tenochtitlán on the islands of Lake Texcoco, having single-story adobe houses and keeping the stone only for temples and palaces¹⁶.

In South America, the Moche culture (from 2nd to 9th centuries CE) built adobe pyramids dedicated to the sun and moon in Cerro Blanco, while the later Chimú civilization constructed Chan Chan, a 20 km² walled city considered as the largest in ancient Peru¹⁷. During the colonial period, earthen construction persisted for example, in 1549, a Jesuit in Sao Paulo requested

¹⁴ Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 19.

¹⁵ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 15.

¹⁶ Ibid. pp. 15.

¹⁷ Ibid. pp. 15.

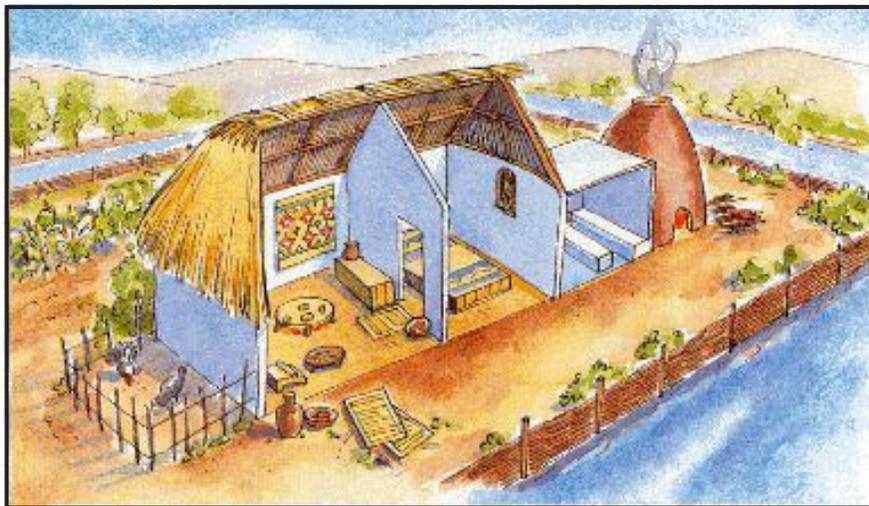
“artisans skilled in working with earth and carpenters” for Jesuit buildings¹⁸. In the Andes, the Mochica were notable for their rammed-earth canals and dikes, while along the Rio Grande, Pueblo communities developed multi-level adobe houses with plastered walls and timber roofs covered in earth¹⁹.

Image 10. Tomacacori - United States.



Source: <https://dynamic-media-cdn.tripadvisor.com/media/photo-o/1b/41/59/6c/tumacacori-national-historical.jpg>

Image 11. Tecnochtitlan - Mexico.



Source: <https://i.pinimg.com/736x/6c/c9/f1/6cc9f16391bfdbb268537c6a4125a69d.jpg>

18 Mattone, M. (2021). *Historical Earthen Architecture in Italy*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 19 – 20.

19 El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 15.

Image 12. Chan Chan, Peru.

Source: <https://media-cdn.tripadvisor.com/media/attractions-splice-spp-720x480/07/aa/4b/53.jpg>

1.1.2. Techniques

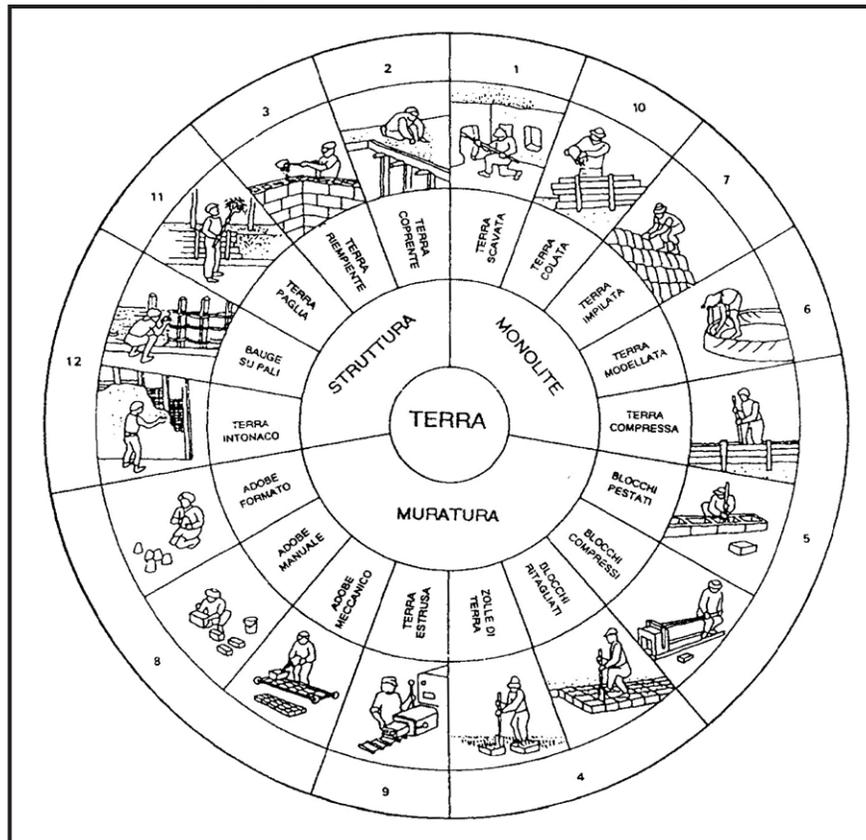
As it could be seen before, the earthen construction techniques appeared almost by themselves in many ancient civilizations and were spread through invasions, trades, and colonizations. Almost all the native methods were merged with those new introduced by foreigners, adapting to local needs, climates, and cultural traditions. However these techniques share similarities across regions, each developed has different features and terminology, often confusing even specialists. Building with earth means working with a material found easily underfoot, whose cohesion depends mainly on clay acting as a natural binder. This architectural tradition reflects the identity and history of different cultures, shaping landscapes where earthen architecture remains a visible part of local heritage²⁰. Gradually, these techniques have evolved through research, experimentation, and social, economic, and cultural change. Also, human “touch” has been progressively replaced by tools and machinery, and both regional and synthetic materials have been incorporated into modern adaptations²¹.

According to CRATerre fundamentally there are three main earthen construction systems: monolithic earth with a load-bearing function, masonry used as load-bearing or infill walls, and earth on a supporting structure serving as enclosure or infill. Each of these, groups different construction techniques that were adapted to the local conditions, materials and traditions.

²⁰ Neves, C., & Faria, O. B. (Org.). (2011). *Técnicas de construcción con tierra*. FEB-UNESP/PROTERRA. pp. 9 - 10.

²¹ Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

Image 13. Earth constructions techniques.



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

1.1.2.1. Adobe

The sun-dried bricks, commonly known as adobe, are made from a malleable mix of earth often combined with straw. Originally shaped by hand, they later began to be formed using wooden or metal molds, a practice that continues today, sometimes supported by machinery²². The word *adobe* comes from the Arabic *al-tub* (brick), derived from the Egyptian *thobe*²³. This ancient building technique is one of humanity's most primitive, many remains are widespread in lots of warm and arid regions of the world. The adobe bricks are made pouring a plastic mixture of water, silt, clay, sand, and small quantities of straw or any other plant fibers into molds, after that, the mix is dried under the sun for changing periods depending on the climate and season²⁴. Also, the adobe bricks' composition and size will vary according to local traditions and soil

²² Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

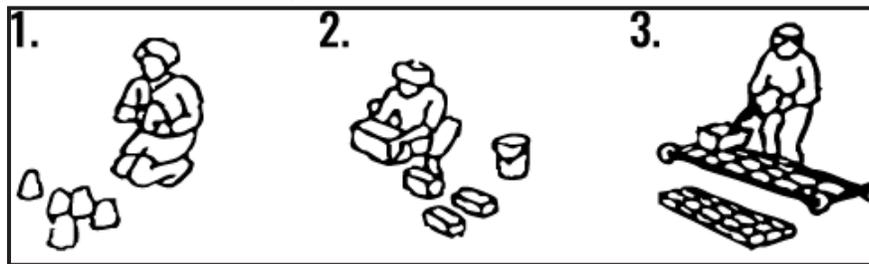
²³ Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 9.

²⁴ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 17.

types. They can be arranged with earthen mortar to build load-bearing walls, enclosures, or interior partitions²⁵.

Around the mid-20th century, compressed earth block (CEB) technology began to be developed, utilizing carefully selected soils with controlled particle size. These blocks are made with manual or mechanical presses that compress the slightly damp soil, producing bricks with regular shapes. This process can improve the compressive strength and can create a major durability compared to the traditional molded adobe bricks. For stabilizing more the material, it is added a small percentage of cement (depending on the soil type) making the block more resistant to water and erosion. This development can open the door for high-quality walls construction, carried out by unskilled workers, and could be particularly useful in developing contexts²⁶.

Image 14. Adobe, different types (1. Molded, 2. Hand - made, 3. Machine - made).



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

1.1.2.2. Pisé

The rammed earth technique involves compacting moist soil inside formworks, layer by layer, using mallets (traditionally made of wood and now often mechanical)²⁷ to create strong, monolithic walls²⁸. This technique was originated in the Middle East around the year 6000 BCE, this method was spread across North Africa, Spain, and Europe, promoted by the scientific essays of François Cointeraux and Jean Baptiste Rondelet in the 18th and 19th centuries.

The rammed earth is particularly suitable for warm regions or areas with significant daily temperature fluctuations, as its thick walls help to maintain a stable indoor temperature. In colder climates, when it is combined with proper insulation, it can retain heat captured during the day²⁹.

²⁵ Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 9.

²⁶ Ibid. pp. 10.

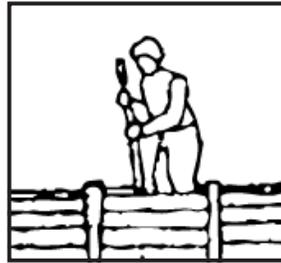
²⁷ Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

²⁸ Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 11 - 12.

²⁹ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 17.

Once the foundation is completed, the soil is placed into mobile formworks³⁰ matching the needed wall thickness and compacted layer by layer until the adequate density is achieved. The construction continues block by block until the wall is complete. Progressively, the technique has evolved with the introduction of mechanical compactors, metal formworks, and some stabilized soil mixtures containing small amounts of cement³¹.

Image 15. Pisé.



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

1.1.2.3. Earth – straw

This technique is based on the cohesion of the soil, this is achieved by mixing soil with long straw fibers to create a lightweight, insulating material. After this, the soil is then mixed with water until it reaches a thick and homogeneous consistency, which is then poured or sprayed onto the straw, covering each stalk with a layer of the mix³². Finally, this mix is placed between formworks, lightly compacted, and left to dry, forming panels or blocks that retain the texture of the straw³³.

It can be said that this technique is derived from the traditional “*torchis*” because of its timber-frame walls (*colombage* or *fachwerkhaus*), it’s not a load bearing method, but it gives a very good thermal and acoustic insulation. With the soil acting as a natural binder, it assures the cohesion and durability. Thanks to its simplicity, it can be used as a fast layering for new or existing wooden structures, reaching good insulation levels and helping to naturally preserve the timber³⁴.

30 Achenza, M., & Sanna, U. (Eds.). (2009). *Il manuale tematico della terra cruda*. DEI Tipografia del Genio Civile. pp. 29.

31 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 11 - 12.

32 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

33 Achenza, M., & Sanna, U. (Eds.). (2009). *Il manuale tematico della terra cruda*. DEI Tipografia del Genio Civile. pp. 29.

34 El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 17.

Image 16. Earth - Straw.



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

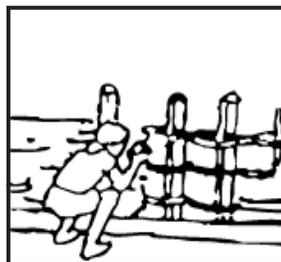
1.1.2.4. Torchis

The torchis technique involves coating a framework (usually made of wood, bamboo, or branches) with a plastic mixture of clay-rich earth and vegetable fibers such as straw. The mixture, can be applied by hand or with a trowel over a cane or strip base attached to a load-bearing structure, creating a non-structural wall that provides insulation and weather protection³⁵.

Was historically used across Europe, Africa, and Asia, the *torchis* was common in timber-framed buildings like *colombage* or *fachwerkhaus* in France and Germany. The preparation of the mix once involved treading it by foot on the ground, but today it can be produced mechanically using tractors, modified tools, or horizontal mixers. The application is still an intense labor, and requires a careful layering depending on the density of the mixture and the type of mesh used³⁶.

This traditional but versatile technique allows creating curved surfaces without having formworks and is currently experiencing renewed interest in industrialized countries. In France and Germany, pre-mixed materials and prefabricated torchis panels are now available for easy installation on wooden frames³⁷.

Image 17. Torchis.



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

35 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

36 El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 17.

37 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 14.

1.1.2.5. Façonnage

Façonnage is a traditional technique that remains widely used today. It consists of shaping the earth by hand (similar to pottery) without the use of tools³⁸.

Image 18. Façonnage.



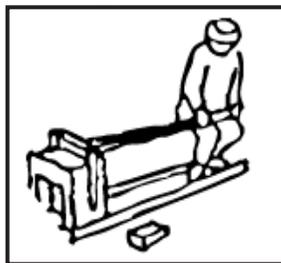
Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

1.1.2.6. Compressed earth blocks

For a long time, earth blocks were made in molds where slightly moist soil was compacted manually using a rammer or with a strike of a heavy cover. Progressively, this technique's process has been mechanized, and nowadays various types of presses (manual, semi-mechanical, or fully automatic) are used to achieve a more uniformed compaction³⁹. The resulting blocks can be left unstabilized or improved with small additions of lime or cement to increase strength and durability⁴⁰.

The first presses were made in Northern Europe, particularly in Belgium, and quickly spread to developing countries due to their practicality, low cost, and ability to produce high-quality blocks. Currently, this technique is widely used, allowing for consistent quality control and the production of precise, regular construction elements⁴¹.

Image 19. Compressed earth blocks.



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

38 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

39 Ibid. pp. 12.

40 Achenza, M., & Sanna, U. (Eds.). (2009). *Il manuale tematico della terra cruda*. DEI Tipografia del Genio Civile. pp. 30.

41 Ibid. pp. 30.

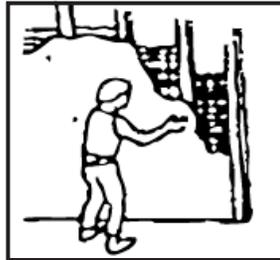
1.1.2.7. Bauge

This traditional earth construction technique consists of stacking thick balls of soil mixed with plant fibers such as straw, one on top of another, and lightly compacting them by hand or foot to form monolithic walls. This dense mixture is hand-shaped without molds and placed directly on-site to build solid, cohesive load-bearing walls⁴². In central Italy it is known as *massone*, while in England it is referred to as *cob*⁴³.

Traditionally, the mixture is prepared by treading earth and straw, although today it can be produced mechanically using tractors or mixing machines. During construction, workers often stand on the wall to compact the material with their feet, and once the desired height is achieved, the surface is leveled by cutting off any excess⁴⁴. The Bauge is suitable for both interior and exterior load-bearing walls. Due to its thermal mass and moisture-regulating capacity, it is particularly effective in warm climates or for thermal storage walls behind greenhouses. The technique also allows the construction of curved and organic forms, as well as thinner interior partitions, sometimes incorporating niches⁴⁵.

In contrast to the *pisé*, *bauge* does not require formwork, as the mixture is placed directly in overlaid layers (called *massoni*) and compacted by walking over them. While the material is still fresh, the walls are leveled with a wooden stick, and reveals imperfections caused by the placement method, also, the straws are removed with a sharp-edged trowel⁴⁶.

Image 20. Bauge.



Source: <https://architetturedallaterra.it/wp-content/uploads/2013/12/QUADRO-SINOTTICO-CRAterre-1024x1024.jpg>

42 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. pp. 12.

43 Achenza, M., & Sanna, U. (Eds.). (2009). *Il manuale tematico della terra cruda*. DEI Tipografia del Genio Civile. pp. 30.

44 El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 19.

45 Ibid. pp. 19.

46 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 31.

1.2. Earthen constructions in Italy.

In Italy, the use of earth as a building material has historically been widespread throughout the country, except in the more mountainous areas of the central and northern regions. The twenty political regions, from south to north (from Sicily to Piedmont) show a diverse and rich architectural production in which earth was, until recently, a very common material. It was used in many ways, for walls, mortars, plasters, floors, and ceilings. Some different techniques were used in the construction of simple buildings demonstrate the skill developed over centuries in making houses and cities. Around the 6th-3rd century with the Etruscans, adobe walls on stone or earthen foundations were built for either rural and urban constructions, just like fortifications to the Romans (around the 5th-1st century BC), there were left many examples across the country, these constructions create the historic and traditional heritage of earthen architecture through Italy⁴⁷.

The evidence of raw earth construction in Italy dates back to the Neolithic period. Roman historians like Vitruvius, Pliny, and Tacitus wrote about the use of unfired clay bricks even for building foundations: “...walls made of earth [...] built between wooden boards can last for centuries, resisting rain, wind, and fire, and are more stable than any cement.” Only after the 15th century new earthen building techniques arrived to the country, introduced by other people. Since then, earth has been used in many regions of the country, where numerous raw earth buildings still exist (both in rural and urban areas) such as adobe in Sardinia, rammed earth in Piedmont and “massone” in Marche and Abruzzo. These examples reflect the same technological diversity found in other countries. It was around the decade 1950s that raw earth was commonly used for construction in Italy, but after the real estate boom of the 1960s, it was started to be replaced with more standardized materials considered safer and healthier⁴⁸.

This noticeable change caused the abandonment of earthen techniques, seen as obsolete and as a clear symbol of poverty and social marginalization. Basically it had to be something to be erased even from memory, no longer suitable to represent the postwar social status achieved through the country’s industrial growth⁴⁹.

As a result, lots of the traditional knowledge of earthen construction has been lost, basically surviving only in a few manuals and in some memories of elderly builders. Also, the inadequate maintenance has led to the deterioration of many of these constructions, causing the loss of this type of heritage with a rich history and craftsmanship. Around the 1970s the earthen

47 Luvidi, L., Fratini, F., Rescic, S., & Zhang, J. (Eds.). (2021). *Past and Present of the Earthen Architectures in China and Italy*. Roma: CNR Edizioni. pp. 39.

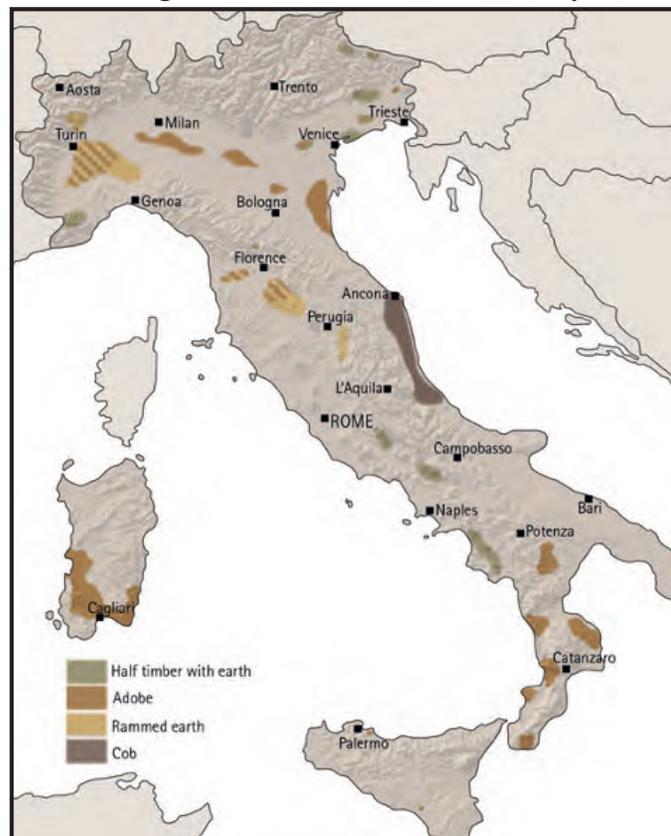
48 Vaschetto, F. (2014). *Alla scoperta del Roero: itinerario tematico per la valorizzazione della cultura, del paesaggio e del patrimonio architettonico in terra cruda roerini*. Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 52.

49 Ibid. pp. 53.

houses, considered examples of “minor architecture” have been subject of many studies focused on preserving them as part of Italy’s cultural heritage. Besides this, from a sustainable point of view the earthen construction is considered a good alternative. In order to encourage the conservation of this heritage, it is essential to identify and map the earthen constructions around the country. It is also necessary to raise awareness and involve the communities in the process of understanding the cultural value of these buildings, also to define the appropriate intervention methods for their preservation while meeting the functional requirements of contemporary and nowadays use⁵⁰.

Italy has a rich raw earth architectural heritage, specially, because of the mix of factors like: the availability of the material, the climate, the inhabitants’ needs and the mineral composition of the soil. This can be seen in southern Sardinia, also, in regions like: Veneto, Emilia-Romagna, Marche, Abruzzo, Calabria, Piedmont (especially in the province of Alessandria), Lombardy, Friuli, Umbria, and Basilicata. The earthen constructions are very extended thanks to local knowledge and traditions, these buildings are usually linked to regional economies⁵¹.

Image 21. Earth constructions in Italy.



Source: <https://casediterra.com/web/le-case-terra-italia/>

50 Vaschetto, F. (2014). *Alla scoperta del Roero: itinerario tematico per la valorizzazione della cultura, del paesaggio e del patrimonio architettonico in terra cruda roerini*. Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 53.

51 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 20.

The rural cultures passed down many of their building traditions, its diversity in form and function reflects the local skill of the builders, from the cold and humid northern to the dry, arid climates of the south. The earthen architectural heritage is characterized primarily by the use of unfired bricks. In Italy, there are numerous examples of this technique, although it varies by region. Sardinia and the province of Alessandria have the highest concentration of earthen buildings; in the Campidano plain in southern Sardinia, many “*domu*” (traditional Irish houses) are built with unfired bricks called *ladiri* (from the Latin “*ladiri*”), which measure approximately 10 x 20 x 40 cm⁵².

Image 22. *Ladiri*.



Source: <https://www.architetturaecosostenibile.it/materiali/laterizi-terra-cruda/ladiri-tradizione-terra-cruda-471>

The earth was normally taken from foundation excavations, then mixed with straw and placed into molds to dry. Once hardened, the bricks were used with fire bricks and on site using an earthen mortar. In Calabria’s Catanzaro province, the *casedde* were also built with raw bricks, but they change from the Sardinian ones in the type of soil used and in the addition of rice straw instead of regular straw. In Basilicata, the bricks, called *ciciule*, were used to build simple rural houses next to farmlands. In the Marche – Abruzzo area, a primitive technique called *maltone* (Marche) or *massone* (Abruzzo) developed, where a mix of earth and straw was layered using a fork⁵³.

These large earthen blocks were compacted by foot to improve the adhesion between layers. In Veneto and the lower Po Valley, the traditional buildings called *casoni* and were made of raw bricks and cane roofs. Today, few examples remain, this traditional type of construction has almost disappeared because of the use of fired bricks. In Trentino-Alto Adige, especially in Tyrol, the *fachwerk* technique (originated in Germany) became very common, combining a

52 Achenza, M., & Sanna, U. (Eds.). (2009). *Il manuale tematico della terra cruda*. DEI Tipografia del Genio Civile. pp. 60.

53 *Ibid.* pp. 21.

wooden structural frame with raw earth bricks filling (11.5x16.5x25 cm). Within Italy's earthen architecture, the Piedmont region holds particular importance. The main area of diffusion is the Fraschetta plain, located between Alessandria, Novi Ligure, and Tortona⁵⁴.

Image 23. Venetian “casoni”.



Source: <https://crespino.italiani.it/i-casoni-veneti-fragili-strutture-che-hanno-attraversato-i-millenni/>

Image 24. House in the Fraschetta plain.



Source: https://upload.wikimedia.org/wikipedia/commons/b/be/Casa_di_terra.jpg

Besides the common use of unfired bricks (without straw), the constructions were also built using the rammed earth technique, known as *pisé*. The typical red soil of this region was left to “mature” over the winter under natural weather conditions. In spring, the *house rammer* began to build by compacting the earth with a wooden mallet (*pestou*) inside special molds. Once the

⁵⁴ Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 22.

first block was completed, the mold was moved to create the next one. With the repetition of this process, the builder could complete the first course of outer walls and then start the second. The use of this technique was not limited to a specific building type, it was used in all kinds of structures: farm shelters, barns, churches, chapels, public and private buildings, and both rural and urban examples⁵⁵.

Image 25. House in pisé.



Source: https://fai-platform.imgix.net/media/piemonte/al/21082_fraschetta-alessandrina-costruzioni-in-terra-battuta.jpg

1.3. The case of the Piedmont region.

According to Roberto Mattone the Piedmont region along with Sardinia, possesses one of the most significant rammed earth heritage sites in Italy. This group constitutes a “material testimony with civilizational value”, and in many cases has received attention when it comes to its conservation. Only recently, has existed the need to protect the “minor building” in rammed earth because its loss would be irreversible. As it was said before, the first step in order to safeguard this heritage is to identify and know the distribution of these constructions, as well as to understand the local techniques and architectural typologies that characterize them. In this way, rammed earth houses are recognized not only as a cultural resource but also as a reference for sustainable architecture in the future⁵⁶.

Earth is the most widely used material in historic towns, transmitting the construction knowledge

⁵⁵ Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 23.

⁵⁶ Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L’artistica. pp. 13 - 14.

and cultural traditions from many years until was interrupted in the 1950s. Its recovery requires many factors such as: the study of history, degradation phenomena and appropriate intervention techniques. This always has to be done with a big respect for compatibility, reversibility, and the use of historical materials⁵⁷.

In Piedmont, the culture of earth has deep farmer root and rammed earth architecture has been a constant presence in rural and urban landscapes⁵⁸. The rural housing emerged as response mainly to the farmer's needs, also it integrates people, animals and belongings in a geographical and economic context. Due to the limited resources in the rural life, were created effective and lasting construction solutions. In the Frascchetta zone, the rural houses are built with local materials (earth, wood and straw) and the building's composition depends on the availability and climate variations. The buildings' design is based on the thermal efficiency and durability, that's why are composed with: thick walls (60 – 80cm), small and few windows and to catch some sunlight the facades faced the south (it included trellises to mitigate the summer heat). The spatial typology is: a ground floor with kitchen-living space and adjacent stable, the upper floor is set for bedrooms, store or warehouse and a gabled roof capable of supporting snow. The roof slopes could be asymmetrical to improve climatic protection⁵⁹.

These buildings respond to the parcels disposition that usually quadrangular, with the house and service buildings are arranged around an illuminated central courtyard. Outside buildings (granaries, sheds, chicken coops, ovens or washhouses) are normally placed in parallel or perpendicular to the house. With time, many modifications have carried out in the houses, specially the leveled roofs and brick pillars⁶⁰.

Until the decade of 1960, rammed earth houses defined the appearance of entire villages. Every construction detail was meaningful, contributing to the typological unity of the territory. These houses showed designs adapted to climate, solar orientation, and thermal efficiency, ensuring food and animal preservation, and resistance to fire, wind, and earthquakes⁶¹. The province of Alessandria stands out for its wide presence of rammed earth constructions, particularly in the Frascchetta area, where the *pisé* buildings dominate. Moving away from this area, soil is more suitable for raw brick, used either exclusively or in combination with *pisé*. In Turin, Asti, and Cuneo, only raw brick is used, sometimes combined with fired brick and stone in walls or for the

57 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 19.

58 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 54.

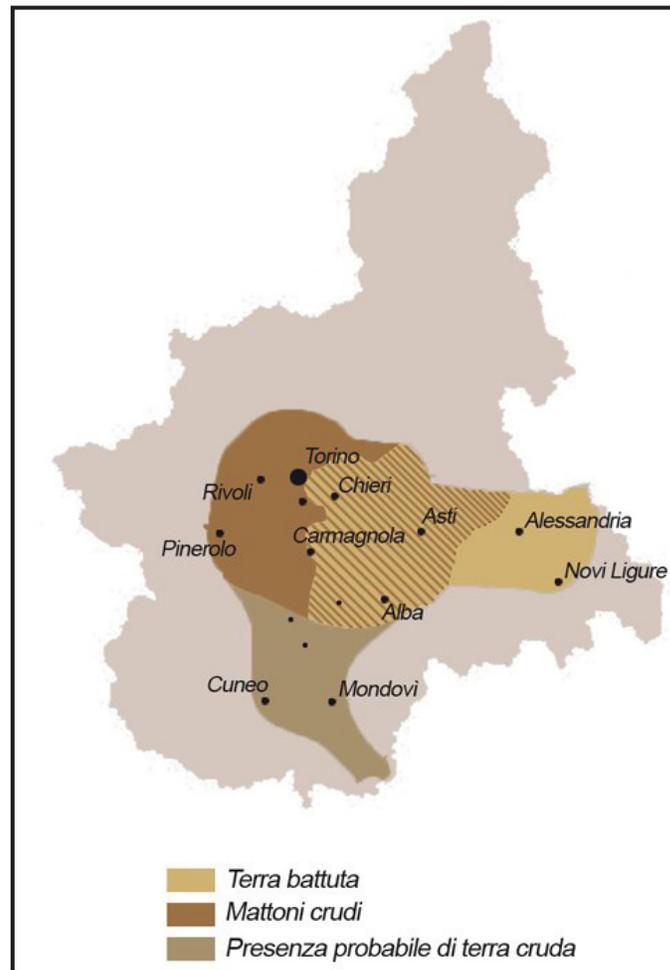
59 Robboni, C. (2007). *Terrarossa: Le case di terra della Frascchetta*. Storia, cultura e paesaggio. s.l. pp. 105 – 107.

60 Ibid. pp. 109 – 111.

61 Robboni, C. (2010). *Il paesaggio agricolo*. In R. Mattone (Ed.), *Il paesaggio delle case in terra cruda* (pp. 21 – 34). L'artistica. pp. 22 – 23.

entire important buildings⁶².

Image 26. Earth constructions in the Piedmont Region.



Source: https://iris.polito.it/retrieve/e384c42d-be68-d4b2-e053-9f05fe0a1d67/Tesi_Dottorato_Pennacchio_01_Cap03.pdf

Although the Piedmontese agricultural landscape has been fragmented by new constructions and roads, it still keeps its distinctive features thanks to rammed earth. Uncoordinated contemporary interventions have altered the urban and rural fabric, reducing the authenticity of spaces and affecting their historical memory⁶³. Despite the diversity of constructions, techniques, and locations, a unified reading is still possible with the identification of similarities in use, internal distribution, and the position of volumes. Residential and productive units were generated to meet housing needs, preserve food, and provide spaces for production or animal shelter⁶⁴. There are six main typologies identified: the Trunera, the Cascinotto, the Urban palazzotto, the Rural

⁶² Robboni, C. (2010). *Il paesaggio agricolo*. In R. Mattone (Ed.), *Il paesaggio delle case in terra cruda* (pp. 21 – 34). L'artistica. pp. 55 – 56.

⁶³ Ibid. pp. 28 – 31.

⁶⁴ Ibid. pp. 41.

or village cascina, the Agricultural sheds and Earthen churches or chapels. This classification allows for the analysis of technical evolution and recent transformations of the built heritage⁶⁵.

The “*trunera*” is the simplest and most economical farmer house in the Frascchetta, possibly is the oldest typology. Its size is small and has thick walls and few openings, it offered effective protection against seasonal temperature variations. It was found in open countryside and in small settlements too, the orientations is east-west at the front of a small square plot. Its basic layout consisted of a single multifunctional space combining kitchen, living area, and bedroom, with a floor of filled earth or terracotta tiles and an originally wooden roof (later replaced by a brick vault). The heat was provided by a earth, with smoke produced through a wall channel. Due to the lacking of modern services, these needs were met via small external auxiliary structures⁶⁶.

They are completely built of rammed earth on a stone or brick base, the *Trunera* could be expanded with a “*canva*” to the north, creating doubled volumes and asymmetrical roofs. It is surrounded by a garden, well and service spaces, it eventually evolved through successive enlargements into the “*cascinotto*”, which it represents the original module⁶⁷.

Image 27. *Trunera*.



Source: Robboni, C. (2007). *Terrarossa: Le case di terra della Frascchetta*.

65 Robboni, C. (2007). *Terrarossa: Le case di terra della Frascchetta*. Storia, cultura e paesaggio. s.l. pp. 113.

66 Ibid. pp. 114.

67 Ibid. pp. 114.

The “*cascinotto*” represents the evolution of the “*trunera*”, is a single-family building combining residential and rustic spaces, sometimes with auxiliary structures such as a portico, well, oven, and “*stabbio*”. It keeps an east-west orientation and placement at the head of the lot but can be two to four times larger than the “*trunera*”. They are also mainly built in rammed earth, occasionally reinforced with bricks in pillars, lintels or arches. The ground floor has the residence and stable, while the upper floor holds the hay mow and wood storage. The openings are small, using wooden lintels or arches formed during the rammed-earth process. The kitchen communicates directly with the stable and if the building is wide, a *canva* or cellar can be added⁶⁸.

The courtyard includes a portico for storing hay or integrates the hay mow into the building, its access to the upper floor can be interior or via exterior with stairs. Depending on the household’s economy, the *Cascinotto* may feature a threshing yard, dividing walls, oven, watering trough, well, garden, chicken coop, tool shed and other sanitary facilities converting the waste into fertilizer. It is the most common rammed-earth farmhouse, it is found in open countryside and urban areas, where façades are more refined and some keep asymmetrical roofs. In urban contexts, the *Cascinotto* acquires a more formal appearance, reorganizes access, aligns buildings to protect their inner courtyards, increasing space and volume and anticipates the village “*cascina*”⁶⁹.

Image 28. *Cascinotto*.



Source: Robboni, C. (2007). *Terrarossa: Le case di terra della Frascheta*.

68 Robboni, C. (2007). *Terrarossa: Le case di terra della Frascheta*. Storia, cultura e paesaggio. s.l. pp. 119.

69 Ibid. pp. 119.

The “*palazzotto urbano*” is a residence built with rammed-earth located on the borders of the Fraschetta, recalling the brick *palazzotti* in the historic town centers. It is also constructed mainly in rammed earth, sometimes combined with brick, it is based on the *Cascinotto*’s layout and has a more formal appearance, featuring hidden eaves, pavilion roofs, brick pillars and decorative stucco finishes. In this case, the inner spaces face the streets, is composed also with balconies and larger windows. The building can have two or three floors, including mezzanines. This typology shows a technical refinement and the brick use is increased, linking the aesthetic of rural buildings with urban styles. With time, the exterior plasters normally get deteriorated and reveals the solid mass of rammed earth beneath⁷⁰.

Image 29. Palazzotto urbano.



Source: Robboni, C. (2007). *Terrarossa: Le case di terra della Fraschetta*.

The “*Cascina*” was created with increased economic resources, land ownership and agricultural machinery, creating the need for larger, more functional and representative spaces. Many of them were based on the expanded “*cascinotti*”, they are often located in isolated areas to manage crops. Through time, the “*cascine*” were improved and specialized and organized the spaces evolving in self-sufficient units. The rammed earth was mostly replaced by fired brick, showing a higher status, durability and decorative needs⁷¹.

The “*cascina*” was consolidated between the 16th and 18th centuries and combined residential, agricultural and sometimes religious functions. It was arranged around a central courtyard with residential and rural buildings, where the main house stood out for its height or architectural

⁷⁰ Robboni, C. (2007). *Terrarossa: Le case di terra della Fraschetta*. Storia, cultura e paesaggio. s.l. pp. 127 - 128.

⁷¹ Ibid. pp. 140 - 141.

elements. It had two floors, the ground floor had the kitchen, living room and a cellar, meanwhile the upper floor, the bedrooms and granary and was always connected to the stable next. The hay mow was above the stable and it was supported by arches or lintels, meanwhile, the porticoes sheltered sheaves, machinery and grain. The courtyard had multiple uses: the internal circulation, to storage of tools, the preparation and drying of crops. An open-field cascine held multiple families and workers, it had fenced courtyards and auxiliary structures (well, chicken coop, garden). In rural clusters, the buildings were aligned and encircled, meanwhile in the villages they were smaller and for one or two families, with contiguous buildings, large gates and rammed-earth walls the boundaries⁷².

Image 30. Cascina.



Source: Robboni, C. (2007). *Terrarossa: Le case di terra della Fraschetta*.

In the Fraschetta, there are also open-field agricultural sheds used as porticoes or small storage buildings for tools. Although its unusual, they enhance identity to the rural landscape and there are of two main types: porticoes for storing hay or straw (similar to those in *cascinotti* and *cascine*) and tool sheds (small rammed-earth buildings) with a single door, no windows and a gabled roof, similar to the *trunera*'s volumetry on a smaller scale. Some remarkable examples include a portico near Merella, succesfully integrated into the landscape, another one along the Pollastra road, is distinguished by double openings, thin walls, and brick reinforcement at the top. Currently, an isolated portico still exists in Capannoni, near San Giuliano Vecchio. The tool sheds follow a south-north orientation and maintain the *Trunera*'s proportions, with

⁷² Robboni, C. (2007). *Terrarossa: Le case di terra della Fraschetta*. *Storia, cultura e paesaggio*. s.l. pp. 140 - 141.

dimensions under 2.5 meters⁷³.

Image 31. Rimessa agricola.



Source: Robboni, C. (2007). *Terrarossa: Le case di terra della Fraschetta*.

Finally, the religious buildings are classified as *templete*, rural chapels and village churches. The “*Templete*” are small structures that hold the sacred images, featuring classical elements such as columns and pediments, while rural chapels are larger with a single hall and an altar. The *Templete* are built in brick, meanwhile many chapels and churches use rammed earth. These buildings are the manifest of the popular devotion and community identity, they had variations depending on the builder’s skill, available resources and materials. Some include decorative features such as capitals, moldings, frescoes or miniature churches with bell towers. Usually, they are located at crossroads or on the settlements’ borders, visible to people, reinforcing local cults commemorating religious festivals or events⁷⁴.

The construction was often communal, involving donated land and collective labor. The *Templete votivi* are structures made of brick with niches and gabled roofs, while chapels have a single hall, frontal access, pediments, pilasters, and interiors with altars, benches, niches, and liturgical objects. They serve as communal prayer spaces or as part of isolated rural complexes⁷⁵.

⁷³ Robboni, C. (2007). *Terrarossa: Le case di terra della Fraschetta*. Storia, cultura e paesaggio. s.l. pp. 158.

⁷⁴ Ibid. pp. 163.

⁷⁵ Ibid. pp. 163.

Image 32. Chiesa.



Source: Robboni, C. (2007). Terrarossa: Le case di terra della Frascheta.

Image 33. Cappella.



Source: Robboni, C. (2007). Terrarossa: Le case di terra della Frascheta.

The life in these constructions reflected a balance between history, nature, and society. Rammed earth allows a direct relationship with the environment, generating sustainable houses adapted to daily life and seasonal cycles. Also, the modernization and mass construction with new materials homogenized the urban and rural landscape, creating a fragmentation of the unique character of rammed earth houses and reducing their singularity. Finally, to analyze and

preserve this heritage, it is useful to classify constructions according to typology, use, internal distribution, and position of volumes, allowing recognition of the elements of Piedmontese construction culture transmitted from generation to generation⁷⁶.

1.3.1. Regional law n.2 of 2006.

As its being said, the Piedmont region's rammed earth heritage stands out in Italy, it has a particular quantitative and qualitative. In order to validate its importance and demonstrate the regional commitment, the Regional Council decreed the Regional Law 2 of 2006, *Norms for the Valorization of Rammed Earth Constructions*. It had also the intention of deepen and broaden the knowledge regarding the rammed earth buildings in the territory. This too, was also providing financial incentives to promote their recovery and reuse⁷⁷.

As a reiteration, the use of rammed earth in construction was reduced around the late 19th and early 20th century (especially after World War II) with the introduction of new construction technologies such as concrete and steel. However, it can be seen a recent interest of reintroducing this material, but hasn't been that easy, due to earth is still considered a low-quality, unreliable material with limited mechanical performance. Also, there is a lack of standardized criteria worldwide for evaluating its performance. It is important to take into account, that each type of earth has unique intrinsic properties that depend on its origin, requiring different treatments or additives. Some countries like: New Zealand, Peru, Australia, New Mexico, and India, have developed legislation, guidelines, and testing protocols to define minimum strength and durability standards for materials such as adobe and pisé⁷⁸.

In Italy, the research about rammed earth construction began around the 1980s, with the purpose of understanding and regulating the material. Although rammed earth is present practically all over the country, there is not a national law that rules it, only regional legislation. One of the first legislative attempts was the Bill No. 2347 of February 14, 2002, introduced by Marco Lion, deputy from the Marche region. After a unsuccessful attempt, another one was made with Bill No. 4019 in May 2003, with the title "*Norms Supporting Rammed Earth Construction*". This bill was submitted to the Environmental and Territorial Commission but was never finalized⁷⁹.

However, in 1997 the Abruzzo region approved the *Provision for the Recovery and Valorization of Tholos Huts and Rammed Earth Houses*, being an initial attempt for recovering and valorizing

76 Robboni, C. (2010). *Tipologie costruttive in terra cruda*. In R. Mattone (Ed.), *Il paesaggio delle case in terra cruda* (pp. 41 - 52). L'artistica. pp. 38 - 42.

77 Vaschetto, F. (2014). *Alla scoperta del Roero: itinerario tematico per la valorizzazione della cultura, del paesaggio e del patrimonio architettonico in terra cruda roerini*. Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 54.

78 Marchiaro, A., & Berzano, M. (2014). *Conservare e proteggere il patrimonio in terra cruda: sperimentazione di intonaci in terra*. Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 21.

79 Ibid. pp. 22.

the rammed earth constructions⁸⁰. This law included building censuses and allowed public and private entities to present recovery and reuse projects, allowing a preliminary functional restoration. Unfortunately, the law's effectiveness was short-lived due to lack of funding⁸¹.

In the case of the Piedmont region, Roberto Mattone affirms that it was formally establish the importance and value of this heritage with the promulgation of the Regional Law 2 of 2006. It explicitly commits to the “*conservation and valorization of rammed earth constructions through the promotion of knowledge about the existing heritage and financial support for recovery interventions aimed at ensuring the optimal use of these buildings*”. According to Article 1 of the law, the Region's main objective was to recognize its historical and architectural rammed earth heritage, allowing following interventions to conserve and enhance it. This had to be carried out through two parallel strategies: first, by recognizing and critically analyzing the existing rammed earth buildings in the territory. The second, by providing financial incentives to promote their recovery and reuse⁸².

One of the key objectives of this law was to establish a specific survey and guarantee monitoring of the conservation status of the recorded buildings. The survey had to be carried out in coherence with any existing surveys or catalogs. Piedmont also developed a comprehensive program of research, raising the awareness and training with the involvement of multiple stakeholders. The research projects were implemented in partnership with universities and secondary schools, supported through scholarships. Also, the public and private operators could access to the technical and professional training courses to gain knowledge about the characteristics of rammed earth, construction techniques, and types of interventions, allowing them to develop appropriate project proposals. Additionally, one of the law's concerns was the possibility of receiving funding for extraordinary maintenance, restoration, and conservative rehabilitation, only if the proposal uses rammed earth and if the building is included in the survey. Also, the property owners were motivated through non-repayable grants covering up to 60% of eligible expenses, with a maximum limit of €12.000 per intervention⁸³.

On the other hand, it was possible to observe that regional regulations have certain limitations: they focus primarily on the valorization of existing buildings, often ignoring fundamental aspects such as the link with the sustainability feature and the potential use of rammed earth in new construction. This can help for earth to be considered along the other conventional building materials like cement, fired brick, steel, and wood. These issues evidenced the need of

80 Marchiaro, A., & Berzano, M. (2014). *Conservare e proteggere il patrimonio in terra cruda: sperimentazione di intonaci in terra*. Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 27.

81 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 25.

82 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 13.

83 Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 24 - 25.

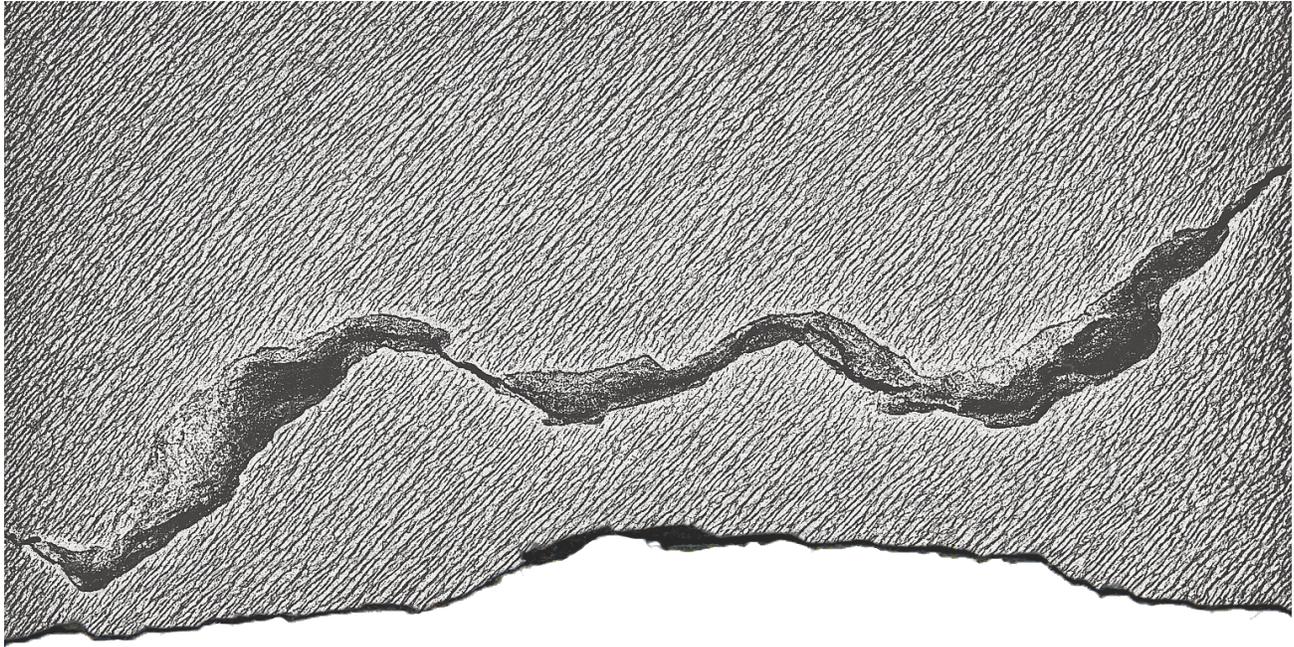
a new phase for discussion and research, pointing to imagine a future for rammed earth beyond the postwar prejudices that have reduced its use until today⁸⁴.

⁸⁴ Amisano, C. (2010). *La conservazione del patrimonio in terra cruda: la protezione delle superfici*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 26.

2

Conservation issues and analysis of pathologies.

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Conservation issues and analysis of pathologies.



The practice of restoration goes beyond the conventional knowledge of architects, demanding a deep understanding of the building pathologies and the criteria necessary to design appropriate repair interventions. These processes are very relevant when it comes to the case of historic buildings, because of the direct threat that pathologies represent for their preservation. A big and deep understanding allows an accurate diagnose and the definition of some effective intervention strategies, in this way contributing to the protection of cultural and architectural heritage⁸⁵.

When it comes to the earthen plasters, it has to be considered that they require a regular maintenance. However, their big advantage is being easily repairable: like cracks or minor damage can be fixed by applying the same mixture, ensuring the plaster's continuity also protecting the underlying wall. Therefore, a regular and simple maintenance can be more effective than invasive or large - scale interventions for the earthen constructions⁸⁶.

Following this, the Chapter 2 is divided into two subchapters. These subchapters explain the conservation issues and study the cause of pathologies that affect the earth as a building

85 Monjo Carrió, J., & Maldonado Ramos, L. (2001). *Patología y técnicas de intervención en estructuras arquitectónicas*. Munilla-Lería. pp. 17 - 18.

86 Lara, M. L., & Galarza-Gallardo, G. (2020). *Pathology in crude earth, research on constructions in the Ecuadorian Andean area*. In *Construction Pathology, Rehabilitation Technology and Heritage Management* (pp. 736-743). Granada, España. pp. 737.

material. The Section 1.1 explains some conservation issues to which earth plasters are exposed, determining the most common ones. In the section 1.2. it is approached the concept of pathology from a theoretical perspective, allowing its classification. It also presents the different types of pathologies, identifying the most common ones in earth plasters and how to mitigate them.

2.1. Conservation issues.

According to Carla Bartomolucci, since historic earthen architecture constitutes a significant portion of the World's Cultural Heritage (about 15% of the UNESCO World Heritage List), its conservation must prioritize the essential characteristics for which it was recognized as "Heritage of Humanity". Despite the vulnerable nature of the material, it presents particularly complex conservation challenges, this difficulty does not justify having a total reconstruction or complete replacement of elements. Such practices would threaten the work's authenticity and erase its history, making them opposite to the core principles of historical-cultural heritage conservation⁸⁷.

The earth buildings face significant hazards primarily from water and other environmental agents, but there are also the human and animal activities that can be also substantial risks⁸⁸. The degradation of earthen architecture can be grouped in natural and anthropogenic factors⁸⁹, both of which interact to compromise structural stability and material integrity⁹⁰.

Natural factors: Primarily include water and other environmental agents. As it is told, the water is the main physical cause of degradation, it usually acts through capillary rise from the soil, infiltration because of rain or snow, and occasionally, flooding. The moisture created gets accumulated on the base of walls, which causes the clay in the earth material to expand, lose cohesion and it becomes more malleable. Generally, this process starts by changing its surface color and having some damp patches, this can lead to cracking, plaster detachment and erosion of plaster's layers. With time, the continuous exposure to moisture can erode the base of the wall, threatening the structural stability. Especially, the rain can intensify these effects when the roof protection or drainage is inadequate, meanwhile, the atmospheric phenomena such as: wind, heavy rain and extreme weather events can accelerate and facilitate the moisture penetration⁹¹.

87 Bartolomucci, C. (2021). *Conservation of earthen architecture: An overview of international guidelines and resolutions*. In L. Luvidi, F. Fratini, S. Rescic, & J. Zhang (Eds.), *Past and present of the earthen architectures in China and Italy*. pp. 23 – 35.

88 Calabrese, G. (2012). *Conservation of historic earth buildings*. In *Modern Earth Buildings: Materials, Engineering, Constructions and Applications*. pp. 401 – 424.

89 López Pérez, C. (2019). *Revestimientos en tierra en edificaciones patrimoniales en Colombia* (pp. 8 – 19). REVISTA NODO, 12(23), pp. 15.

90 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 75.

91 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 78.

A proper material selection, compaction and execution can reduce water infiltration, but the exposure of vulnerable areas such as the base or the top remains a critical factor in the wall's degradation⁹².

The presence of vegetation is another natural agent of degradation. Some large plants can grow in the fissures and weakened areas, creating mechanical pressure that makes the cracks to widen, destabilizes soil particles and facilitates water penetration. Also, the decomposition of the roots, can form tunnels that attract small animals and other plants, worsening the degradation. In the case of the smaller plants (mosses, lichens, algae and fungi), they usually grow within the soil pores and apply pressure between the particles. Their process of decomposition and metabolism, release organic acids that can alter the clay chemical structure, making it weaker in its cohesion fragmenting it⁹³. These combined effects of vegetation and moisture, can accelerate the degradation either in the outside and inside, especially in areas without protection or adequate maintenance⁹⁴.

The impact of animals includes the insects such as termites and rodents, also, they act as natural agents of deterioration. The termites excavate tunnels within walls, weakening the mortar and embedded timbers, which facilitates the invasion of other insects and compromising the load-bearing capacity. The larger animals can cause localized mechanical damage through physical impacts⁹⁵.

Finally, the wind applies significant effects on earthen structures by the transportation of loose particles, promoting the evaporation and generation of localized wetting and drying patterns. It is common that by weight, the moisture content in earthen walls can vary between the 3 to 5% and 20%, affecting the structural behavior because of the expansion or contraction. The microclimatic conditions that are usually produced by airflow patterns (shaped by the building's form and orientation, surrounding structures and vegetation) can intensify the process of erosion, deposition and localized weakening. Also, the combination of wind and rain increases surface erosion, accelerates the plaster degradation and promotes the crystallization of soluble salts, creating a reduction of the cohesion and leads to cracks. The continuous cycles of moisture absorption, drying and mechanical impact caused by wind-transported sand or debris generate additional stress, progressively compromising the material's structural stability and visual appearance⁹⁶.

92 Ministerio de Educación, Cultura y Deporte. (2017). *Proyecto COREMANS: criterios de intervención en la arquitectura de tierra*. Subdirección General de Documentación y Publicaciones. pp. 79.

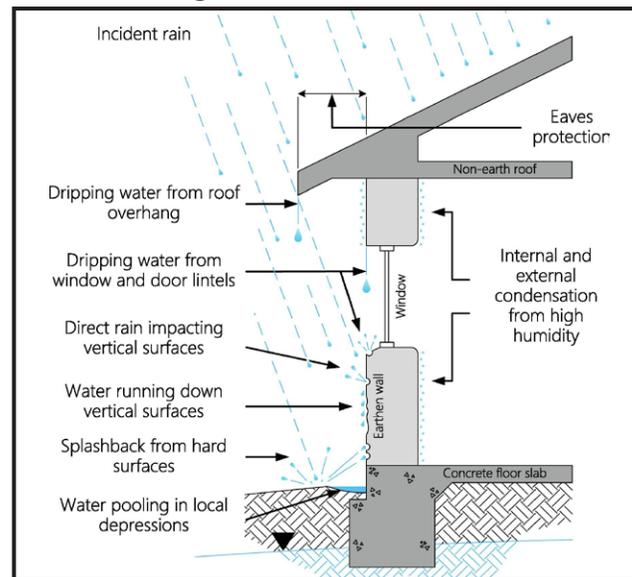
93 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 82.

94 Ministerio de Educación, Cultura y Deporte. (2017). *Proyecto COREMANS: criterios de intervención en la arquitectura de tierra*. Subdirección General de Documentación y Publicaciones. pp. 81 - 82.

95 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 85.

96 Ibid. pp. 87 - 88.

Image 34. Water affectations.



Source: <https://www.sciencedirect.com/science/article/pii/S0950061820301033>

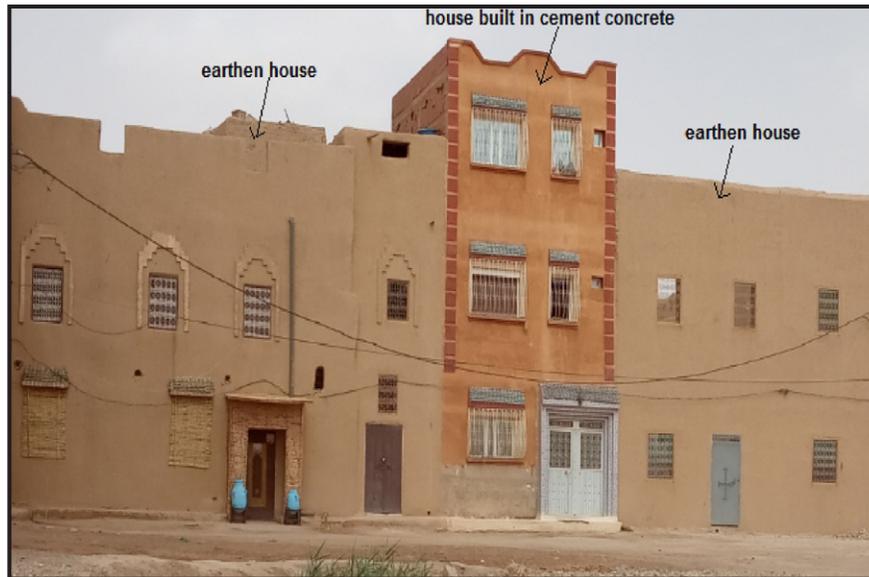
Anthropogenic factors: They have been historically among the main causes of deterioration in earthen architecture. The human actions such as: poorly planned structural modifications, the use of non – compatible materials (cement plasters), the electrical and plumbing systems installations and lack of maintenance or neglect, can interrupt the natural balance of earthen walls. Previously, to product gunpowder it has to be extracted saltpeter from the walls, creating severe structural damage. Nowadays, variables related to tourism, unappropriated interventions and changes in the building use continue to be threats to these structures⁹⁷.

Some mechanical actions are also the result from human activity, such as vibrations from vehicles, improper excavations or point loads from construction equipment, can accelerate degradation. Besides, the human-controlled animals, including farm animals and small pests, can contribute to the structural weakening. Usually, the human-induced troubles often create microenvironments for the accumulation of water or biological colonization, increasing the effects of natural agents⁹⁸.

⁹⁷ Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 82.

⁹⁸ Ministerio de Educación, Cultura y Deporte. (2017). *Proyecto COREMANS: criterios de intervención en la arquitectura de tierra*. Subdirección General de Documentación y Publicaciones. pp. 86.

Image 35. Human interventions.



Source: https://ars.els-cdn.com/content/image/1-s2.0-S2214509521000115-gr2_lrg.jpg

The interaction of both: natural and anthropogenic factors, produces visible degradation phenomena, like: cracks, bulging, surface erosion, plaster detachment, and a partial collapse in severe cases. Each manifestation is a stage in the degradation process, in which an early detection and understanding of the main causes are essential to avoid further damage. A detailed observation, identification of degradation signs and the understanding of the site-specific conditions, allow for a better intervention planning that preserve the authenticity, structural stability and material integrity of the historic earthen buildings⁹⁹.

It can be said that the understanding of the mechanisms allows to analyze each visible manifestation, identifying its causes and planning appropriate interventions, making the difference between the superficial alterations that won't compromise the building's integrity and degradation that requires corrective action. This approach ensures that interventions are effective, respecting the authenticity of the building and prevent a future deterioration¹⁰⁰.

2.2. Analysis of pathologies.

Following Juan Monjo Carrió and Luis Maldonado Ramos, the building pathology is defined as the discipline that studies the problems that appear in buildings or their elements once the construction phase is complete. In the professional practice, the term “pathologies” is often used imprecisely referring to isolated defects or failures, however, these constitute the object of study of the discipline and not the discipline itself. In this context, the term “pathology” should be understood as the scientific field responsible of the analysis of construction problems, the

99 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 78.

100 Ibid. pp. 78.

processes that generate them, and some possible solutions. Meanwhile the adjective pathological has to be used to describe the phenomena or analyses linked to these processes¹⁰¹.

Furthermore, Monjo Carrió and Maldonado Ramos define the pathological process as a sequence that allows for the diagnosis of a structural problem, approaching the identification of its origin, causes, evolution, manifestations, and current state. This analysis is the base for either defining repair strategies or adopting preventive measures. It generally proceeds in reverse, starting from the visible effects and working backward to their original causes¹⁰².

Within this process, a lesion or damage is understood as any visible manifestation of a structural problem, that is, the final symptom of the pathological process. Its correct identification is important, because errors at this stage can lead to incorrect diagnoses and useless interventions. Lesions can be classified as primary, when they appear in the initial phase of the process, and secondary, when they occur as a consequence of primary lesions¹⁰³.

Monjo Carrió and Maldonado Ramos define the cause as the agent, active or passive, responsible for the beginning of a pathological process and the appearance of one or more lesions. Although the analysis begins with the visible manifestation, the central objective of the diagnosis is to identify the cause, due to an effective intervention is only possible by eliminating the source of the problem. When the intervention is limited to treating the symptom, the pathological process persists, which explains the failure of many interventions¹⁰⁴.

Once the pathological process has been diagnosed (considering its origin, evolution, and manifestation) the reparation can begin. Reparation is understood as the set of interventions focused on restoring the architectural functionality of the affected building unit. Depending on the severity of the damage, these actions can be partial or total. Also, this concept should be distinguished from restoration, which refers to intervention on a specific element of historical or artistic value, and from rehabilitation, which is targeted to the functional recovery of the building as a whole¹⁰⁵.

It is also said that the study of pathological processes (in particular their causes) allows for the definition of preventive measures focused on avoiding the development of new problems in future constructions. This approach, called preventive pathology, focuses on eliminating indirect causes linked to the design, construction, and maintenance phases of the building process¹⁰⁶.

101 Monjo Carrió, J., & Maldonado Ramos, L. (1997). *Patología de cerramientos y acabados arquitectónicos*. Munilla-Lería. pp. 19 - 20.

102 Ibid. pp. 20.

103 Ibid. pp. 20 - 21.

104 Ibid. pp. 21.

105 Ibid. pp. 21.

106 Ibid. pp. 22 - 23.

Regarding the earthen plasters pathologies and following the classification proposed by Cecilia López, the deterioration is mainly affected by two main degradation factors: natural and anthropogenic. However, the diverse locations of the buildings lead to a wide range of possible forms of damage, affecting the coatings and finishes making their diagnosis and treatment more complex. These pathologies can be classified into five (5) categories: physical, mechanical, chemical, biological and human-made.

2.2.1. Physical

This type of pathology is originated from physical phenomena such as soiling particles, frost or condensation. In most of the cases, the initial cause is also physical and its evolution depends on similar factors, without implying a chemical alteration of the affected materials. However, changes in form, color or moisture content can happen. Consequently, this first type includes many types of damage which can show variations depending on the material, the constructive element or element, and the building's use¹⁰⁷.

- **Rising damp – Capillarity:** It is generated as a result of water rising, usually from the ground through the capillaries of foundation and wall materials, in an upward direction. It is identified by its appearance at the base of walls.
- **Descending damp:** It is the presence of water in vertical elements where stains appear, progressing from top to bottom.
- **Water infiltration:** It is caused by the accumulation of water on high surfaces or by water passing through structural elements of roofs, floors, or façades.
- **Deposited dirt – Surface soiling:** It is the dirt produced by the action of gravity on aerial particles that settles and accumulates on surfaces.
- **Differential washing – Stains – Black patina:** It is produced by the washing away of particles deposited on the surface by rainwater, causing stains or streaks.
- **Weathering erosion – Disintegration:** It is the wear or gradual loss of the surface or coating of a material or system. Is caused by mechanical actions (abrasion, friction), physical actions (air – water), and chemical actions (acidic or alkaline products that alter the material's composition).
- **Material Alteration:** It is the change of shape, texture or cohesion of the material without altering its chemical composition, due to environmental agents.
- **Delamination:** It is the loss of material in sheets or flakes, common in stones or clay pieces exposed to weathering.
- **Bulging – Blistering:** It refers to the appearance of small blisters or air bubbles between the base material and the finishing paint.
- **Flaking – Peeling:** It refers to the peeling or detachment of the finishing paint from a

107 Monjo Carrió, J., & Maldonado Ramos, L. (1997). *Patología de cerramientos y acabados arquitectónicos*. Munilla-Lería. pp. 24 - 25.

surface or material.

- **Losses and voids:** It is a localized loss of material on the surface of an element, generating holes and showing the absence of original parts.

Table 1. Physical pathologies.

	Code	Type of damage	Unit of measurement
A. Physical	A 1	Rising damp – Capillarity	m2
	A 1.1	Descending damp	m2
	A 2	Water infiltration	m2
	A 3	Deposited dirt – Surface soiling	m2
	A 3.1	Differential washing – Stains – Black patina	m2
	A 4	Erosion – Weathering – Disintegration	m2
	A 5	Material Alteration	m2
	A 6	Delamination	m2
	A 7	Bulging – Blistering	m2
	A 8	Flaking – Peeling	m2
A 9	Losses and voids	m2 / un	

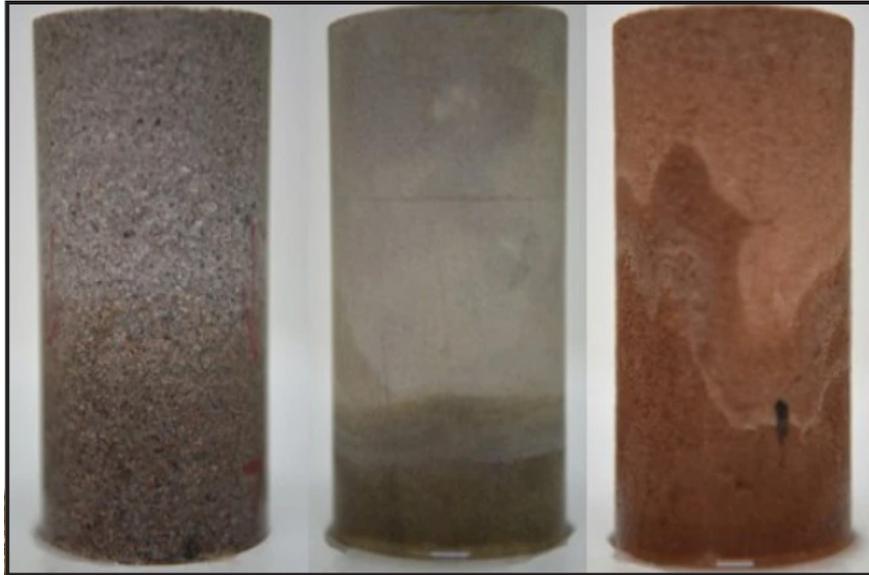
Made by: Maria Alejandra Agudelo Briceño
Based on “Manual de Patología de la Edificación” - UPM.

The earthen constructions and plasters, are often affected by two main physical pathologies. The first one is the rising damp or capillarity and the second one is the weathering erosion or disintegration.

In first place, water is the primary agent of deterioration in buildings constructed with raw earth. Its effects manifest themselves, among other mechanisms, through penetration into the material via natural ways such as capillary action. The water infiltration can cause some variation in the volume of clay’s particles (an expansion during the absorption and a contraction after the evaporation) originating the appearance of cracks, its length depends on both the moisture content and the material’s physical and chemical properties. Also, the presence of water can reduce significantly the material’s compressive strength, leading to a weakening of the building’s structural stability¹⁰⁸.

108 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L’artistica. pp. 79 – 80.

Image 36. Rising damp - Capillarity.



Source: <https://www.nature.com/articles/s40494-022-00656-y/figures/8>

Some actions to mitigate this problem can be focused on the exterior part of the building. This includes the adaptation of the surrounding terrain to facilitate the rainwater runoff, verifying the right performance of the existing drainage systems. Also, the implementation of drainage systems, both within the buildings themselves and by adopting various solutions, such as¹⁰⁹:

- The placement of a horizontal waterproof barrier must be carried out carefully, especially if the building has structural damage.
- The creation of a moisture barrier by injecting waterproofing products, this has to be done with a lot of attention when the pressure is being applied (it must be compatible with the physical and mechanical properties of the element) and also to the potential temporary effects on the humidity level. The success of this intervention depends on factors such as the porosity of the wall, the size of the perforations, the moisture index of the masonry and the characteristics of the product (including its chemical composition, viscosity and stabilization rate).
- The implementation of interventions to facilitate water drainage from the wall, such as electro-osmosis, drilling into the masonry, or the installation of atmospheric siphons¹¹⁰.

Also, plaster detachment is one of the main forms of degradation in earthen buildings, although it protects in high level the surfaces against weather elements such as wind and rain. This system

109 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 79 – 80.

110 Ibid. pp. 79 – 80.

has been used since old times, Rondelet¹¹¹ says that some mud-brick walls were coated with clay and straw or with lime and gypsum in more prestigious constructions. Its low cost and simplicity of application make a balance between its limited durability and a regular maintenance. In order to guarantee its effectiveness, the plaster must be resistant to atmospheric agents, be vapor-permeable and have a proper bonding to the substrate. This can be achieved with mixtures of earth, sand, and lime, and clay can be added to improve plasticity, deformability, and adhesion to the earthen wall¹¹².

Image 37. Weathering erosion - Disintegration.



Source: <https://www.scarlettearchitecture.com/post/beauty-in-weathering>

To mitigate this problem, after several experimental tests, the use (in this case, replacement of the “piece”) of lime and sand-based plasters, also with gypsum, is suggested. The characteristics of the substrate must be taken into account¹¹³.

Seeing this, the moisture control is an important aspect in earthen constructions, due to its susceptibility to water damage. That is why, it is essential to ensure proper rainwater drainage, maintain protective elements such as eaves, drainage systems, “breathable” plasters and carry out regular inspections to detect and mitigate deterioration before it becomes irreversible.

2.2.2. Mechanical

The mechanical ones are all pathological situations in which the mechanical factor predominates, whether in their causes, evolution or manifestations. It therefore includes damages caused by movements, openings or separations between materials or elements, as well as those resulting in deterioration. Although mechanical pathologies could be confused with physical ones, in

¹¹¹ Jean-Baptiste Rondelet (1743 - 1829) was a french architect and theorist, wrote the “*Traité théorique et pratique de l'art de bâtir*” between 1802 and 1817.

¹¹² Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 82 - 85.

¹¹³ Ibid. pp. 82 - 85.

construction they get a big importance that they need to be treated as an independent group. Also, it can be identified different types of damages, each with multiple variations depending on the specific conditions of the material, the construction unit, the use of the building, and other factors¹¹⁴.

- **Buckling:** It is the loss of stability in a slender element that bends sideways under compressive load.
- **Compression:** It is the shortening or crushing of a material under compressive forces.
- **Bending:** It is the curvature of an element subjected to transverse loads.
- **Warping:** It is the deformation caused by loss of flatness in slabs or flat surfaces.
- **Torsion:** It is the twisting or warping of an element.
- **Tilting – Out-of-plumb:** It is the loss of verticality of an element, leaving it tilted with respect to its original axis.
- **Fissures:** It is the discontinuity less than 3 mm, affecting the surface of the element or material.
- **Cracks:** It is the longitudinal discontinuity greater than 3.1 mm, crossing the thickness of the element.
- **Fractures:** It is the breakage and/or separation of the material when its resistance is exceeded.
- **Craquelure:** It is a surface micro-cracking in a network pattern.
- **Chipping – Spalling:** It is the localized material loss on edges and/or corners.
- **Detachments – Displacement:** It is the separation of two materials, generally due to lack of adhesion between finishing layers and their support. – Includes changes in the original position of elements, finishes, or systems.
- **Subsidence – Level change:** The changes in the level of the floor or support surface. These occur as a result of subsidence of the base level, foundation shifts, or changes in the ground.

114 Monjo Carrió, J., & Maldonado Ramos, L. (1997). *Patología de cerramientos y acabados arquitectónicos*. Munilla-Lería. pp. 26.

Table 2. Mechanical pathologies.

	Code	Type of damage	Unit of measurement
B. Mechanical	B 1. Deformations	B. 1.1. Buckling	un
		B. 1.2. Compression	un
		B. 1.3. Bending	un
		B. 1.4. Warping	un
		B. 1.5. Torsion	un
		B. 1.6. Tilting – Out-of-plumb	un
	B 2. Discontinuities	B. 2.1. Fissures	ml
		B. 2.2. Cracks	m2
		B. 2.3. Fractures	un
		B. 2.4. Craquelure	m2
		B. 2.5. Chipping – Spalling	un
	B 3	Detachments – Displacement	m2 / un
	B 4	Subsidence – Level change	m2

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Mattone (2010) also states that there are two very common types of damage for this category: erosion and fissures. It should be noted that if earthen walls lack a suitable base or foundation of stone or fired brick, the base can suffer erosion caused by rain, wind, or the action of salts.

To mitigate this problem, the dimension of the damage must be considered. In minor cases, applying successive layers of plaster is enough, while in areas with significant deterioration, it is necessary to remove the degraded sections and replace them with unfired bricks joined with earth mortar or pressed blocks stabilized with lime and brick dust, using a fibrous mortar at the boundary between the old and new walls. It is also possible to replace the affected areas by compacting within a formwork a mixture of earth, straw, and water. It can be stabilized with lime, incorporating wooden connectors to ensure a bond and sealing the boundary with a thin layer of controlled-shrinkage mortar. The intervention can be completed by creating ventilated air chambers and adjusting the slope of the surrounding terrain to facilitate rainwater runoff. In new constructions, a stone or brick base of approximately 50 cm is recommended to protect the walls from erosion caused by rain splash, avoiding exterior bumps aligned with the support plane of the wall that could generate water stagnation and leading to the degradation of the soil¹¹⁵.

¹¹⁵ Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 79.

Image 38. Erosion.

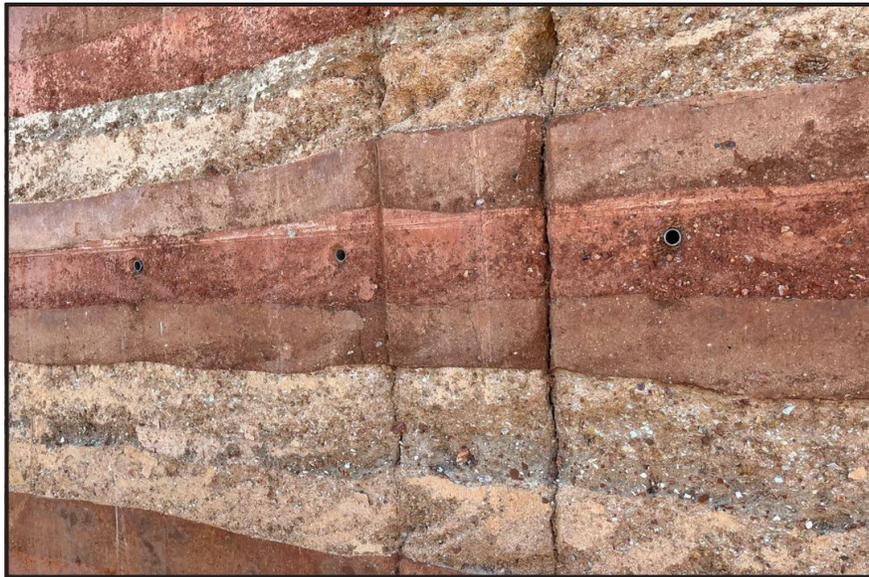
Source: <https://www.researchgate.net/profile/Miguel-Rocha-13/publication/290872017/figure/fig2.jpg>

Also, cracks can originate from various factors, such as thermal expansion, insufficient distribution of concentrated loads, foundation settlements, thrust from roof structures, or the presence of water due to capillary rise, etc...

Before making any intervention to mitigate this problem, it is essential to identify the main cause of the defect. Also, is better first to have an experimental test before selecting the techniques or materials for sealing or repairing the masonry, verifying the material compatibility, control deformation and allowing the structural integrity between parts for the restoration. Currently, in the majority of interventions it is used mixtures of earth, sand, and lime, these have to guarantee a right adhesion to the pre-moistened substrate and a very low shrinkage. That is why the sand's particle size distribution must be carefully controlled and, in some cases, fibers, fly ash, or gypsum must be incorporated. In more severe cases, it may be necessary to completely remove the deteriorated material and fill the gap with a lime-stabilized soil mixture or, instead, with compressed earth blocks (CEB), as a result reducing the shrinkage effects of the new masonry relative to the original¹¹⁶.

¹¹⁶ Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 80 – 82.

Image 39. Fissure.



Source: <https://media.licdn.com/dms/image/v2>

It can be said that cracks, fissures and deformations in adobe walls are clear sign of structural and material weakness, it's often increased by mechanical stress, differential material behavior and moisture exposure. On the contrary of minor fissures (initially considered as aesthetic issues) their progression can compromise both the stability and integrity of the building. Some preventive measures (effective bonding in corners, adequate support and tie beams, good protection from rainwater and suitable foundation systems) are essential to minimize damage. Also, a regular inspection and maintenance can help for an early detection of structural weaknesses, making a better durability, safety, and habitability of earthen constructions.

2.2.3. Chemical

The chemical ones are originated from the presence of salts, acids, or alkalis that react with the materials, leading to decomposition processes that eventually compromise their integrity and, consequently, their durability. This type of damages presents processes that are clearly distinguishable from those of the physical and mechanical categories, although their symptoms may at times be mistaken for them¹¹⁷.

- **Efflorescence – subflorescence:** It is caused by the dissolution of salts present in masonry or mortars, which are carried by water to the surface, where they crystallize in the form of small blooms.
- **Oxidation:** It refers to a molecular-level transformation of metallic materials when they come into contact with oxygen, generating paint blistering, brown or reddish stains and

117 Monjo Carrió, J., & Maldonado Ramos, L. (1997). *Patología de cerramientos y acabados arquitectónicos*. Munilla-Lería. pp. 27-25.

a layer of rust on the surface.

- **Corrosion:** It is the progressive loss of particles from a metallic material. It arises as a result of constant exposure to humid environments, atmospheric agents, salts or chemical agents.
- **Weathering:** It occurs when the material undergoes transformations in its mineral or molecular composition due to agents such as water, oxygen, CO₂ and atmospheric pollutants (Stone - Masonry).
- **Black crust:** It is a hardened superficial deposit, dark or black in color, that adheres strongly to the stone surface, generally in areas protected from direct rain.

Table 3. Chemical pathologies.

	Code	Type of damage	Unit of measurement
C. Chemical	C 1	Efflorescence - subflorescence	m ²
	C 2	Oxidation	m ²
	C 3	Corrosion	m ²
	C 4	Weathering	m ²
	C 5	Black crust	m ²

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Based on "Manual de Patología de la Edificación" - UPM.

It can be seen that the chemical pathologies are not that common in earthen constructions, because of the natural and "stable" composition of the material. Mainly earth, is composed by clay, silt, and sand, and also lacks of reactive compounds that could create a chemical transformation such as oxidation or corrosion.

2.2.4. Biological

The group of biological ones are the set of damages where the presence of a living organism (whether animal or plant) plays an important role. These affect the surface of materials either by their presence or through the attack carried out by the organisms themselves, or by the chemical products they release, which alter the physical or chemical structure of the supporting material¹¹⁸.

- **Xylophagous insects:** It is a damage to wood caused by insects that feed on cellulose and lignin, creating internal galleries, loss of density and structural weakening.
- **Fungi - Mold:** It refers to the presence of organisms from the fungi kingdom. They may appear as masses with a fluffy appearance, filaments or radial filiform shapes in different

118 Monjo Carrió, J., & Maldonado Ramos, L. (1997). *Patología de cerramientos y acabados arquitectónicos*. Munilla-Lería. pp. 28.

colors such as white, black or gray. They often have a characteristic odor in poorly ventilated spaces.

- **Invasive vegetation:** It refers to the growth of vegetation in joints, walls or cornices.
- **Mosses – Lichens – Algae:** It refers to smaller-sized plant organisms. They appear especially in humid areas.
- **Traces of fauna – Biological vectors – Excrement deposits:** It refers to the presence of animals (insects or others) that negatively affect the behavior, performance, and aesthetics of materials through their droppings, feathers or hair.

Table 4. Biological pathologies.

	Code	Type of damage	Unit of measurement
D. Biological	D 1	Xylophagous insects	un
	D 2	Fungi – Mold	m2
	D 3	Invasive vegetation	un
	D 4	Mosses – Lichens – Algae	m2
	D 5	Traces of fauna – Biological vectors – Excrement deposits	m2

Made by: Maria Alejandra Agudelo Briceño
Based on “Manual de Patología de la Edificación” - UPM.

It is confirmed that, due to their “natural” properties, the walls of earthen constructions can suffer degradation caused by spontaneous vegetation. Climbing or stem-bearing plants can take root in the rammed earth surfaces and through the mechanical action of their roots in cracks, cause the plaster to detach, moisture to accumulate and the wall to disintegrate. These phenomena also affect adobe constructions, especially when they are in a state of ruin. The lack of maintenance facilitates the growth of ruderal weeds, which readily settle in both the earth between the blocks and the mortar¹¹⁹.

What has been seen in the regions where this type of construction is concentrated, the actions to carry out to restore the affected areas are: the vegetation should be carefully removed from the roots, minimizing any affectation of the surroundings. For fungal presences, the deteriorated sections must be removed using appropriate tools, such as a pick, ensuring the complete elimination of the damaged material and residual moisture¹²⁰.

119 Mattone, R. (2010). *Il paesaggio delle case in terra cruda*. L'artistica. pp. 85.

120 Adrianzén Peña, I., Albuquerque Quintanilla, L., Curay Quevedo, J., & Vilcherres López, R. (s.f.). *Patologías del adobe*. Universidad Nacional de Piura. Retrieved September 16th, 2025, from <https://es.scribd.com/document/563682401/Patologias-del-Adobe>

Image 40. Invasive vegetation.



Source: <https://www.researchgate.net/profile/Javier-Soria/publication/268239218/figure/fig1.png>

It can be said that, the presence of moisture infiltration, inadequate protection and poor maintenance has the presence of vegetation and fungi on adobe walls, being a significant indicator of structural and material deterioration. Gradually, the plant roots can compromise the integrity of walls and roofing elements, while fungal growth can lead to the decay of wood elements and reduce the mechanical strength. Also, some preventive measures (proper drainage systems, roof maintenance and regular inspections) need to be carried out to reduce the intensity of these effects. In cases where damage exists, there has to be a careful removal of vegetation and affected fungal material, along with the control of moisture sources, is crucial to preserve the durability, safety, and habitability of earthen constructions.

2.2.5. Human made

The last group refers to the construction damages caused by failures in design, execution, or human decisions. Although physical and environmental factors play a role, it is estimated that about 75% of pathologies originate from human errors, many of which could be avoided through proper planning and control¹²¹.

- **Parasitic or additional installations:** It refers to installations and/or exposed networks inside the building, affecting spatial and finishing characteristics. (Inspection boxes, ventilation ducts, RCI).
- **Additions – Alterations:** It refers to a spatial alteration through the addition of walls or elements (outside of networks) that are not part of the original design.

121 Elguero, A. M. (2004). *Patologías elementales*. Editorial Nobuko. Buenos Aires. pp. 39.

- **Demolitions – Removals:** It refers to the disappearance of original elements or later additions, leaving traces in spaces or buildings, easily identifiable by differences in color or material.
- **Vandalism – Graffiti:** It refers to painting (illegal) actions or removal of pieces carried out by humans, which negatively affect the aesthetics and functionality of the building.
- **Material replacement – Material change:** It is the incorrect choice of material, or lack of definition (physicochemical specification).
- **Poor workmanship – Bad execution:** It means all factors inherent to the constructed work that result from errors in its execution or in that of any of its units.

Table 5. Human made pathologies.

	Code	Type of damage	Unit of measurement
E. Human made	E 1	Parasitic or additional installations	m2 / un
	E 2	Additions – Alterations	m2
	E 3	Demolitions – Removals	m2
	E 4	Vandalism – Graffiti	m2
	E 5	Material replacement – Material change	m2
	E 6	Poor workmanship – Bad execution	m2 / un

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Based on “Manual de Patología de la Edificación” - UPM.

In this pathology regarding deterioration caused by human actions, two primary factors are recognized: insufficient maintenance and inappropriate interventions. The negligence or lack of care by owners or residents often leads to moisture problems, structural deformations and surface material loss in walls and finishes. Inappropriate interventions, meanwhile, are usually caused by a loss of traditional knowledge regarding earthen construction materials. The application of incompatible or unsuitable materials (including cement or chemical treatments) may induce further damage and accelerate the deterioration of the structure¹²².

In conclusion, the way to mitigate this pathology is avoiding all the causes that were mentioned. When an intervention is made, it has to be with the materials and specialized hand craft.

122 López Pérez, C. (2019). *Revestimientos en tierra en edificaciones patrimoniales en Colombia* (pp. 8 – 19). REVISTA NODO, 12(23), pp. 9.

Image 41. Human action on wall.

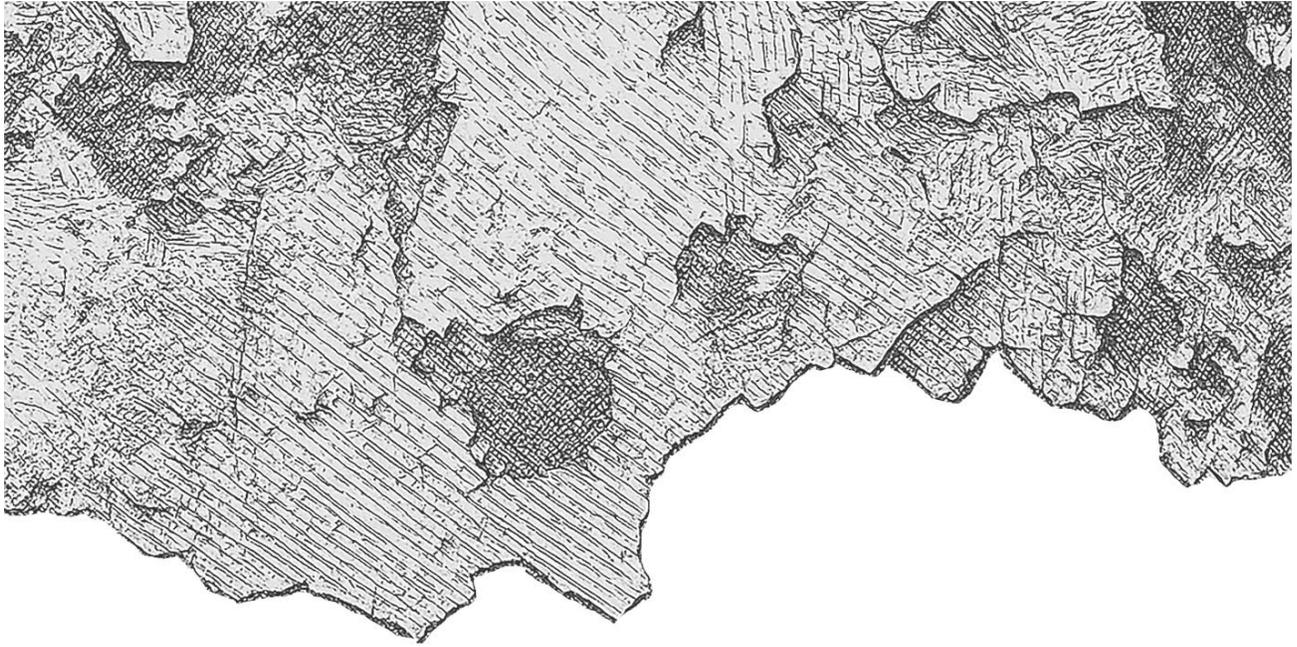


Source: <https://images.squarespace-cdn.com/content/v1.jpeg>

3

Analysis of pathologies and conservation issues.

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Plasters, experimental phase and results.

As previously explained, due to the action of natural agents (especially water) and insufficient maintenance, earthen constructions are susceptible to various pathologies. According to Manuela Mattone (2017), protecting these structures requires the application of a coating that acts as a “*sacrificial layer*”¹²³. As a complement, Hugo Houben (1985) adds, that protective coatings have multiple functions: cover the walls from moistures and impacts, extending its lifecycle, enhancing its appearance and thermal comfort and doing so economically efficient. These features can be sometimes contradictory when it comes to their requirements: the coating must be impermeable to external rain, but it has to allow the internal water to escape, has to be flexible enough to absorb deformations without cracking, resist frost and remain achieve the surrounding aesthetic¹²⁴.

To achieve these properties, the testing stage is necessary to evaluate the type of earth mixture. This leads to determine the composition of particles and the presence of contaminants. Also, some differences in the type of particles and additives can influence the performance of the materials¹²⁵.

Therefore, Chapter 3 is organized into three subchapters, focusing on the development of the

123 Mattone, M., Rescic, S., Fratini, F., & Manganelli Del Fà, R. (2017). *Experimentation of earth-gypsum plasters for the conservation of earthen constructions*. *International Journal of Architectural Heritage*. Pag. 1.

124 Houben, H., & Guillaud, H. (1985). *Manuel de construction en terre*. Pag. 333.

125 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. Pag. 99.

plasters, the execution of laboratory tests, and the presentation of the results, providing an understanding of which plaster is most suitable.

The Section 3.1 describes the composition of the plasters, including the additives used and some of their properties. In the Section 3.2 there are explained the laboratory tests, their purpose, procedures, and objectives. Like this, there were identified the mechanical, physical, biological and chemical properties of the plasters through erosion, absorption, and adhesion tests. These tests were carried out at the Laboratory of Innovative Technological Systems (LASTIN) of the Department of Architecture and Design at the Politecnico di Torino starting on June 12th and finishing in July 17th of 2025. Finally, the Section 3.3 presents the test results, identifying the plasters that offer the best performance for the preservation and conservation of earthen buildings, particularly in the Piemonte region.

3.1. Plaster mixes.

In order to have a starting point with the plaster quantities, it is important to understand what is being done before related to plasters and mixtures. As previously said by Stazi et al¹²⁶, the main disadvantage of raw earth as a building material is its vulnerability to water. In rainy climates, the deterioration of historic earthen buildings is primarily caused by water, often worsened by abandonment, poor roof maintenance, and insufficient protective elements. In consequence, identifying plasters capable of protecting external surfaces against weathering is essential. Effective plasters must meet specific requirements, including good workability, physical and mechanical compatibility with the substrate, hydrophobicity and high resistance to water erosion¹²⁷.

Also, many studies have been done internationally focusing on the raw earth as a construction material, sometimes incorporating small amounts of stabilizers such as cement, lime or natural additives. Some researchers have shown issues such as sustainability, embodied energy and CO₂ emissions, energy efficiency, thermo-hygrometric comfort, durability and physical-mechanical performance. Other investigations have explored the role of fibers (natural and synthetic) in improving the mechanical behavior and reducing shrinkage¹²⁸.

In contrast to this, few studies have approached the protection of earthen surfaces from atmospheric agents, both in historic preservation and new construction. Hamard et al¹²⁹. demonstrated:

126 Stazi, F., Nacci, A., Tittarelli, F., Pasqualini, E., & Munafò, P. (2016). *An experimental study on earth plasters for earthen building protection: The effects of different admixtures and surface treatments*. *Journal of Cultural Heritage*, 17. pp. 27 - 41.

127 Ibid. pp. 1.

128 Ibid. pp. 1.

129 Hamard, E., Morel, J., Salgado, F., Marcom, A., & Meunier, N. (2013). *A procedure to assess the suitability of plaster to protect vernacular earthen architecture*. *Journal of Cultural Heritage*, 14(2). pp. 109 - 115.

- Adhesive strength is strongly influenced by the type of substrate and the clay content of the plaster, higher clay percentages initially increase strength.
- Excessive amounts lead to shrinkage that weakens the plaster and wall bond.
- The incorporation of fibers helps prevent the cracking during drying shrinkage.

Following what Hamard et al said¹³⁰, earth plasters offer two key advantages: they are permeable to water vapor, which allows walls to “breathe”, and their mechanical properties are similar to those of earthen walls. This makes them much more compatible than cement-based coatings, which are waterproof and too rigid.

For this time, the mixtures were prepared using soil from the Alessandria province. There were used two (2) types of soil: the first contained 85% of sand, 5% of silt and 10% of clay. The second one, had corncob as an additive and its composition was 76% of sand, 8% of silt and 16% of clay. These compositions were established by the grain size distribution curves provided by the Laboratory of the Institute for the Conservation and Enhancement of Cultural Heritage of the CNR.

Table 6. Grain size distribution.

	Grain size distribution		
	Sand	Silt	Clay
	f > 63 μm	4 μm <f<63 μm	f < 4 μm
Vercellese modificata 13-05	85	5	10
Vercellese con tutolo 18-04	76	8	16

Source: CNR

In order to have a considerable range of options with different mixes and a base to compare, eight (8) different plasters were prepared on May 13th and 14th of 2025. To replicate the real conditions of an earthen wall, there were used small adobe brick walls. Three (3) types of samples were made. The first and second types were prepared following Erwan Hamard’s¹³¹ guidelines: the first was applied on the brick wall using polystyrene formworks, with dimensions of 25 × 25 × 2 cm, the second one was also applied on the brick wall with polystyrene formworks, but were made three (3) samples with smaller dimensions of 5 × 4 × 2 cm. The third type of sample was prepared on a clay slab and divided into three (3) pieces, each approximately 25 × 20 × 2 cm.

The walls were hydrated and prepared by applying a layer of earth and water, this, to improve the adhesion of the plasters to the adobe bricks. Also, the 2cm thickness was established to avoid fissures. After finishing the preparation of the plasters, they were left to dry in the LASTIN

¹³⁰ Hamard, E., Morel, J., Salgado, F., Marcom, A., & Meunier, N. (2013). A procedure to assess the suitability of plaster to protect vernacular earthen architecture. *Journal of Cultural Heritage*, 14(2). pp. 109 - 115.

¹³¹ Ibid. pp. 109-115.

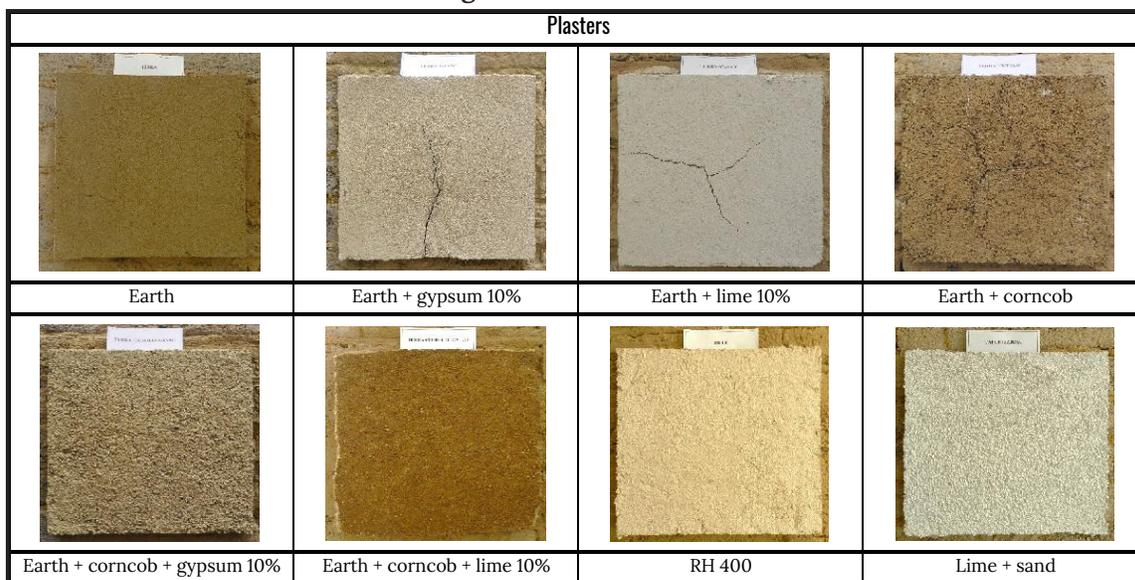
laboratory and during the next first days, the plasters were cured by lightly spraying them with water and smoothing the fissures with a trowel. Other plasters were made with different dimensions and sent to the engineering faculty of the Politecnico di Torino and to the CNR in Sesto Fiorentino (Firenze).

Table 7. Plaster's composition.

Plaster	Composition	Weight (gr)	Earth (gr)	Water (l)	Lime (gr)	Gypsum (gr)	Corncob (gr)	Product (gr)	Sand (gr)
A	Earth	8.718	7.168	1.55	-	-	-	-	-
B	Earth + gypsum 10%	9.935	7.168	2.05	-	717	-	-	-
C	Earth + lime 10%	9,825	7.168	1.94	717	-	-	-	-
D	Earth + corncob	9,678	5.376	3	-	-	1.302	-	-
E	Earth + corncob + gypsum 10%	10,456	5.376	3.24	-	538	1.302	-	-
F	Earth + corncob + lime 10%	10,456	5.376	3.24	538	-	1.302	-	-
G	RH 400	3.120	-	0.62	-	-	-	2.500	-
H	Lime + sand	11,256	-	4.600	-	-	-	-	6.656

Source: Manuela Mattone

Image 42. Plasters on wall.



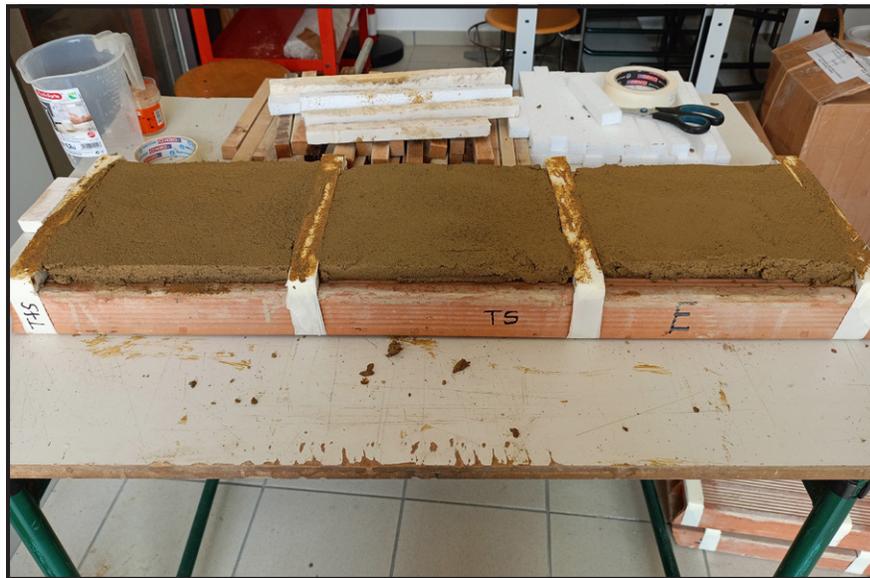
Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Image 43. Shear test's plasters (small ones).

Plasters			
			
Earth	Earth + gypsum 10%	Earth + lime 10%	Earth + corncob
			
Earth + corncob + gypsum 10%	Earth + corncob + lime 10%	RH 400	Lime + sand

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Image 44. Clay slabs samples.



Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

3.1.1. Earth.

The earth is formed from the parent rock after slow processes of weathering and particles migration, having as a result a variety of soils with diverse features. The earth has four (4) main properties, such as: grain size, plasticity, compressibility and cohesion. To make a more rational use of the soil it has to be classified, for earthen constructions, the most relevant are the

geotechnical and pedological¹³².

The soil is originated from the transformation of the underlying rock after physical, chemical and biological processes, related to climate, vegetation and fauna. It is the solid section of the Earth's surface and a loose material of different thicknesses that holds plants, animals and human constructions. Its creation and evolution take place through three (3) main processes¹³³:

- **Weathering of the parent rock:** Climatic factors such as: sun, rain, wind and temperature break the exposed rocks. These are divided in three (3) types: hard (granite, schist, sandstone), soft (chalk, marl, clay) and loose (sand, loess, debris). A mix of mineral particles, stone fragments, sand, silt, clay (sometimes as a paste enriched with iron oxides and soluble salts) is produced by mechanical and chemical weathering.
- **Organic interaction:** The flora and fauna colonize the weathered material, it gets enriched with organic substances like humus. The humus properties vary with the climate, parent rock and vegetation. Along with the climate, it keeps altering the minerals and defines the soil's physical, chemical and biological characteristics.
- **Vertical migration of soluble elements:** If the climate is wet, the soluble elements "go down", meanwhile, in dry climates go upwards enriching the surface. Different layers are created because of this migration, creating the soil profile that is studied by pedology¹³⁴. The soils can be classified in different types: young (not developed), shallow and homogeneous and evolved, deep and distinguished in multiple layers. The soil origin depends in first place on the parent rock, climate, vegetation and topography.

According to John Warren the different soil's layers can be classified in nine (9), these are:

- **AO:** Organic layer, lightly decomposed (>30% organic matter)
- **A1:** Mixed organic-mineral layer (<30% organic matter)
- **A2:** Eluvial horizon, poor in organic matter, leached of clay and iron oxides
- **A3:** Transition between eluvial and illuvial layers
- **B1:** Iron-rich layer with organic matter and Fe/Al oxides
- **B2:** Illuvial horizon, enriched in clay and iron oxides
- **B3:** Transition between B and C layers
- **C:** Original material

132 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 17.

133 Ibid. pp. 18 - 19.

134 Is the science that studies soils, their formation, evolution and characteristics.

- **R:** Unweathered parent rock

Also, the soil holds three (3) main components such as¹³⁵:

- **Gaseous:** Air in pores, containing nitrogen, oxygen, carbon dioxide and decomposition gases.
- **Liquid:** Water originated from rain, atmospheric humidity, water with dissolved organic and mineral substances, human inputs and decomposition.
- **Solid:** It's divided in two categories:
 - **Organic:** Living organisms, undecomposed remains, decomposed matter and stable humus.
 - **Mineral:** Resulting from the disintegration of the parent rock, it includes: gravel, sand, silt and clay.

As well, the soil has a structure and texture classification. The structure is referred to how are organized the solid particles, that affect the circulation of water and air. The main types are¹³⁶:

- **Granular:** Weakly bound gravelly particles.
- **Crumbly:** Aggregated into small clumps.
- **Continuous:** Particles embedded in a clay or silt matrix.

The texture is referred to the grain composition and how it influences the earth properties. The main texture types are:

- **Organic soils:** e.g., peat.
- **Gravelly soils:** Gravel and stones.
- **Sandy soils:** Mainly sand.
- **Silty soils:** Fine, smooth, low cohesion.
- **Clay soils:** High clay content, very cohesive and moldable when wet.

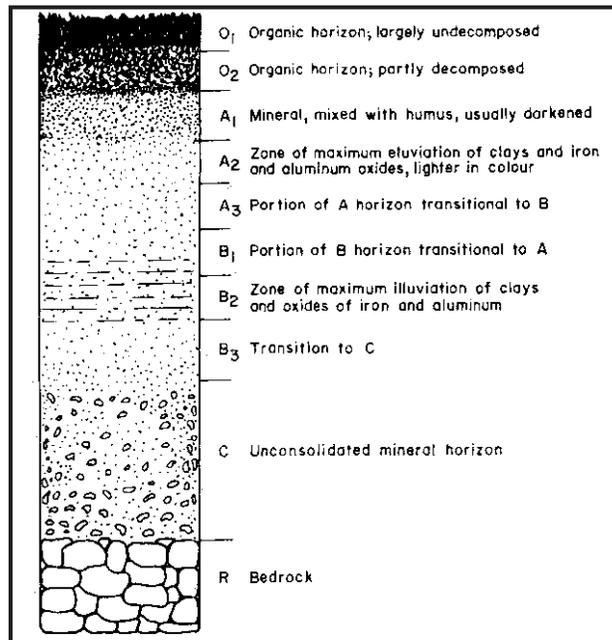
Usually, the earth plasters are made from local soils (clay with sand). Following many centuries of traditions, to improve their properties other elements like vegetable or animal fibers. The traditional plasters normally have variations, compared to the standardized. As it was shown, the soil changes everywhere so it is not possible to have an only and unique mix that can be used in all the locations. That is why is very necessary to make on site tests to know what mixture is suitable, also, it is always ideal to use the local resources and regional building traditions¹³⁷.

135 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 20.

136 Ibid. pp. 21.

137 Hamard, E., Morel, J., Salgado, F., Marcom, A., & Meunier, N. (2013). *A procedure to assess the suitability of plaster to protect vernacular earthen architecture*. *Journal of Cultural Heritage*, 14(2). pp. 109 - 115.

Image 45. Soil layers.



Source: <https://www.fao.org/4/x5546e/x5546e0g.gif>

3.1.2. Earth and Gypsum 10%.

It can be affirmed that gypsum plasters have been used since ancient times, especially in regions with natural gypsum deposits. Because of its composition, Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) acts as a binder, when it is heated, it loses most of its water and then reabsorbs water during setting, becoming harder. One of its properties is the low solubility in water, making a very usual application indoors, especially in rooms with stable humidity. In the construction nowadays, is used on concrete and masonry walls for its economic price and workability and its fire resistance (due to its water content)¹³⁸.

In order to increase its performance, the gypsum must have specific conditions. To avoid the weakening of the plaster with the salt efflorescence, the substrate must be completely dry. Is recommended that in historic buildings, a horizontal damp-proof course has to be applied.

Despite its advantages, gypsum has limitations. Its low elasticity (E-modulus¹³⁹) makes it unsuitable for internal insulation. Its application over damp cement-based materials can lead to expansion from sulfate formation, restricting its use in certain situations.

138 Dettmering, T. (2022). *Historical plasters in connection with thermal insulations*. In *Energy-Efficient Retrofit of Buildings by Interior Insulation*. pp. 58.

139 The E-modulus (elastic modulus or Young's modulus) is a mechanical property of materials, measured in Gigapascals (GPa).

Image 46. Gypsum.

Source: <https://jbplaster.in/gypsum-powder/>

Also, due to its properties gypsum is particularly compatible with earthen walls. Specially for its breathability, elasticity and vapor permeability. It is a bio and eco-friendly material because it is non-toxic and recyclable¹⁴⁰. Some others can be:

- Low energy consumption during production, making it suitable even in low-resource contexts.
- Easy availability.
- Chemical compatibility with natural additives.
- During setting, its volume increases by about 1%, which counteracts the shrinkage of clay minerals in earth walls, reducing the formation of cracks.

3.1.3. Earth and Lime 10%.

The use of lime to stabilize earth structures is an ancient practice and is considered a non-synthetic, though artificial, technique. The limes have variations in composition: hydrated lime doesn't contain enough calcium hydroxide than freshly slaked lime putty, absorbing CO₂ from the air. The hydraulic limes also contain minerals such as magnesium, aluminum and silicon oxides, which can form crystalline mixtures besides calcium carbonate, the main mechanism of crystallization and solidification in lime putty. When mixed with water and sand, the lime gets hard mainly through carbonation, which is a slow process where calcium hydroxide reacts with

¹⁴⁰ El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master's thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 17.

atmospheric CO₂ forming interlocking crystals of calcium carbonate. In soils with high quantity of clay, some reactions take place on the clay particle surfaces, where calcium ions lodge in the extensive surface areas provided by the plate-like mineral structures¹⁴¹.

Since centuries ago, the lime plaster was very used to protect buildings until the starting of the 20th century. Because of the growth of the cement industry around the middle of 19th century, the plasters with low lime content became common. The hydraulic lime was usual in the early plasters, it was applied in multiple layers, additives were highly used such as: pozzolans, brick dust or organic materials like animal proteins to improve its durability¹⁴².

The production of lime is based on raw materials, it begins by heating calcium carbonate (CaCO₃) to produce calcium oxide (CaO), which is then mixed with water to form calcium hydroxide (Ca(OH)₂). The resulting material can be two: a dry powder or a plastic lime putty. Around the late 18th century, the development of hydraulic limes and early cements (from clay-rich limestone) allowed materials to get hard even in contact with water. The traditional lime plasters, in contrast, still hold their natural absorbent and breathable property. In historic buildings, thick masonry walls could absorb rainwater and allow it to evaporate. Nowadays, the higher moisture levels and pollution are often requiring protective coatings that will keep vapor-permeable to prevent the water accumulation causing frost damage and other deterioration¹⁴³.

Image 47. Lime.



Source: <https://darwinslabs.com/wp-content/uploads/2024/02/10.jpg>

141 Warren, J. (1999). *Conservation of earth structures*. Butterworth-Heinemann. pp. 114.

142 Dettmering, T. (2022). *Historical plasters in connection with thermal insulations*. In *Energy-Efficient Retrofit of Buildings by Interior Insulation*. pp. 4.

143 Ibid. pp. 5 - 6.

The slaking process can produce¹⁴⁴:

- Hydrated lime
- Lime putty or “fat lime” (excess water, resulting in a plastic paste)
- Lime milk (high water content, forming a suspension of hydroxide in water)

It can be seen that lime acts as a chemical stabilizer, it improves the strength, stiffness, plasticity and workability of earth. Normally, the reactions in lime-earth plasters involve some mechanisms¹⁴⁵:

- An initial bonding of clay particles is created because of a cation exchange on clay mineral surfaces.
- There are pozzolanic reactions originated, which the calcium ions react with silica and alumina in clay to form hydrated silicate compounds. This is similar to Portland cement hydration. These reactions depend on the temperature and may continue for long periods gradually increasing the strength.
- Lime reacts with CO₂ creating carbonation, the natural one leads to a hardening. The excessive one can avoid the pozzolanic reactions, reducing the material strength.

Overall, the formation of cementitious mixtures (mainly hydrated silicates) is the main source of strength improvement in lime-stabilized soils.

3.1.4. Earth and Corncob.

The corncobs are a residue of the corn plant and its processing industry. Especially in Portugal, they usually were mixed with earth in the building technique known as “tabique”. This dynamic is noticed as the reuse of agricultural waste instead of an attempt to improve thermal insulation. Although some studies have observed the thermal conductivity of corncobs, the values reported are in general too high for them to be classified as an efficient insulating material. However, the corn is still one of the world’s most extensively cultivated crops, especially in the Americas and Asia, ensuring the widespread availability of this product¹⁴⁶.

144 El Ghazzali, N. (2015). *Architettura in terra cruda in Marocco. Sperimentazione di intonaci per la protezione dei paramenti murari*, Master’s thesis, Faculty of Architecture, Politecnico di Torino, Italy. pp. 89.

145 Ibid. pp. 89.

146 Pinto, J., Sá, A. B., Pereira, S., Bentes, I., & Paiva, A. (2016). *Possible Applications of Corncob as a Raw Insulation Material. In Insulation Materials in Context of Sustainability* (pp. 25-43). InTech. pp. 6.

Image 48. Corncob.



Source: https://www.mdpi.com/buildings/buildings-14-00594/article_deploy/html/images/buildings-14-00594-g002-550.jpg

They are a natural, organic material with a heterogeneous composition and defined layers. It can be said that are composed by three (3) layers: a soft inner layer, a middle layer one (resembling the solid wood) and an irregular outer surface. The inner portion has a closed cellular structure that is an indicative of conventional insulation materials such as extruded polystyrene (XPS) and expanded polystyrene (EPS)¹⁴⁷.

The corncobs density average is 212.11 kg/m³. Compared to some other typical synthetic insulators, like XPS (25–40 kg/m³) or EPS (10–25 kg/m³) the value is high, but compared to cork is in the average (100–350 kg/m³). It can be said that is due to its natural origin (cork and corncob) and the industrial one (XPS and EPS)¹⁴⁸.

Also, the corncobs have a very high-water absorption, almost 327%, in contrast to the small absorption of XPS, EPS or expanded clay. Concerning the fire behavior, the expanded clay remained practically unaffected during testing, while corn cobs and cork went through a slow and progressive combustion, indicating a level of fire resistance. Not like the XPS and EPS, that were the most vulnerable showing poor performance under fire exposure¹⁴⁹.

3.1.5. Earth, Corncob and Gypsum 10%.

147 Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional sustainable building insulation materials. *Sustainable Materials and Technologies*, 4, 1-17. pp. 5.

148 Ibid. Pag. 6.

149 Ibid. Pag 7.

Following the main properties of each material, some mixtures were done in order to improve and take advantage of its properties. In this case, this plaster can have a sustainable advantage over the usually used, while also contributing to better thermal insulation, healthier indoor air quality and a reduced environmental footprint.

The earth acts as the main binder thanks to its clay content and naturally porous structure. It not only binds the mixture but also allows the plaster to regulate indoor humidity, creating more comfortable living environments. the gypsum is the stabilizer, and the addition of corncob was done to identify how a natural additive behaves.

3.1.6. Earth, Corncob and Lime 10%.

For this plaster, it was also looked that each component has different role. Earth, also is the primary binder holding the composition together, while regulating indoor humidity and contributing to thermal mass. Like the previous one, the addition of corncob was done to check how a natural addition behaves. Finally, the lime can provide durability and breathability. It is important the compatibility with historic building materials and offers antibacterial and antifungal qualities, making healthier indoor environments.

3.1.7. RH 400.

The RH 400 is obtained mixing clay with rice husk and siliceous aggregates. Has properties like low thermal conductivity, making it an effective thermal insulator and an acoustic one because of its density. Because of its high silica content, makes it resistant to decay, mold and insect infestation, ensuring a high durability especially from stagnant water. Its renewable nature makes it contributes to environmental sustainability by reusing some agricultural waste and reducing CO₂ emissions from production and transport.

It also has hygrothermal properties, like: regulation the internal humidity, preservation of the breathability of masonry and promotes thermoregulation. The clay in the mixture also neutralizes odors, while the combined components help reduce indoor CO₂ levels, improving both air quality and overall comfort¹⁵⁰.

3.1.8. Lime and Sand.

This plaster is one of the traditional ones, is made of slaked lime and sun-dried and sieved sand. It goes under a process (chemical) called carbonation, in which, the lime absorbs CO₂ from and transforms it in calcium carbonate. The carbonation also creates the crystallization of the calcium carbonate binding the mix in a solid and flexible material. In addition, during this process the plaster gets “enriched” by properties like: durability, elasticity and breathability.

¹⁵⁰ Retrieved in september 16th, 2025 from: <https://www.ricehouse.it/en/prodotto/foundation-plaster-based-on-rice-husk-and-natural-lime/clay-base-plaster/>

This is important for applications in historical buildings, also, in contrast the cement ones the lime plaster can accommodate minor structural movements without cracking¹⁵¹.

Like other plasters, this one has also environmental benefits, it allows the walls to “breathe” due to its high vapor permeability. This can help to moisture transfer, avoiding condensation making spaces healthier. Also, it can resist some biological growths like mold and algae. It is important to highlight that is reversible and can be reuse, making it sustainable¹⁵².

3.2. Experimental phase.

As it was said before, there were made eight (8) different plasters grouped in three (3) types of samples. The plasters applied on the adobe wall with the smallest dimensiones were intended for the Adhesion test. The samples done on the clay slab were used to carry out the Erosion and Absorption tests, the order testing was: Karsten tube, Shear, Geelong and Spray Erosion. The tests were made in the LASTIN laboratory, starting on June 12th and finishing on July 17th of 2025.

In order to accomplish the most accurate results, it was followed what it was stated on regulations like NZS 4298 and DIN 18947. Both regulations share the objetive of standardized the technical requirements and test methods for the usea of earth as a construction material. This ensure that earth materials, with or without mixes will reach the minimum standards for strength and durability required by building codes.

3.2.1. Erosion tests.

Following what is established on the NZS 4298:1998, the erosion tests are done in order to evaluate the durability and water resistance of earthen plasters. These tests are essential to identify what plasters have the best performance, in direct contact with water and other environmental factors. Also, the plasters that can be used in historic earthen buildings, ensuring the preservation and protection.

Mainly, the durability of the earth plasters can be analyzed through the water erosion tests. Specifically, the resistance to water can be studied by carrying out two (2) tests:

- Geelong Test: The erosion depth and moisture penetration can be assessed by the observation of the water dripping on an earthen plaster surface.
- Spray Erosion Test: The erosion can be determined by measuring the hole’s depth, this is created by pressurized water projected on an earthen surface from a fixed distance.

The data obtained is empirical evidence and quantifiable, allowing the selection of the long –

151 Elsevier. (n.d.). *Lime mortar*. In ScienceDirect Topics. Retrieved from <https://www.sciencedirect.com/topics/engineering/lime-mortar>. pp. 24 - 26.

152 Ibid. pp. 1 -5.

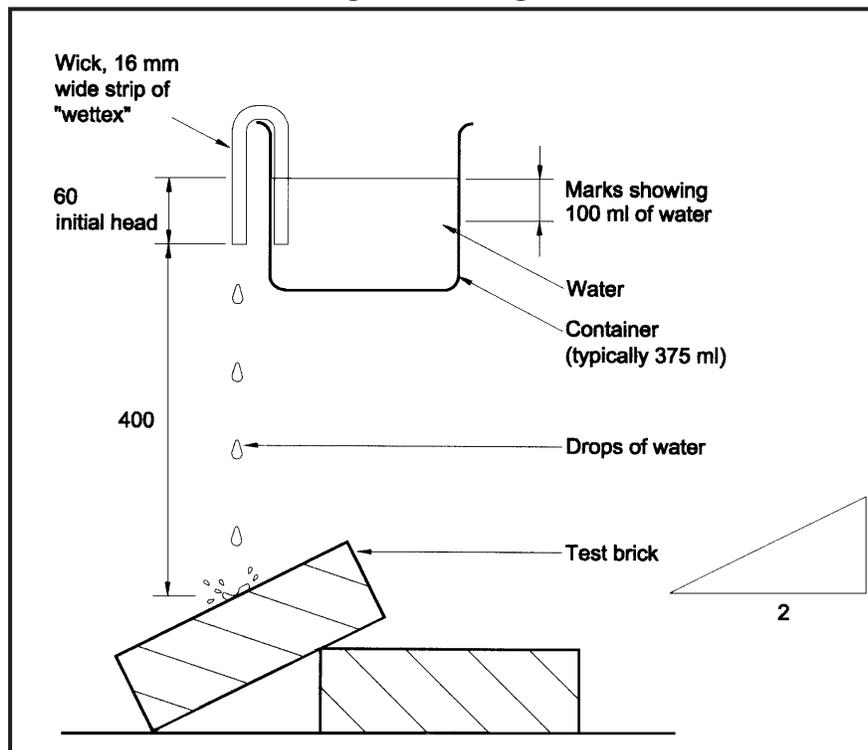
term durability earthen plasters.

3.2.1.1. Geelong test.

The Geelong Test is used to assess the erosion resistance and moisture penetration of porous earthen building materials. It was developed by Peter Yttrup and some students at Deakin University (Geelong, Victoria, Australia). The test involves the controlled dripping of water onto one sample's face, measuring the hole depth and moisture penetration to determine the material's erodibility and suitability for construction uses. This test can be done on rammed earth, poured earth, adobe, and pressed blocks¹⁵³.

The NZS 4298:1998 specifies that before the test, the earth plaster samples must be cured for at least 28 days and tested without surface coatings, in a location protected from wind and direct sunlight, generally using the weather-exposed side. During the test, 100 ml of water are dripped onto the sample surface from a height of 400 mm, completing the drip in a time frame of 20 to 60 minutes¹⁵⁴.

Image 49. Geelong test.



Source: NZS 4298:1998

153 Standards New Zealand. (1998). NZS 4298:1998 *Materials and workmanship for earth buildings*. Wellington, New Zealand: Standards New Zealand. pp. 58 - 59.

154 Ibid. pp. 58 - 59.

Image 50. Geelong test execution.



1. Measuring the 400 mm height.
2. Dripping strips.
3. Presence of holes.

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Finally, if the sample is thicker than 120 mm, it is fractured at the point of maximum erosion to inspect the fracture surface and assess the moisture penetration. The erosion index is determined by the NZS 4298:1998 as:

Table 8. Geelong test Erodibility index.

Property	Criteria	Erodibility index
Pit depth, D (mm)	$0 < D < 5$	2
	$5 \leq D < 10$	3
	$10 \leq D < 15$	4
	$D \geq 15$	5 (fail)
Depth of penetration (break sample immediately after completion of above tests) if sample thicker than 120mm.	< 120 mm	Pass
	≥ 120 mm (measured from face of brick)	Fail

Source: NZS 4298:1998

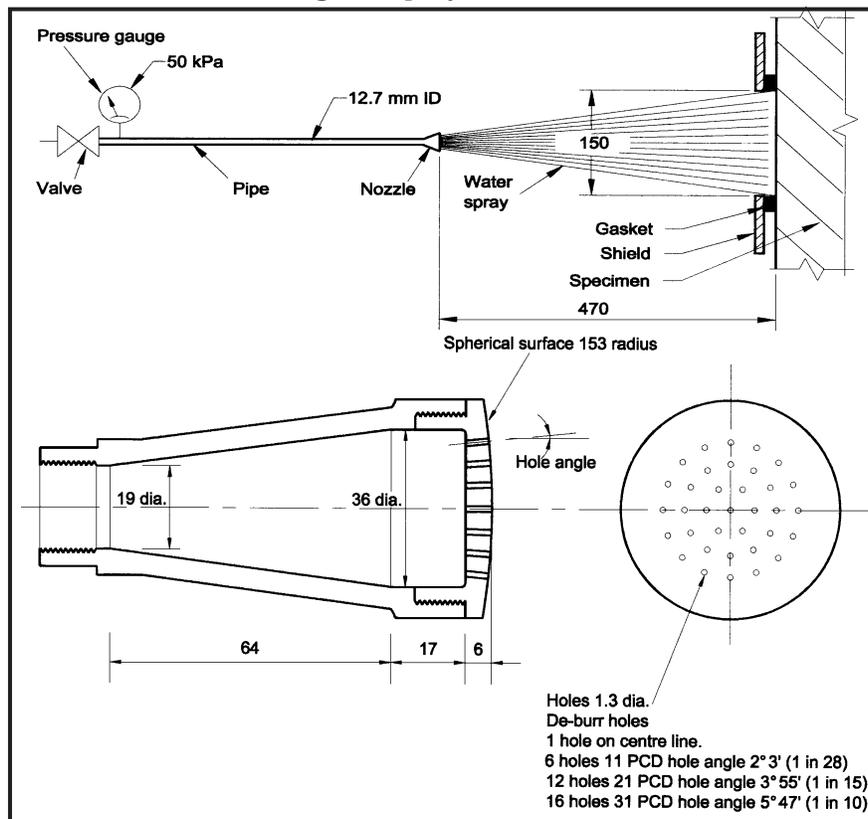
3.2.1.2. Spray Erosion test.

The Spray Erosion Test is designed to evaluate the resistance to erosion and moisture penetration

of earthen plasters. This empirical test, was developed by the National Building Technology Centre, now CSIRO (Commonwealth Scientific and Industrial Research Organisation – Australia), it determines the durability of plasters, their ability to resist the water damage and the suitability of each mixture for application on walls, contributing to the conservation and protection of structures. The test is performed according to New Zealand Standard NZS 4298:1998¹⁵⁵.

The test is also performed on 28 days cured previously prepared earth samples, with no surface coating. A jet of water, applied at a constant pressure of 0.5 bar, is projected onto a plaster's circular surface of 7.5 cm diameter from a distance of 470 mm. Every 15 minutes, the projection is interrupted to record the erosion depth reached, it is repeated for up to one hour or until the sample gets complete eroded¹⁵⁶.

Image 51. Spray Erosion test.



Source: NZS 4298:1998

155 Standards New Zealand. (1998). NZS 4298:1998 *Materials and workmanship for earth buildings*. Wellington, New Zealand: Standards New Zealand. pp. 56 – 57.

156 Ibid. pp. 56 – 57.

Image 52. Spray Erosion test execution.



1. Verification of water pressure and valve opening.
2. Water spraying.
3. Visual inspection for the presence of holes.

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

For each type of plaster, three (3) samples are tested. The average erosion value is calculated for each interval, allowing a comparative evaluation of the plasters' performance under the contact with water. The erosion index is determined by the NZS and is as follows:

Table 9. Spray Erosion test Erodibility index.

Property	Criteria	Erodibility index
Depth of erosion D (mm/hr)	$0 \leq D < 20$	1
	$20 \leq D < 50$	2
	$50 \leq D < 90$	3
	$90 \leq D < 120$	4
	$D \geq 120$	5 (fail)
Depth of penetration (break sample immediately after completion of above tests) if sample thicker than 120 mm.	< 120 mm	Pass
	≥ 120 mm	Fail

Source: NZS 4298:1998

3.2.2. Absorption test.

The absorption test is one of the most relevant in the study of the earthen plasters, this allows

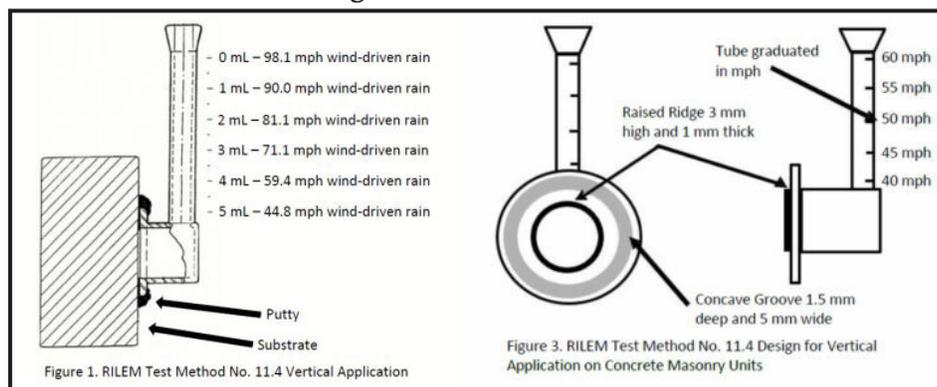
to determine the material's permeability. This capacity of absorbing water is completely linked to the material durability, the highest level of absorption the higher vulnerability to erosion, degradation to the wet and dry cycles and water penetration to the walls. Also, the water absorption must be understood, especially if they are used for facades where the exposition to rain and weathering is usual. Besides, the absorption test can be complemented and compared with the erosion tests (Geelong test and Spray Erosion test) to recognize the plaster's performance under contact with water. This can lead to a proper identification to the plaster's resistance and ideal use, to preserve and protect the earth buildings.

3.2.2.1. Karsten Tube test

The Karsten tube test is meant to evaluate the water absorption and penetration in porous building materials, such as mortars, concrete, stone or earthen plasters. This test measures the amount of water absorbed by the material, indicating its porosity, it simplifies the comparison between different types of plaster. Also, it helps to identify the moisture infiltration paths on affected walls by leaks, consequently contributing to the calculation of the plasters' durability and water resistance¹⁵⁷.

Usually to develop the test, it has to be selected, a clean and dry area of the plaster surface, to apply silicone around the rim of the tube ensuring a seal. When the tube is attached to the surface, it is filled with water to the last measurement guide avoiding the bubbles formation. The amount of absorbed water by each plaster's sample is recorded every minute for a 15-minute time frame, if the water is absorbed before that time it has to be documented. This procedure determines each sample's absorption capacity, as well as the analysis of the porosity and moisture resistance of the different plasters¹⁵⁸.

Image 51. Karsten Tube test.

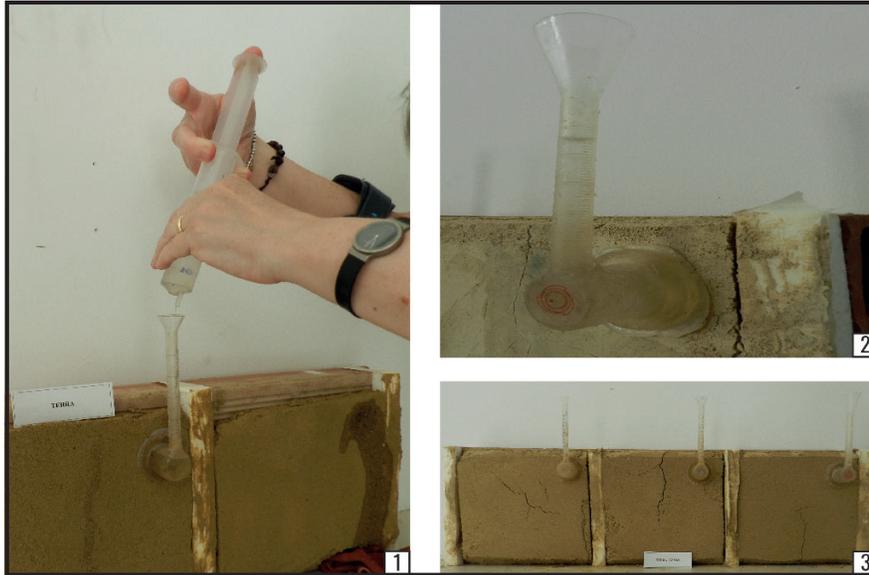


Source: <https://proso.com/measurement-of-water-absorption>

157 Stenholt-Jacobsen, R., Hansen, K. K., & Rörig-Dalgaard, I. (2023). *Karsten tube analysis for joint mortar identification in masonry*. Journal of Physics: Conference Series, 2654, Article 012044. pp. 3.

158 Ibid. pp. 3.

Image 52. Karsten Tube test execution.



1. Verification of silicone sealing and water filling.
2. Observation of water absorption.
3. Comparison of absorption among the samples.

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

3.2.3. Adhesion test.

The adhesion test is also part of the important earth plasters' studies, it helps to measure the bond strength between the plaster and the wall. An appropriate adhesion will assure that the plaster will be correctly attached over the course of time, preserving the structural stability and the coating protection. The non adherence of a plaster can evidence factors like: structural issues, thermal expansion and contraction, moisture fluctuations or/and mechanical problems. This is not only an aesthetic matter, it can increase the risk of erosion, weathering and deterioration of the wall. This can result in determining a suitable earth plaster to use in coatings.

3.2.3.1. Shear test

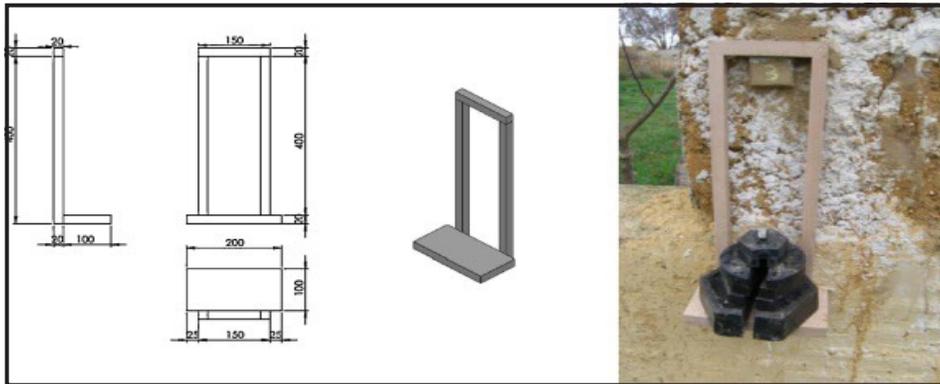
The Shear test is an on-site method designed to calculate the adhesion of earthen plasters to the supporting wall. This test ensures that the plaster maintains a sufficient bond to the substrate, allowing masons to validate formulations that provide adequate mechanical resistance for vernacular earthen architecture¹⁵⁹.

The standard of this test was established in France under the coordination of French network "écobâtir", setting that the test measures the load required to cause failure of the plaster. The test was performed starting by the preparation of the wall surface, it was scraped and dampened

¹⁵⁹ Hamard, E., Morel, J., Salgado, F., Marcom, A., & Meunier, N. (2013). A procedure to assess the suitability of plaster to protect vernacular earthen architecture. *Journal of Cultural Heritage*, 14(2). pp. 579 - 587.

recreating a real situation. Then, according to the number of samples per plaster prepared, it is applied a base coat. The samples dimensions are: 40 mm x 50 mm x 20 mm and they have to be let to dry completely. Then, a device composed by a container and a support is hanged on the top of each sample minimizing friction between the device and the wall. Finally, weights are placed until the plaster is detached from the wall. This load is weighted and recorded. This test provides a quantitative evaluation of the plaster's adhesion, allowing a comparison between different mixtures to determine which one has the best bonding performance¹⁶⁰.

Image 53. Shear test.



Source: <https://ars.els-cdn.com/content/image/1-s2.0-S1296207412000830-gr1.jpg>

Image 54. Shear test execution.



1. VPositioning of the support device and container.
2. Progressive weights placing.
3. Failure and detachment of the samples.

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

160 Hamard, E., Morel, J., Salgado, F., Marcom, A., & Meunier, N. (2013). A procedure to assess the suitability of plaster to protect vernacular earthen architecture. *Journal of Cultural Heritage*, 14(2). pp. 579 - 587.

3.3. Results.

Following the standards previously described, the results obtained include both qualitative observations and quantitative measurements, allowing a broad evaluation of the earthen plasters. Some comparative analyses among the tests results were done, in order to facilitate the identification of the plasters' performance patterns, the determination of the durability improving by the addition of additives, the water resistance and the formulation of recommendations of the plaster's suitability for the application on earthen constructions, resulting too on the contribution to the conservation and protection of these buildings.

The plasters were made on May 13th and 14th of 2025 in the Laboratory of Innovative Technological Systems (LASTIN) of the Department of Architecture and Design of the Politecnico di Torino. The tests were also carried out in the laboratory, they started on June 12th and ended on July 17th of 2025, following the drying and stabilization times specified on the standards.

3.3.1. Geelong test

The test was carried out on eight (8) types of plaster, there were made three (3) samples of each plaster on a clay slab. The resulting data were collected in eight (8) separate tables, one for each plaster, where the variables analyzed were: plaster type, sample number and erosion depth (measured in millimeters). To determine the erosion index, the hole's depth was measured by using a cylindrical probe of a 3.15 mm diameter. From these data, it was possible to evaluate whether each plaster met the test criteria. In order to assess the average performance of each plaster, it was calculated in the three (3) samples the erosion index. It helped to have a clear comparison among the plasters, by checking their erosion and moisture penetration performance

Table 10. Plaster A results.

Geelong Test	Earth (A)		
Sample	1	2	3
Result (mm)	12	10	14

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 11. Plaster B results.

Geelong Test	Earth + Gypsum 10% (B)		
Sample	1	2	3
Result (mm)	5	8	10

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 12. Plaster C results.

Geelong Test	Earth + Lime 10% (C)		
Sample	1	2	3
Result (mm)	0	0	0

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 13. Plaster D results.

Geelong Test	Earth + Corncob (D)		
Sample	1	2	3
Result (mm)	5	10	10

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 14. Plaster E results.

Geelong Test	Earth + Corncob + Gypsum 10% (E)		
Sample	1	2	3
Result (mm)	2	5	3

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 15. Plaster F results.

Geelong Test	Earth + Corncob + Lime 10% (F)		
Sample	1	2	3
Result (mm)	1	1	3

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 16. Plaster G results.

Geelong Test	RH 400 (G)		
Sample	1	2	3
Result (mm)	0	0	0

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 17. Plaster H results.

Geelong Test	Lime + Sand (H)		
Sample	1	2	3
Result (mm)	0	0	0

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

In first place, it was observed that the Earth plaster (A) showed the lowest resistance to erosion, with an average D of 12 mm and an erosion index of 4, confirming its high vulnerability to water. In contrast, the plasters: Earth + Lime 10% (C), RH 400 (G) and Lime + Sand (H) showed a superior performance, with average D values of 0 mm and an erosion index of 0.

The other plasters had a better performance than the Earth plaster (A), specifically those with mineral additives, such as plasters Earth + Corncob + Lime 10% (F) and Earth + Corncob + Gypsum

10% (E). These were closer to an erosion index of 0, showing an appropriate performance with average D values of 1.7 and 3.3, respectively. Plasters with natural fiber additives showed a slight improvement over the plaster Earth plaster (A), the Earth + Gypsum 10% (B) and Earth + Corncob (D) registered average D values of 7.8 and 8.3 mm, respectively, with an erosion index of 3.

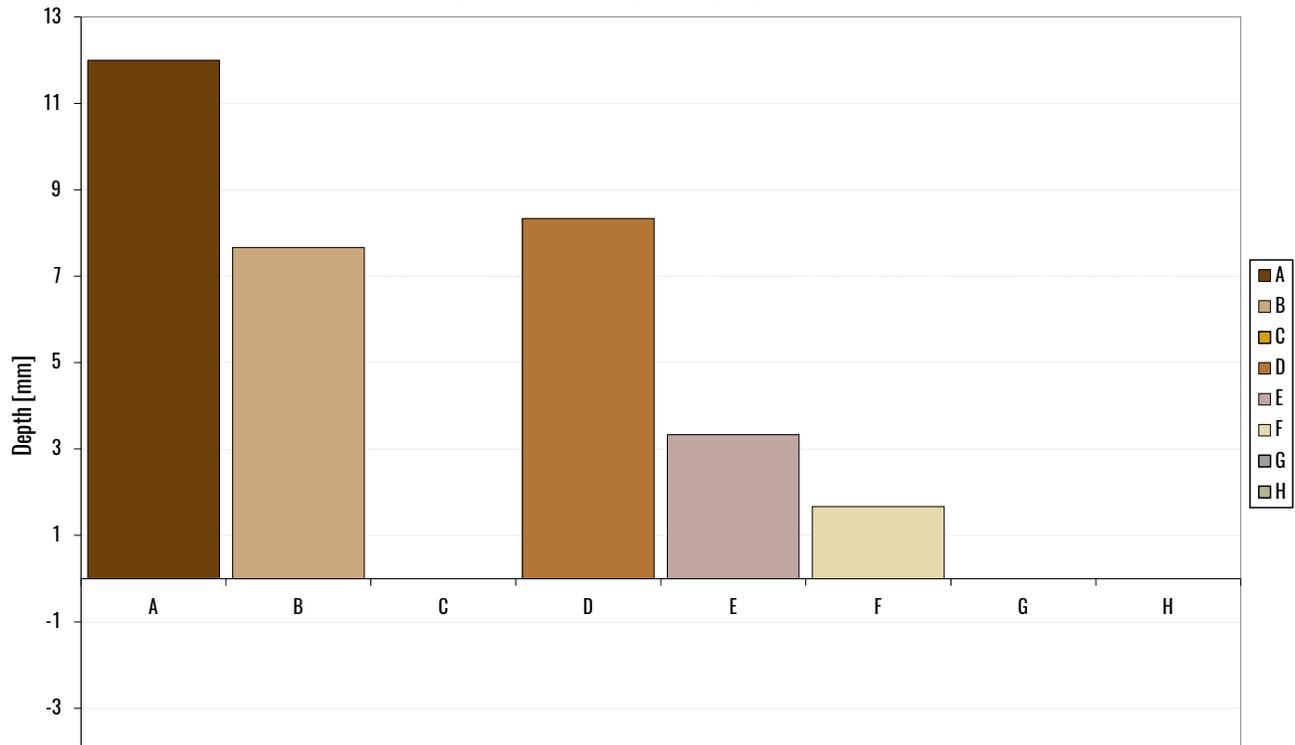
Table 18. Geelong test average values.

Plaster	Composition	Average Hole depth (mm) D	Erosion index	Pass	Fail
A	Earth	12	4	X	
B	Earth + gypsum 10%	7.8	3	X	
C	Earth + lime 10%	0	0	X	
D	Earth + corncob	8.3	3	X	
E	Earth + corncob + gypsum 10%	3.3	2	X	
F	Earth + corncob + lime 10%	1.7	2	X	
G	RH 400	0	0	X	
H	Lime + sand	0	0	X	

Source: Maria Alejandra Agudelo Briceño

According to the erosion index values, a graph was created to illustrate better the difference among the values, allowing a better comparison. This graphic shows that the bar corresponding to the Earth plaster (A) is the tallest, indicating the highest level of erosion. The bars for the plasters: Earth + Lime 10% (C), RH 400 (G) and Lime + Sand (H) are at zero, demonstrating an excellent performance in contact with water, with an erosion value of 0. The Earth + Gypsum 10% (B) and Earth + Corncob (D) plasters show relatively a low performance, while the Earth + Corncob + Gypsum 10% (E) and Earth + Corncob + Lime 10% (F) plasters show a good performance in contact with water.

Graphic 1. Geelong test graphic result.



Source: Manuela Mattone

Based on the erosion index of 4 for the Earth plaster (A), this test confirms that it is not suitable for its use on facades without a water-repellent treatment or the addition of additives. Besides, the addition of lime significantly improves performance, achieving values of 0 mm, as observed in the Earth + Lime 10% (C) and Lime + Sand (H) plasters. However, the plasters with additions of gypsum and corncob (B, D, E, F) showed a significant degree of erosion resistance, with average erosion indices of 2 and 3, confirming that these types of additives improve the material's durability, in some varying degrees.

Finally, and following the standard, it can be determined that none reached the maximum level of 5. This would have caused the plaster to be completely discarded due to its low, almost non-existent resistance to erosion.

Image 55. Geelong test plasters result.

Geelong test results			
			
Earth Average erosion: 12 mm	Earth + gypsum 10% Average erosion: 7.8 mm	Earth + lime 10% Average erosion: 0 mm	Earth + corncob Average erosion: 8.3 mm
			
Earth + corncob + gypsum 10% Average erosion: 3.3 mm	Earth + corncob + lime 10% Average erosion: 1.7 mm	RH 400 Average erosion: 0 mm	Lime + sand Average erosion: 0 mm

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

3.3.2. Spray Erosion test

This test was done on eight (8) types of plaster, considering three (3) samples of each type placed on a clay slab. The resulting data were collected in eight (8) separate tables, one for each plaster, where the variables analyzed were: type of plaster, sample number and time frame until the erosion started (measured in 15-minute intervals). To determine the erosion index, the hole's depth was also measured with the same cylindrical probe of a 3.15 mm diameter. From these data, it was possible to evaluate whether each plaster met the test criteria. Like the previous test, the average performance of each plaster was calculated in the three (3) samples the erosion index. Also, it helped to have a clear comparison among the plasters, by checking their erosion and moisture penetration performance.

Table 19. Plaster A results.

Spray Test	Earth (A)			
	15	30	45	60
Sample 1	08"			
Sample 2	07"			
Sample 3	15"			

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 20. Plaster B results.

Spray Test	Earth + Gypsum 10% (B)			
Time (minutes)	15	30	45	60
Sample 1	3' 48"			
Sample 2	4' 42"			
Sample 3	4' 27"			

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 21. Plaster C results.

Spray Test	Earth + Lime 10% (C)			
Time (minutes)	15	30	45	60
Sample 1	0 mm	0 mm	0 mm	0 mm
Sample 2	0 mm	0 mm	0 mm	0 mm
Sample 3	0 mm	0 mm	0 mm	0 mm

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 22. Plaster D results.

Spray Test	Earth + Corncob (D)			
Time (minutes)	15	30	45	60
Sample 1	3' 15"			
Sample 2	3' 37"			
Sample 3	3' 34"			

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 23. Plaster E results.

Spray Test	Earth + Corncob + Gypsum 10% (E)			
Time (minutes)	15	30	45	60
Sample 1	06"			
Sample 2	38"			
Sample 3	47"			

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 24. Plaster F results.

Spray Test	Earth + Corncob + Lime 10% (F)			
Time (minutes)	15	30	45	60
Sample 1	1' 31"			
Sample 2	2' 47"			
Sample 3	33"			

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 25. Plaster G results.

Spray Test	RH 400 (G)			
Time (minutes)	15	30	45	60
Sample 1	0 mm	0 mm	0 mm	0 mm
Sample 2	0 mm	0 mm	0 mm	0 mm
Sample 3	0 mm	0 mm	0 mm	0 mm

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 26. Plaster H results.

Spray Test	Lime + Sand (H)			
	15	30	45	60
Time (minutes)				
Sample 1	0 mm	0 mm	0 mm	0 mm
Sample 2	0 mm	0 mm	0 mm	0 mm
Sample 3	0 mm	0 mm	0 mm	0 mm

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

First, it was immediately noticeable that the Earth plaster (A) developed holes within 10 seconds, having also a low resistance to erosion with an erosion index of 5. Also, the Earth + Corncob + Gypsum 10% (E) plaster, got an erosion index of 5 and was eroded within 30 seconds. Contrasting this, the plasters: Earth + Lime 10% (C), RH 400 (G) and Lime + Sand (H) had an excellent performance having an erosion index of 0 after the 60-minute water exposure.

The same plasters with mineral and natural fibers additives trend of improving the performance compared to the Earth plaster (A), was seen on this test. Specially, the plaster Earth + Corncob + Lime 10% (F) got its erosion index of 5 in 1 minute and 37 seconds. The erosion time difference between the Earth + Gypsum 10% (B) and Earth + Corncob (D) plasters was almost 50 seconds, with 4 minutes and 19 seconds and 3 minutes and 29 seconds respectively. However, these plasters got complete eroded with an erosion index of 5.

Table 27. Spray Erosion test average values.

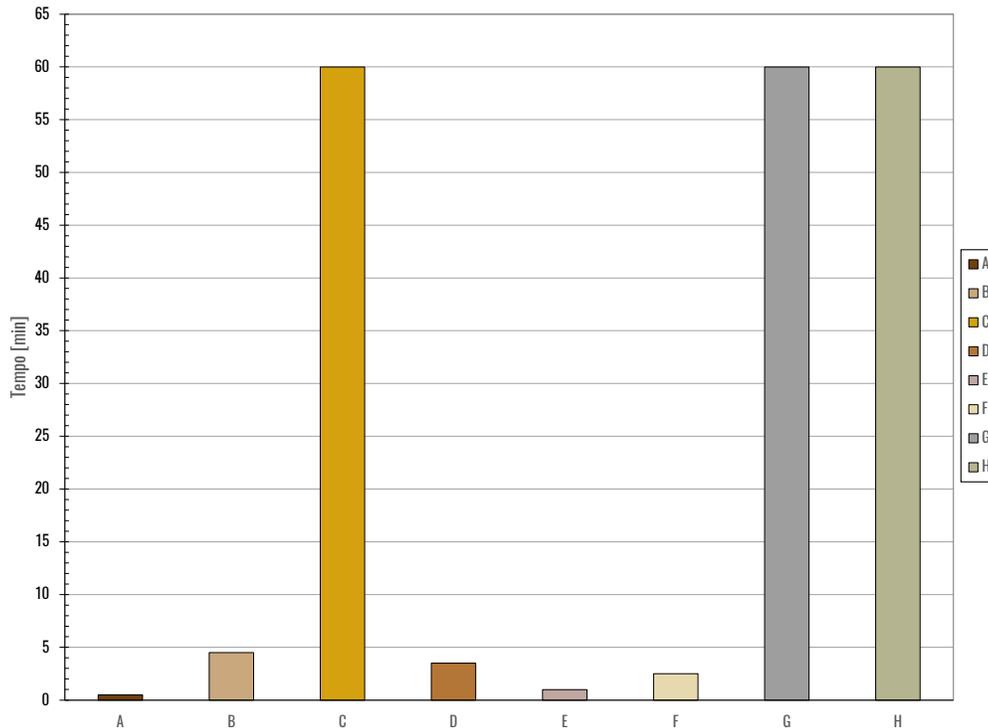
Plaster	Composition	Average Hole depth (mm / hr) D	Erosion index	Pass	Fail
A	Earth	20mm / 10"	5		X
B	Earth + gypsum 10%	20mm / 4' 19"	5		X
C	Earth + lime 10%	0	0	X	
D	Earth + corncob	20mm / 3' 29"	5		X
E	Earth + corncob + gypsum 10%	20mm / 30"	5		X
F	Earth + corncob + lime 10%	20mm / 1' 37"	5		X
G	RH 400	0	0	X	
H	Lime + sand	0	0	X	

Source: Maria Alejandra Agudelo Briceño

Based on the erosion depth vs the time frame, a bar graph was created to illustrate erosion trend of each plaster. This graphic can show the difference among the values, allowing a better comparison. The bars corresponding to the plasters: Earth plaster (A) and the Earth + Corncob + Gypsum 10% (E) show the shortest ones, indicating a very fast erosion, therefore, the lowest water resistance. In contrast, the plasters: Earth + Lime 10% (C), RH 400 (G) and Lime + Sand (H) show the highest resistance, with the tallest bars that demonstrate minimal or no erosion index

during the 60 minutes of water exposure. The plasters with additives: Earth + Gypsum 10% (B), Earth + Corncob (D) and Earth + Corncob + Lime 10% (F), indicated a moderate performance under water exposure, making them suitable for certain uses depending on the required level of exposure.

Graphic 2. Spray Erosion test graphic result.



Source: Manuela Mattone

Based on the two sharp erosion indexes level (0 and 5), it can be confirmed that the plasters: Earth plaster (A), Earth + Gypsum 10% (B), Earth + Corncob (D), Earth + Corncob + Gypsum 10% (E) and Earth + Corncob + Lime 10% (F) failed the test. It means that these plasters can be used in very dry climates and cannot be directly exposed to water. Contrasting the plasters: Earth + Lime 10% (C), RH 400 (G) and Lime + Sand (H), can be exposed to direct water due to its erosion index of 0.

Finally, and following the standard, it can be determined that due to the low erosion resistance the plasters (A, B, D, E, F) can be avoided in rainy zones. Contrasting, the plasters (C, G, H) having 0mm of erosion “passing the test”.

Image 56. Spray Erosion test plasters result.

Spray Erosion test results			
Earth Average erosion: 20mm / 10"	Earth + gypsum 10% Average erosion: 20mm / 4' 19"	Earth + lime 10% Average erosion: 0 mm / 15 min	Earth + corncob Average erosion: 20mm / 3' 29"
Earth + corncob + gypsum 10% Average erosion: 20mm / 30"	Earth + corncob + lime 10% Average erosion: 20mm / 1' 37"	RH 400 Average erosion: 0 mm / 15 min	Lime + sand Average erosion: 0 mm / 15 min

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

3.3.3. Karsten Tube test

The test was performed on eight (8) types of plaster, there were three (3) samples of each type placed on a clay slab. The resulting data were collected in eight (8) separate tables, one for each plaster, where the variables analyzed were: type of plaster, sample number and the test time, measured in intervals of 1 minute up to a maximum of 15 minutes. To obtain a performance measurement of each type of plaster, the average absorption of its three (3) samples was calculated using 40 ml test tubes. This procedure allows the observation and comparison of the performance difference of the plasters, by checking their erosion and moisture penetration performance.

Table 28. Plaster A results.

Karsten Tube	Earth (A)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time (minutes)															
Sample 1	2 ml	4.5 ml	6 ml	8.5 ml	10 ml	12 ml	13 ml	14.5 ml	15 ml	17 ml	18 ml	19 ml	20 ml	21 ml	22 ml
Sample 2	4 ml	6.5 ml	9 ml	11 ml	13 ml	15 ml	16 ml	18 ml	20 ml	21 ml	22 ml	23.5 ml	25 ml	26 ml	27 ml
Sample 3	5 ml	8 ml	11 ml	13 ml	15 ml	17 ml	19.5 ml	21 ml	22 ml	24 ml	26 ml - detached				

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 29. Plaster B results.

Karsten Tube	Earth + Gypsum 10% (B)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	3.5 ml	6.5 ml	10 ml	12.5 ml	15 ml	18 ml	20 ml	23 ml	25 ml	28 ml	30 ml	32 ml	34 ml	36 ml	38.5 ml
Sample 2	2.5 ml	6 ml	9 ml	15 ml	18.5 ml	20 ml	23 ml	25.5 ml	27 ml	30 ml	32 ml	34 ml	36 ml	38.5 ml	40 ml
Sample 3	2.5 ml	5 ml	6.5 ml	8 ml	10 ml	12 ml	13.5 ml	15 ml	18 ml	20 ml	21.5 ml	22.5 ml	25 ml	26 ml	27 ml

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 30. Plaster C results.

Karsten Tube	Earth + Lime 10% (C)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	4 ml	6 ml	8.5 ml	10.5 ml	13 ml	15 ml	17 ml	19 ml	21 ml	23 ml	25 ml	27 ml	29 ml	32 ml	34 ml
Sample 2	3 ml	6 ml	9 ml	11.5 ml	14 ml	16 ml	20 ml	23 ml	26 ml	29 ml	32 ml	35 ml	38 ml	40 ml - 14' 39"	
Sample 3	5 ml	8 ml	12 ml	15 ml	18 ml	21 ml	24 ml	27 ml	31 ml	34 ml	36 ml	39 ml	40 ml - 13' 15"		

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 31. Plaster D results.

Karsten Tube	Earth + Corncob (D)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	0 ml	0.5 ml	0.5 ml	0.5 ml	0.5 ml	1 ml	1 ml	1 ml	1 ml	1 ml	1 ml	1 ml	1 ml	1 ml	1.5 ml
Sample 2	7.5 ml	8 ml	8.5 ml	9 ml	10 ml	10 ml	10 ml	10.5 ml	11 ml	11 ml	11.5 ml	11.5 ml	12 ml	12 ml	12 ml
Sample 3	1 ml	1 ml	1.5 ml	1.5 ml	2 ml	2 ml	2 ml	2.5 ml	2.5 ml	2.5 ml	3 ml	3 ml	3 ml	3.5 ml	3.5 ml

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 32. Plaster E results.

Karsten Tube	Earth + Corncob + Gypsum 10% (E)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	1 ml	2 ml	2 ml	2 ml	2.5 ml	3 ml	3 ml	3.5 ml	3.5 ml	4 ml	4 ml	4.5 ml	5 ml	5 ml	5 ml
Sample 2	1 ml	2 ml	2.5 ml	3 ml	4 ml	4 ml	5 ml	5 ml	5.5 ml	6 ml	6 ml	7 ml	7 ml	7 ml	7.5 ml
Sample 3	1 ml	2.5 ml	4 ml	4.5 ml	5.5 ml	6 ml	6.5 ml	7 ml	7.5 ml	8 ml	9 ml	9.5 ml	10 ml	10.5 ml	11 ml

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 33. Plaster F results.

Karsten Tube	Earth + Corncob + Lime 10% (F)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	40 ml - 26"														
Sample 2	40 ml - 13"														
Sample 3	40 ml - 16"														

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 34. Plaster G results.

Karsten Tube	RH 400 (G)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	5 ml	6 ml	7 ml	8 ml	9 ml	21.5 ml	24 ml	27 ml	30 ml	32 ml	34 ml	36 ml	38 ml	40 ml - 13' 48"	
Sample 2	4.5 ml	9 ml	12.5 ml	16 ml	20 ml	22 ml	26 ml	29 ml	31.5 ml	34 ml	36.5 ml	39 ml	40 ml - 12' 30"		
Sample 3	7 ml	13 ml	19 ml	24 ml	30 ml	33 ml	36 ml	40 ml - 7' 55"							

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 35. Plaster H results.

Karsten Tube	Lime + Sand (H)														
Time (minutes)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample 1	12 ml	20 ml	27 ml	33 ml	40 ml										
Sample 2	9 ml	16 ml	22 ml	27 ml	32 ml	40 ml - 7' 32"									
Sample 3	9 ml	15 ml	20 ml	25 ml	30 ml	34 ml	38 ml	40 ml - 8' 39"							

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Initially, the Earth + Corncob (D) and Earth + Corncob + Gypsum 10% (E) plasters showed the best performance, having the lowest measuring 5.67 ml/15 min and 7.83 ml/15 min respectively, indicating high efficiency in water absorption. In contrast, the Earth + Corncob + Lime 10% (F) plaster showed the highest absorption rate, reaching its saturation point in a matter of seconds (18 seconds). A similar behavior was observed in the Lime + Sand (H) plaster, which absorbed the 40ml in 7 minutes and 4 seconds. The other plasters, such as Earth (A), Earth + Gypsum 10% (B), Earth + Lime 10% (C) and RH 400 (G), showed an intermediate performance with moderate absorption values reaching an average of 32ml in 13 minutes.

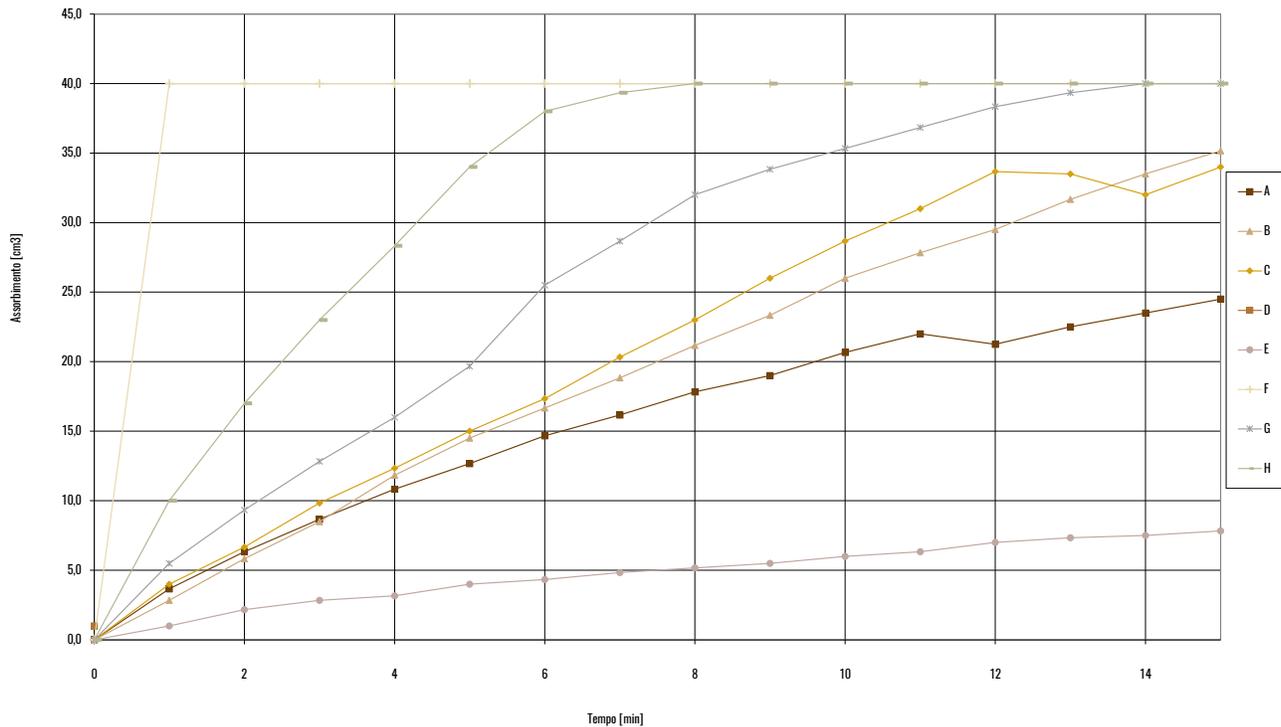
Table 36. Karsten Tube test average values.

Plaster	Composition	Average absorption (ml/min)	High	Low
A	Earth	25 ml/15 min	X	
B	Earth + gypsum 10%	35.17 ml/15 min	X	
C	Earth + lime 10%	38 ml/14' 17"	X	
D	Earth + corncob	5.67 ml/15 min		X
E	Earth + corncob + gypsum 10%	7.83 ml/15 min		X
F	Earth + corncob + lime 10%	40 ml/ 18 secs	X	
G	RH 400	40 ml/ 11' 24"	X	
H	Lime + sand	40 ml/ 7' 04"	X	

Source: Maria Alejandra Agudelo Briceño

Based on the absorption volume vs the time frame, a line graph was created to illustrate absorption trend of each plaster. This graphic shows that the line corresponding to the Earth + Corncob + Lime 10% (F) rises very quickly being the sharpest one, demonstrating its high absorption rate and rapid saturation. Contrasting this, the Earth + Corncob + Gypsum 10% (E) plaster bar shows the lowest slope, indicating the lowest water absorption during the test. The in-between lines, evidence the other plasters intermediate performance with moderate absorption measures.

Graphic 3. Karsten Tube test graphic result.



Source: Manuela Mattone

It was also seen that plasters with mineral additives, such as: Earth + Gypsum 10% (B) and Earth + Lime 10% (C), almost absorbed the 40ml in the 15-minute time frame. Contrasting the plaster Earth + Corncob (D) with natural additives, having the lowest absorption in the time frame set. In the case of the mixed additives ones (natural and mineral) the absorption values were completely diverse.

Finally and according to what is set in previous tests, it has to be understood that having the lowest absorption measurement is not equal to have the lowest performance. On the contrary, the highest absorption the lowest performance when it comes to the water resistance. It means, the plaster is not suitable for facades due to the lacking of rain protection. In this case, the plasters that “passed” the test were: Earth + Corncob (D) and Earth + Corncob + Gypsum 10% (E) showing a low average absorption.

Image 57. Karsten Tube test plasters result.

Karsten Tube test results			
			
Earth	Earth + gypsum 10%	Earth + lime 10%	Earth + corncob
Average absorption: 25ml / 15 min	Average absorption: 35.17 ml / 15 min	Average absorption: 38 ml / 14' 17"	Average absorption: 5.67 ml / 15 min
			
Earth + corncob + gypsum 10%	Earth + corncob + lime 10%	RH 400	Lime + sand
Average absorption: 7.83 ml / 15 min	Average absorption: 40 ml / 18 secs	Average absorption: 40 ml / 11' 24"	Average absorption: 40 ml / 7' 04"

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

3.3.4. Shear Test

This test measures the adhesion strength between plaster and the wall to which it is applied. It was performed on eight (8) types of plaster, considering three (3) samples of each type. The results were recorded in eight (8) tables, one for each plaster, considering the following variables: plaster type, sample number and maximum load supported in grams. This method allows for direct observation and comparison of performance differences between mixtures. To obtain an overview of the performance of each type of plaster, the average maximum load of its three samples was calculated.

Table 37. Plaster A results.

Shear Test	Earth (A)		
Sample	1	2	3
Result (gr)	7.726	11.352	10.410

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 38. Plaster B results.

Shear Test	Earth + Gypsum 10% (B)		
Sample	1	2	3
Result (gr)	8.894	5.752	5.404

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 39. Plaster C results.

Shear Test	Earth + Lime 10% (C)		
Sample	1	2	3
Result (gr)	2.902	6.918	3.934

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 40. Plaster D results.

Shear Test	Earth + Corncob (D)		
Sample	1	2	3
Result (gr)	4.388	3.426	4.040

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 41. Plaster E results.

Shear Test	Earth + Corncob + Gypsum 10% (E)		
Sample	1	2	3
Result (gr)	9.410	9.676	8.870

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 42. Plaster F results.

Shear Test	Earth + Corncob + Lime 10% (F)		
Sample	1	2	3
Result (gr)	1.712	2.362	1.544

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 43. Plaster G results.

Shear Test	RH 400 (G)		
Sample	1	2	3
Result (gr)	1.878	3.206	2.814

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

Table 44. Plaster H results.

Shear Test	Lime + Sand (H)		
Sample	1	2	3
Result (gr)	Detached	Detached	Detached

Source: Manuela Mattone - Maria Alejandra Agudelo Briceño

When the test was going to start, the Lime + Sand (H) plaster samples got detached. Initially the Earth plaster (A) had the highest adhesion measurement with 9.829 gr, also showing a high adhesion trend, the Earth + Corncob + Gypsum 10% (E) and the Earth + Gypsum 10% (B) with 9.319 gr and 6.683 gr respectively. The intermediate values were observed in the Earth + Lime 10% (C) and Earth + Corncob (D) plasters. The lowest ones were the Earth + Corncob + Lime 10% (F) and the RH 400 (G) with 1.873 gr and 2.632 respectively.

Specifically, the plasters with the mineral additive of gypsum 10% such as: Corncob + Gypsum 10% (E) and Earth + Gypsum 20% (B), had a high resistance compared to the lime 10% plasters: Earth + Lime 10% (C) and Earth + Corncob + Lime 10% (F) that had one of the lowest ones. In the case of the natural ones, was a observed a very diverse resistance value.

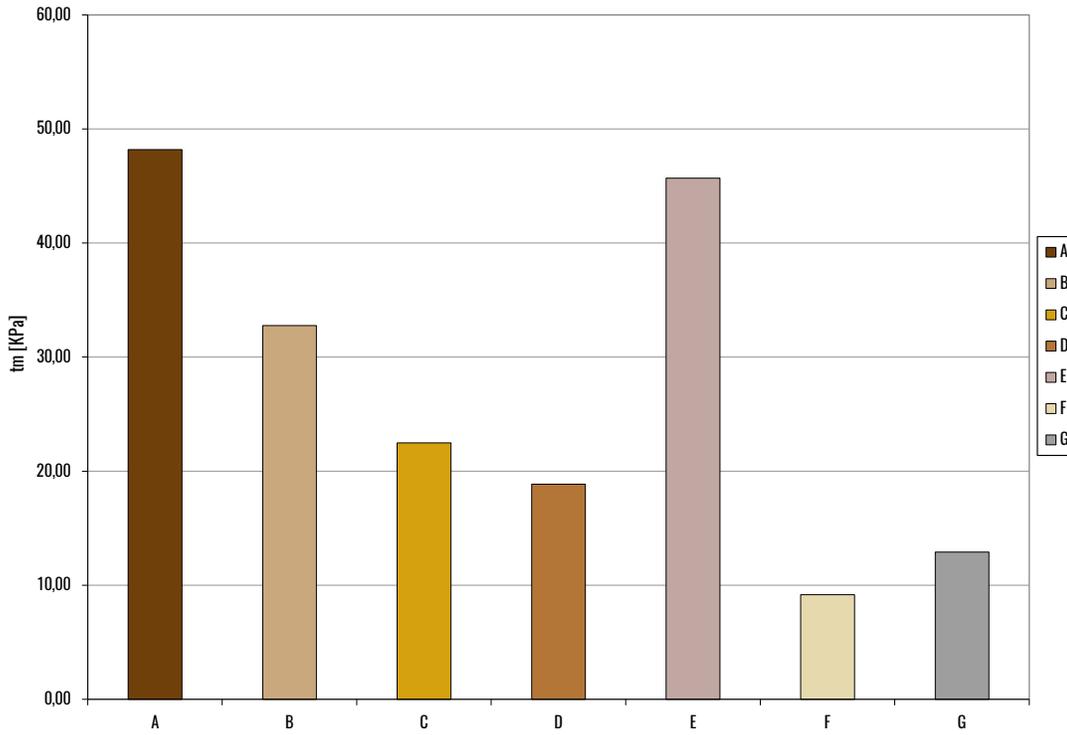
Table 45. Shear test average values.

Plaster	Composition	Average load (gr)	High	Moderate	Low
A	Earth	9.829	X		
B	Earth + gypsum 10%	6.683	X		
C	Earth + lime 10%	4.585		X	
D	Earth + corncob	3.951		X	
E	Earth + corncob + gypsum 10%	9.319	X		
F	Earth + corncob + lime 10%	1.873			X
G	RH 400	2.632			X
H	Lime + sand	Detached			X

Source: Maria Alejandra Agudelo Briceño

Based on the data recorded, the average shear stress (t , N/mm²) was calculated for each plaster, taking into account the failure load (mf , kg) and the surface area of the sample (S , mm²), according to the formula: $t=(mf \times g)/S$ “where “ $g=9.81$ ” m/s²”. The result was a bar chart where was showed the differences between the plasters measured in KPa. This graphic shows that the bar corresponding to the Earth plaster (A) is the tallest, followed by the Earth + Corncob + Gypsum 10% (E), indicating the highest resistance almost reaching 50 KPa. The bars for the plasters: Earth + Corncob (D), Earth + Corncob + Lime 10% (F) and RH 400 (G), are the shortest ones indicating a very low resistance with an average of 9 to 18 KPa. The Earth + Gypsum 10% (B) and Earth + Lime 10% (C) plasters had an intermediate resistance.

Graphic 4. Shear test graphic result.



Source: Manuela Mattone

Finally, it can be concluded that the average resistance is accomplished by the majority of plasters in with a minimum of 20 Kpa of pressure and stress. Also, can be determined that due to the low resistance the plasters (D, F, G) a frequent maintenance will be needed if they are used on earth buildings.

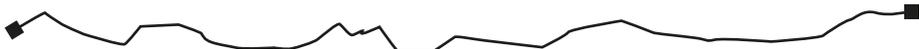
As a conclusion, a table comparing the plasters final performances in the laboratory tests was made, in order to allow a comparison among them. In this table is also possible to identify by colors how the parameters are categorized, the green one defines the passing or a good performance, the yellow a moderate and the red one the failing and bad performance.

Table 46. Plasters general performance.

Plaster 's performance					
Plaster	Composition	Geelong test	Spray Erosion test	Karsten Tube test	Shear test
A	Earth	Passed	Failed	Bad	Good
B	Earth + gypsum 20%	Passed	Failed	Bad	Good
C	Earth + lime 10%	Passed	Passed	Bad	Moderate
D	Earth + corncob	Passed	Failed	Good	Moderate
E	Earth + corncob + gypsum 20%	Passed	Failed	Good	Good
F	Earth + corncob + lime 10%	Passed	Failed	Bad	Bad
G	RH 400	Passed	Passed	Bad	Bad
H	Lime + sand	Passed	Passed	Bad	Bad

Source: Maria Alejandra Agudelo Briceño

III



Conclusions

The study that was conducted allowed the experimentation with eight (8) different types of earth-based plasters stabilized with lime and gypsum, which objective was evaluating their physical and mechanical performances. Through four (4) laboratory tests, was analyzed, the erosion and water resistance and adhesion capacity.

Regarding the Geelong test, the results obtained showed that the plasters didn't reach the "failing" index. However, the addition of lime showed good results, contrasting the, gypsum that show bad ones. The natural additive had a low performance, but, the mix between mineral and natural additives had a good one. The plaster with no additives almost fails the test, having the worst result. It was also noted that the environment where the test is carried out, must have a minimum humidity, because the dropping element can get dry affecting the result recording causing a delay.

The Spray Erosion test revealed significant differences between the plasters. The best performance was showed by the plasters with only lime as an additive and the industrial ones. Meanwhile, the plaster with no additives and natural additives had big limitations against the direct contact with water. It can be seen that the lime addition can improve the resistance to erosion.

When it comes to the absorption test, the Karsten tube indicated that the plaster made of earth with natural additives, had the best results indicating a high-water impermeability. With the addition of gypsum, it still has a good performance. The plasters with mineral additives and without any, had a high absorption value, just like the industrial ones that had the worst results. It evidenced that the use of corncob improves the performance against the capillarity, also, if gypsum is added. In contrast with the lime addition, that makes the plasters more absorbent.

Concerning the adhesion tests, the best results obtained with the Shear test indicates that earth without additives and plasters with gypsum (especially mixed with corncob) performed a good adhesion to the bricked wall. In comparison, the plasters with lime addition or with industrial binders showed less appropriate adhesion. This could be a risk during conservation interventions due to a big probability of detachment.

This joint results' analysis can confirm that there is not a plaster 100% capable of presenting the best performance in all the tests. Also, each type of additive provides a specific improvement, like: lime increases the resistance to erosion, gypsum boosts the adhesion and cohesion and the corncob stimulates the water absorption. That is why, the most suitable plaster has to be selected based on what pathology needs to be mitigated, checking the environmental conditions of the site too.

However, the plasters that mix earth with mineral traditional additives (lime and gypsum) and



natural ones (corncob), are seen to have a suitable balance between protection, compatibility, and reversibility. Respectively, the plaster with lime addition and the plaster with mixture of gypsum and corncob, demonstrated a “good balanced” performance in terms of resistance, absorption and adhesion.

Despite the incorporation of corncob in the plasters to improve the thermal performance, no experimental tests of this type were carried out in this project..

Finally, these laboratory results contribute to a scientific basis for guiding conservation interventions. Even though, there has to be further investigations and tests to identify a suitable plaster, also, they need to be validated through in situ applications, where factors such as climate, exposure and maintenance can influence the real performance.

INW



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V



Appendices

APPENDIX D EROSION TEST (PRESSURE SPRAY METHOD)

(Normative)

D1 GENERAL

The test consists of spraying the face of a prepared sample of the soil for a period of 1 hour or until the specimen is penetrated.

CD1

The test is an empirical one developed by the former National Building Technology Centre now CSIRO (Commonwealth Scientific and Industrial Research Organisation – Australia).

D2 PROCEDURE

D2.1

The components of the equipment are shown in figure D1.

D2.2

The specimen shall be cured a minimum of 28 days before testing.

The exposed section of the specimen is subjected to the standard spray for 1 hour or until the specimen is eroded through. The test is interrupted at 15-minute intervals and the depth of erosion recorded.

D3 RESULTS

The maximum depth of erosion of the deepest pit in one hour is measured in millimetres with a 10 mm diameter flat-ended rod. When the spray bores a hole right through the specimen in less than one hour the rate of erosion is obtained by dividing the thickness of the specimen by the time taken for full penetration to occur. The erodibility index shall be determined by reference to table D1 below.

Table D1 – Erodibility indices from pressure spray erosion test

Property	Criteria	Erodibility index
Depth of erosion D (mm/hr)	$0 \leq D < 20$	1
	$20 \leq D < 50$	2
	$50 \leq D < 90$	3
	$90 \leq D < 120$	4
	$D \leq 120$	5 (Fail)
Depth of penetration (break sample immediately after completion of above tests) if sample thicker than 120 mm	< 120	Pass
	≥ 120	Fail

D4 PENETRATION OF MOISTURE

After completion of the spray test, penetration of moisture is measured by breaking the specimen across the point where erosion is deepest and inspecting the break surface if the sample is more than 120 mm thick.

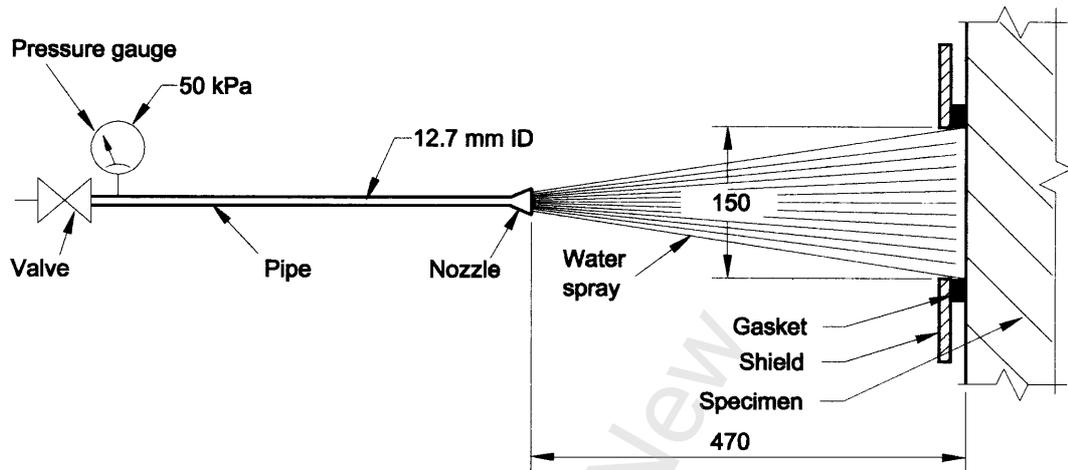


Figure D1 – Pressure spray test general arrangement

D5 CYCLIC WET/DRY APPRAISAL TEST

The cyclic wet and dry appraisal test as specified in Appendix C is required to eliminate reactive and dispersive soils.

D6 SURFACE COATINGS

The sample shall be tested without any surface coating. (See clauses L5.2, L5.3, L5.4 and L5.6).

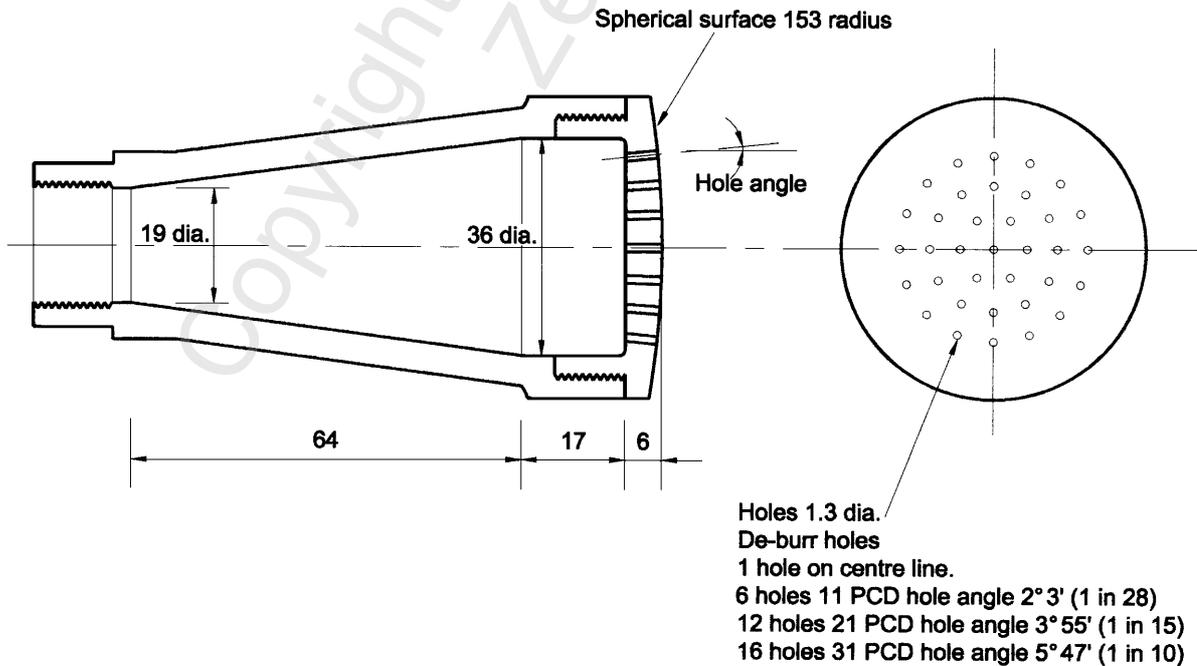


Figure D2 – Pressure spray test nozzle

APPENDIX E EROSION TEST (Geelong method) (Normative)

E1 GENERAL

E1.1

For rammed earth testing, “bricks” 300 mm square by 125 mm thick shall be made by ramming earth on edge in a mould with these internal dimensions.

E1.2

Poured earth samples can be made by casting “bricks” in a similar sized mould.

The person making the test shall determine which face to test. However, it is generally accepted that the “off-form” side of the face of the wall/sample facing toward the weather is to be tested.

E1.3

Samples may be cut from existing walls of any dimension and tested with the drip onto an uncut wall face.

E1.4

The specimen shall be cured a minimum of 28 days before testing.

E1.5

This test must be carried out in a location sheltered from wind and direct sun.

CE1

Other convenient mould or rammed earth “brick” sizes may be used if desired.

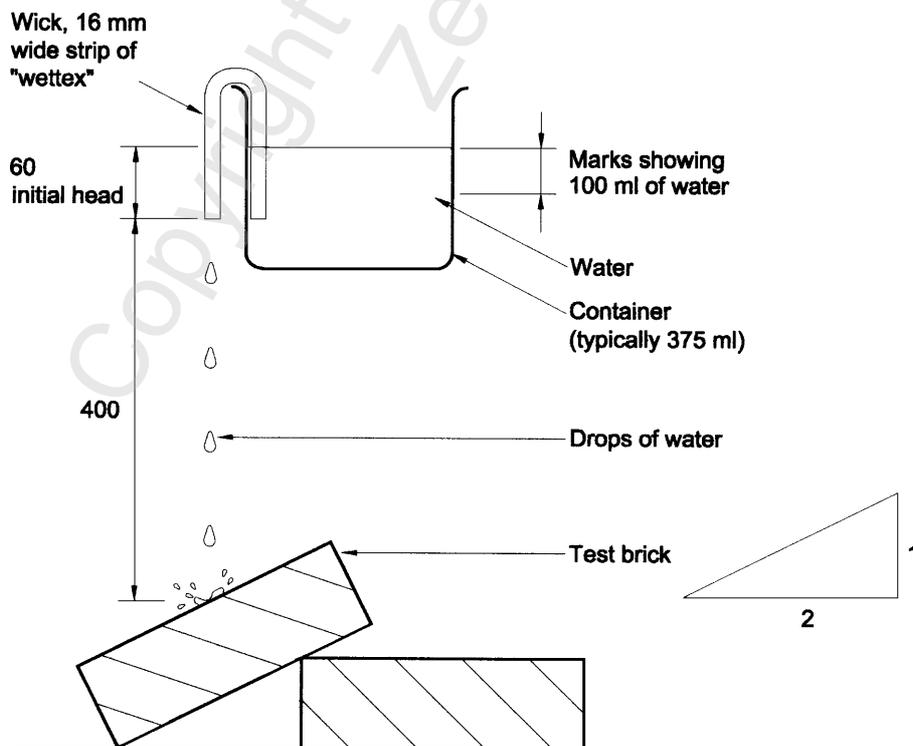


Figure E1 – Geelong method erosion test details

E2 SAMPLE BRICKS

For adobe or pressed bricks, randomly selected bricks shall be used.

E3 MEASUREMENT OF PIT DEPTH**E3.1**

The pit depth is to be measured with a cylindrical probe with an end diameter of 3.15 mm.

The method is as follows:

E3.2

Allow 100 ml of water to drop 400 mm on to sloped face of test brick.

E3.3

Time taken for 100 ml to drip from container to be 20 minutes minimum to 60 minutes maximum.

CE3

The pit depth probe may be made from a 3.15 mm diameter ungalvanized nail filed to a square end.

E4 CYCLIC WET/DRY APPRAISAL TEST

The cyclic wet/dry appraisal test as specified in Appendix C is required to eliminate reactive and dispersive soils.

E5 SURFACE COATINGS

The sample shall be tested without any surface coating. (See clauses L5.2, L5.3, L5.4 and L6).

E6 MOISTURE PENETRATION**E6.1**

Immediately after completion of the drip test, penetration of moisture is measured by breaking the specimen across the point where erosion is deepest and inspecting the break surface if the brick is thicker than 120 mm.

E6.2

Dry the sample after testing and check for the conditions noted in Appendix C3.4. The appearance of these conditions is grounds for rejection of the material.

E7 Results

The erodibility index shall be determined by reference to table E1 below. An erodibility index of 1 shall be determined only by use of the pressure spray erosion test given in Appendix D.

Table E1 – Erodibility indices from Geelong method erosion test

Property	Criteria	Erodibility index
Pit depth, D (mm)	$0 < D < 5$	2
	$5 \leq D < 10$	3
	$10 \leq D < 15$	4
	$D \geq 15$	5 (fail)
Depth of penetration (break sample immediately after completion of above tests) if sample thicker than 120 mm	< 120 mm	Pass
	≥ 120 mm (measured from face of brick)	Fail

CE8 Acknowledgement

This test was developed by Peter Yttrup and students at Deakin University, Geelong, Victoria, Australia.

► Legge regionale n. 2 del 16 gennaio 2006 (Versione vigente)

"Norme per la valorizzazione delle costruzioni in terra cruda".
(B.U. 19 gennaio 2006, n. 3)

Il Consiglio regionale ha approvato.

IL PRESIDENTE DELLA GIUNTA REGIONALE

promulga

la seguente legge:

Art. 1.

(Finalità)

1. La Regione Piemonte con la presente legge persegue la conservazione e la valorizzazione delle costruzioni in terra cruda attraverso la promozione della conoscenza del patrimonio esistente ed il sostegno finanziario di interventi di recupero volti ad assicurare le migliori condizioni di utilizzazione delle costruzioni stesse.

Art. 2.

(Censimento)

1. I comuni effettuano il censimento delle costruzioni in terra cruda esistenti e relative pertinenze entro sei mesi dall'entrata in vigore del regolamento di cui all'articolo 6 ed assicurano il costante monitoraggio dello stato del degrado delle costruzioni stesse.
2. La Giunta regionale definisce le procedure e le modalità del censimento con il regolamento di cui all'articolo 6 tenendo conto delle raccolte di dati già esistenti a livello comunale o provinciale ed in raccordo con gli eventuali censimenti operati a livello nazionale.
3. Il censimento costituisce riferimento per la redazione dei piani regolatori comunali e loro varianti in ordine ai beni culturali ambientali di cui all' articolo 24 della legge regionale 5 dicembre 1977, n. 56 (Tutela e uso del suolo), da ultimo modificato dall' articolo 26 della legge regionale 6 dicembre 1984, n. 61 .

Art. 3.

(Sostegno alle attività di censimento, ricerca e formazione)

1. La Regione promuove il censimento nonché lo sviluppo di progetti di ricerca e dell'attività di formazione sulle tecniche di edificazione e di recupero delle costruzioni in terra cruda ed assicura la divulgazione dei risultati delle iniziative attivate.
2. I progetti di ricerca sono attuati in collaborazione con le istituzioni universitarie e gli istituti di istruzione secondaria di secondo grado e sono sostenuti tramite l'assegnazione di borse di studio agli studenti secondo i criteri definiti dalla Giunta regionale con il regolamento di cui all'articolo 6.
3. L'attività di formazione è promossa attraverso la realizzazione di appositi corsi di aggiornamento tecnico-professionale nonché attraverso forme di sostegno e di collaborazione con soggetti pubblici e privati che, per specifica competenza, possano offrire contributi alla divulgazione della tecnica di edificazione e di recupero delle costruzioni in terra cruda.

Art. 4.

(Contributi per interventi di recupero)

1. Sono ammessi a finanziamento, ai sensi della presente legge, gli interventi di manutenzione straordinaria e di restauro e risanamento conservativo, come definiti ai sensi dell'articolo 3, comma 1, lettere b) e c) del decreto del Presidente della Repubblica 6 giugno 2001, n. 380 (Testo unico delle disposizioni legislative e regolamentari in materia edilizia), a condizione che il recupero avvenga con l'utilizzo di materiale in terra cruda e che la costruzione sia compresa nel censimento di cui all'articolo 2. Fino alla conclusione dell'attività di censimento di cui all'articolo 2 sono comunque ammessi a finanziamento gli interventi di recupero di costruzioni ritenute censibili.
2. La Regione concorre al finanziamento degli interventi di cui al comma 1 mediante contributi in conto capitale nella misura non superiore al 60 per cento della spesa ritenuta ammissibile e con un limite massimo di 12 mila euro per singolo intervento.
3. I lavori relativi agli interventi indicati al comma 1 devono iniziare entro novanta giorni dalla comunicazione di ammissione a finanziamento e concludersi entro tre anni da tale data. Sono esclusi dal finanziamento gli interventi i cui lavori risultino ultimati in data antecedente alla presentazione della domanda.
4. Il contributo è revocato ed è disposto il recupero delle somme erogate, maggiorate degli interessi legali vigenti a decorrere dal provvedimento regionale di erogazione, in caso di violazione delle disposizioni di cui ai commi 1 e 3.

Art. 5.

(Procedure per la concessione dei contributi)

1. Le domande di contributo relative agli interventi di cui all'articolo 4 sono presentate alla Regione entro il 30 settembre di ciascun anno utilizzando la modulistica predisposta dalla Regione.

2. Possono presentare domanda di contributo i proprietari o aventi titolo, pubblici o privati, delle costruzioni in terra cruda.
3. La Regione seleziona le domande da ammettere a contributo sulla base di criteri che tengano prioritariamente conto della proprietà pubblica o ecclesiastica del bene oggetto di intervento, della sua fruibilità pubblica, della rilevanza del manufatto rispetto al contesto paesaggistico.
4. Il contributo è erogato nella misura del 40 per cento al momento dell'inizio dei lavori ed il restante 60 per cento all'avvenuta ultimazione dei lavori.

Art. 6.

(Regolamento di attuazione)

1. La Giunta regionale, sentita la competente Commissione consiliare, adotta, entro novanta giorni dall'entrata in vigore della presente legge, il regolamento di attuazione.
2. Il regolamento definisce in particolare:
 - a) i criteri per il finanziamento del censimento nonché le procedure e le modalità di svolgimento attraverso la predisposizione di apposito applicativo informatico da mettere a disposizione dei comuni;
 - b) i criteri per l'assegnazione delle borse di studio di cui all'articolo 3, comma 2;
 - c) le modalità per la presentazione della domanda di contributo, la documentazione da allegare alla domanda e quella necessaria per l'erogazione in acconto o a saldo del contributo concesso;
 - d) gli adempimenti istruttori;
 - e) gli ulteriori criteri di priorità per la selezione delle domande in aggiunta ai criteri indicati all'articolo 5, comma 3, ed il valore ponderale da assegnare a ciascuno di essi;
 - f) le procedure per la concessione e l'erogazione dei contributi;
 - g) le procedure per la revoca del contributo ed il recupero delle somme erogate, nei casi previsti dall'articolo 4, comma 4.

Art. 7.

(Clausola valutativa)

1. La Giunta regionale rende conto al Consiglio regionale dell'attuazione della legge e dei risultati ottenuti in termini di conservazione e di valorizzazione delle costruzioni in terra cruda. A tal fine, ogni tre anni, la Giunta regionale presenta alla Commissione consiliare competente una relazione che contenga risposte documentate ai seguenti quesiti:
 - a) quali iniziative sono state promosse per diffondere la conoscenza dei benefici previsti dalla legge;
 - b) quali progetti di ricerca sono stati attuati e in che modo si è svolta l'attività di formazione di cui all'articolo 3;
 - c) quali sono state le criticità riscontrate nell'attuazione della legge, con particolare riferimento all'attività di censimento di cui all'articolo 2;
 - d) quali controlli sono stati effettuati al fine di verificare che i beneficiari abbiano effettivamente usato i contributi secondo le disposizioni di cui all'articolo 4;
 - e) quali sono le tipologie delle costruzioni che hanno usufruito dei benefici previsti dalla legge in riferimento ai criteri di priorità indicati all'articolo 5, comma 3, ed al regolamento di cui all'articolo 6;
 - f) in che misura i contributi concessi e la formazione erogata hanno determinato una valorizzazione della terra cruda.
2. La relazione di cui al comma 1 è resa pubblica unitamente agli eventuali documenti del Consiglio regionale che ne concludono l'esame.

Art. 8.

(Norma finanziaria)

1. Per l'attuazione della presente legge, è autorizzata per il biennio 2006-2007 la spesa complessiva di due milioni di euro per ciascun anno, ripartita rispettivamente in 1.500.000,00 euro per spesa di investimento e in 500.000,00 euro per spesa corrente.
2. Agli oneri relativi agli interventi di manutenzione straordinaria e di restauro e risanamento conservativo, stimati, in termini di competenza, in 1.500.000,00 euro per il biennio 2006-2007, imputati all'Unità previsionale di base (UPB) 19082 (Pianificazione gestione urbanistica Studi regolamenti Programmi attuativi Titolo II - Spese di investimento) del bilancio pluriennale per gli anni 2005-2007 si fa fronte con le dotazioni finanziarie dell'UPB 09012 (Bilanci e finanze Bilanci Titolo II - Spese di investimento) del bilancio pluriennale 2005-2007.
3. Agli oneri derivanti dal censimento, dalla realizzazione dei corsi di aggiornamento tecnico-professionale e dall'assegnazione di borse di studio agli studenti, quantificati, in termini di competenza, in 500.000,00 euro, per il biennio 2006-2007, e imputati all'UPB 19011 (Pianificazione Gestione urbanistica Pianificazione territoriale regionale Titolo I - Spese correnti) del bilancio pluriennale per gli anni 2005-2007 si fa fronte con gli stanziamenti dell'UPB 09011 (Bilanci e finanze Bilanci Titolo I - Spese correnti) del bilancio pluriennale 2005-2007.

La presente legge regionale sarà pubblicata nel Bollettino Ufficiale della Regione. È fatto obbligo a chiunque spetti di osservarla e di farla osservare come legge della Regione Piemonte.

Data a Torino, addì 16 gennaio 2006

p. Mercedes Bresso Il Vicepresidente Gianluca Susta