Clay and cereal fiber coating with waterproofing finishes for internal surfaces in the Mantaro valley.

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Abstract. The article aimed to develop a clay finishing system to reduce labor, material, and additive costs in mortar plastering, using renewable raw materials with low energy consumption for homes in the Mantaro Valley, Peru. Clay samples were taken from two locations in the central highlands of Peru, and a house built with earth in the district of San Pedro de Saño was studied. Wheat, barley, and quinoa fiber, along with sand, were used in the mortar to improve its compressive and flexural strength. The process was divided into layers, and additives were added to make the clay waterproof and prevent deterioration from moisture. White clay showed the best results in ease of application and adherence to the wall. Findings include the viability of using local clay soils to reduce costs in earth homes, the reduction of surface cracks through the use of natural fibers, and the improvement of insulation against targeted moisture with waterproofing agents, representing an enhancement in finishes for rural homes in the central Andes of Peru.

Keywords: Coating, Clay, waterproofing additives, Peru.

1 Introduction

The first works of humanity were developed from the earth, a raw material that is found in abundance and available in the development of all cultures throughout history [1], where the first appearances of construction date back to ten thousand years BC. based on evidence found in early cities and settlements in Mesopotamia, Crete, Egypt, the Middle East, and Southwest Asia [2]. Over time, earth construction evolved, and this article explores some projects that stand out in the application of clay coating. For instance, in the Asian continent, specifically in Tianjin, China, the Yu Qingcheng Gallery building experienced significant advancements in clay coating for its finishes, allowing for the manipulation of straight to curved sequences and an organic visualization that contributes to maintaining harmony with the surroundings by utilizing locally provided materials [3]. On the African continent, the country of Morocco in the city of Marrakesh, the Yves Saint Laurent Marrakech Museum was designed, which is composed of decorated cubic shapes that create a pattern that

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resembles threads, making the main component clay and its other derivatives, creating a luminosity effect and earth color effects in its exterior finishes where the building uses materials such as local stone, marble and decorations with clay bricks on the façade that together propose a sustainable building [4]. Continuing with Latin America, country Argentina, city of Córdoba, there is the multipurpose room called Pulmón de Iscot / Patio Estudio that has a sustainable relationship with the care of the environment, the design contemplates a space that allows occupants to interact with nature By having a garden that serves as a lung for the entire area, the curved morphology of the space allows establishing a connection with the clay and this in turn achieves a space where you can relax and feel like a natural environment, the pre-mass What they used was to extract the earth from the same place that was later recovered in the construction and other natural additives were added such as grass water, guano and linseed oil [5]. On a national level, it is essential to highlight the historical beginnings and the earliest earth-based constructions, such as the pre-Columbian citadel of Chan Chan, dating back to the 9th century A.D., belonging to the Chimú culture. Chan Chan stands out for its earth walls consisting of a wooden framework forming lintels and roofs covered with mud and straw. The site housed compartments for conventional activities and ritual sacrifices [6]. Currently there are buildings that show the presence of clay, as is the case in the city of Cuzco, in the district of Chinchero, mention is made of Lodge the mud house, which is a welcoming place for tourists due to its family style and its similarity of housing that transmits the typical Andean style and revives the local culture, the place is composed of rectangular blocks of molded earth that have been manufactured manually with coherent materials and that these do not alter the typology of the place and likewise its coating in a cream color tone that combines with the natural environment [7].

From observations on earth construction practices in the Mantaro Valley, specifically in the districts of Orcotuna, Jauja, Mito, Chongos Bajo, San Pedro de Saño, and Chongos Bajo, provide concrete evidence of construction methods used for rural dwellings, predominantly ancient earth-based structures that endure over time. Due to their significance in the environment, they serve as an example of sustainability, representing the area.[8] Based on these observations, the use of clay coating is proposed to preserve existing structures and contribute to techniques that enhance and value earth finishes, aligning with the Sustainable Development Goals (SDGs) of "Sustainable Cities and Communities." This goal focuses on ensuring inclusive, resilient, and sustainable cities and human settlements by using local materials, reducing costs, and possibly generating economic opportunities for communities.[9]

In this sense, the research proposal generalizes to clay coating, which is an ancestral material of wide diversification and application in multiple structural systems that are differentiated by execution procedures and construction configurations. The main construction systems on land in Peru are (adobe, tapia, quincha).[10] In which they do not have a finishing system in their coatings because the current trend in construction distances users from continuing to use natural materials for their coating.[11] The coating layer is configured using a mixture of paste or mortar, characterized by its plastic density, which is applied manually with tools such as trowels, among others. In order to achieve optimal consistency and ensure its adherence to the support, fibers are incorporated to reduce cracking. The proportions used in its application are highly diverse.[12]

In the scope of this research, discoveries are compiled and structured that focus on the treatment or element applied after the construction of the wall in order to improve its properties or intention to provide a visually attractive appearance and be compatible in a way that does not harm no other characteristics of the wall correlating with the nature of the material used. In order to create a completely natural and recyclable coating, the decision was to incorporate exclusively natural fibers derived from agricultural crops.[13]

The use of these fibers makes it possible to lighten the coating and improve thermal properties by applying a continuous coating on the outside. Furthermore, as mentioned above, these fibers absorb the stresses generated during the drying of the coating. [14] In the historical quest to control the absorption and release of moisture in soil coatings, ingredients such as animal or vegetable fats, calcium hydroxide, fibers, and extracts from certain plants have been used.[15] They are liquids and fats obtained by processing fats from mineral, vegetable or animal sources. These liquids are insoluble in water, have combustible properties, and generally have a density less than that of water.[16]

Finally, the incorporation of specific materials and substances, such as cactus and linseed oil, in different proportions during the clay finishing process is proposed, in order to improve its impermeability and physical-mechanical behavior compared to conventional coating. [17]

2 Literature Review

2.1. Previous studies

To continue with the analysis of the components used for earth and plant fiber coatings, we reviewed research that served as background to evaluate the different behaviors of the applied coatings.

Garcia, Milla, and others [13] conducted research on the dosing of barley and rice husk plant fibers that were processed to obtain different sizes of diameters, and dosages were applied according to the volume of the earth. The results were compared between the two types of fibers, barley and rice husk. The analysis shows that rice husk at 50% exhibits more shrinkage, while barley shows 30%. It is concluded that rice husk is more effective because it absorbs moisture more efficiently. Similarly, Gonzalo [14] analyzed the behavior of mud mortars using stabilizers such as straw, esparto, and sisal for coatings on earth. An experimental process was conducted to evaluate the three natural stabilizers: straw, esparto, and sisal. The results show that a fiber content of 3% maintains workability, while higher proportions hinder the homogeneous mixing of all components. López [18], refers to the analysis of the coating that serves to protect earth-based walls such as rammed earth, adobe or bahareque in Colombia. During the development, the behavior of the different components such as earth, stabilizer, additives, binders and water is studied. It is concluded that there are several factors that intervene in the behavior of the mortar, such as the properties of the earth used, additives, stabilizers and the thickness of the layer with which the building is covered. Guerrero [19] mentions that fibers act as stabilizers that help control dilation, expansion, and retraction during setting. Fibrous material can originate from plants, such as various grass straw, wood shavings, pine needles, coconut husks, corn stalks, pita, or sisal fibers. Finally, the recommendation is made that when using fibers, it is relevant to mix first with these substances and then with the fiber. Molina and Becerra [20] focused on analyzing different techniques and strategies for improving the mechanical properties of earth. Among these, they highlighted the use of stabilizers such as manure urine and blood. An investigation was conducted indicating that the percentage of cow manure with earth influences erosion behavior. Bolzano [21] focuses on deepening and systematizing existing information on the materials used, their physical and chemical properties, functions, uses, requirements, and specific usage guidelines. Constructive systems applied, preparation and implementation techniques, maintenance, and pathology are also described. It also describes related works in the form of recipe books or manuals. Similarly, Romero [22] aimed to identify an affordable natural additive to enhance the mechanical properties of earth. An interesting development of superplasticizers based on gallic acid from plant products is highlighted. The use of this plasticizer has a direct effect on minimizing the amount of water. Another advantage is that it allows for compression resistance and minimization of cracks. It also demonstrates a significant reduction in carbon emissions and generates an environmental impact.

3 Materials and Methods

3.1 Study Area

The research area is located in the Junín department, in central Peru, specifically in the Mantaro Valley, with a focus on San Pedro de Saño (latitude 11°99'77" and longitude 75°18'83") and Cochas Chico (longitude 75°15'26" and latitude 11°57'26"). These places are rich in culture and history, hosting a population engaged in agriculture, livestock, and pottery in a cold climate environment [8].

3.2 Materials and methods

In the research, local materials such as soil extracted from the site and plant fiber were chosen for clay coating finishes. Soil is a commonly used construction resource due to its abundance, availability, and the cost-effectiveness associated with the nearby presence of clay in the environment [6].

Clays are natural raw materials that extend across the Earth's surface and, at times, when mixed with water, can form plastic masses used to manufacture ceramic products, among others. These clayey materials exhibit different particle sizes, hence the terms clay fraction, fine fraction of soil, or sediment [23].

In the granulometric classification of soil particles, as shown in Table 1, clayey soil measures less than 0.0039, while loamy soil ranges from 0.0039 to 0.0625, demonstrating the differences in fineness between each soil type.

Table 1. Measurements of material particles.

Particle	Size
Clay	<0.0039 mm
Limos	0.0039-0.0625

The Unified Soil Classification System (USCS), widely used in engineering, establishes 4.75 mm for sand and 0.075 for clay and silt. Clay is primarily composed of hydrated aluminum phyllosilicates, with variations in the presence of iron, magnesium, alkali metals, alkaline earth metals, and other cations [24].

Vegetable fiber, specifically wheat fiber, has excelled compared to other materials in conventional earth construction methods since ancient times. It offers advantages such as wide availability, low costs, low density, and thermal and acoustic properties. Additionally, research has demonstrated its ability to compact, strengthen, and stabilize, as documented in previous studies [25]. Table 2 presents the selected materials for the coating application. Barley was chosen not only for its positive test results but also for its cost-effectiveness, being recycled and not incurring additional costs. Similarly, clay was selected due to its local availability. Detailed specifications of each material can be found within the table.

Table 2. Materials, technical specifications and figures.

Materials	Technical Specifications		Figures
Wheat fiber Wheat fiber is extracted from the husk of the cereal. This is insoluble in nature and has thermal and acoustic insulation properties. [8]	Condition: dried	Poly oligosaccharides :90%	 Fig. 1. wheat fiber.
	Thermal conductivity: 0.007 W/m.K	Base dry: 70%	
	Thermal insulator	Cost: recycling	
Sand Sand is made up of small fragments of loose rocks and has thermal and acoustic insulation properties for walls and ceilings.[4]	Condition: dried	Length: 60 to 100 cm high	 Fig. 2. Fine sand.
	Thermal conductivity: 0.53 a 0.04 W/m.K	Humidity: 14.2 %	
		Cost: Cubo 20 soles	
Clay Clay is decomposed rock that is made up of aluminum silicates that contain feldspar, y they present different colors when it is pure.[14]	Condition: soaked in water	Characteristic: retains up to 80 % internal heat	 Fig. 3. Clay.
	Location: Cajas	Humidity: 12 %	

To achieve waterproofing in adobe cladding, two types of waterproofers will be used, as detailed in Table 3: teak oil and exterior Bella Laja. For the final finish, carnauba wax will be applied to achieve a proper and effective seal in waterproofing.

Table 3. Additives, technical specifications, and Figures.

Additives	Technical specifications		Figures
Teak oil Protection for wood and interior and exterior walls.	Brand: Varathane	Endurance: Straight/Reverse	 Fig. 4. Teak oil
	Cost: S/ 104.00	Result: Shiny	
Carnauba wax It is a product that has the purpose of giving resistance and protection to an object.	Brand: Formula 1 Cost :S/49.50	Color: White Kind of product: wax	 Fig.5. Carnauba wax.

https://doi.org/10.1051/e3sconf/202454504003

Exterior Bella Laja Sealer with shiny finishes that protects and waterproofs the coating on rustic walls.	Brand: Chema Cost:S/ 154.00	Aspect: Liquid Color: colorless Subject: Ethanol, Ethyl Acetato	 Fig.6. Exterior Bella Laja

For this study, clays extracted from Cochas Chico and San Pedro de Saño were analyzed, resulting in six types. Rectangular specimens measuring 3.40 cm in width, 23.00 cm in length, and 3.00 cm in height were prepared to assess the consistency and hardness of the clay, aiming to determine suitable clays for coating. All tests were conducted with a constant volume of 234.60 cm3, evaluating shrinkage and the presence of fissures. The evaluation consisted of carrying out tests with the six types of clays without any fiber, only earth and water with a dosage of 70% and 30%, making this a workable mass and then introducing it into the mold and thus proceeding to leave it curing for a week, at the end of the week it was observed that there was a contraction in the samples. The measurement that was carried out was done manually using a measuring instrument (scalelimeter), subsequently an area subtraction operation was carried out to determine the contraction. The selection was based on tests and studies referenced in previous theses [26]. In Table 4, the results of the selected and non-selected clays are shown.

The selected clays: The pink clay had a shrinkage of 58.20, did not exhibit any cracks or fissures, and had a better finish upon drying. The brown clay had the lowest shrinkage of all, with 41.20, and showed a fissure of 0.1. The bronze clay had a shrinkage of 52.40 and did not exhibit any cracks or fissures. One of the best finishes was achieved by the white clay, which had a shrinkage of 52.20 and did not show any cracks or fissures.

Among the non-selected clays, the mustard-colored clay had the highest shrinkage of 61.40 and a deep crack of 0.5, similar to the yellow clay, which had a shrinkage of 61.10 and a deep crack of 0.4.

Table 4. Clay results.

Clay	Contraction	Fissures	Cracks	Depth
Rosewood	58.20	0	0	Intact
Mustard	61.40	0	0.5	Deep
Brown	42.20	0.1	0	Superficial
Bronze	52.40	0	0	Intact
Yellow	61.10	0.1	0.4	Deep
White	52.20	0	0	Intact

In Figure 7, a bar graph compares clays based on their lesser shrinkage, aiming to determine which ones will be used in subsequent tests and which ones were discarded, such as the yellow clay and mustard.

Figure 8 presents the final results of the initial test, helping to select which clay to use based on its best finish, such as pink, bronze, brown, and white.

Fig. 7. Clay results weightings.

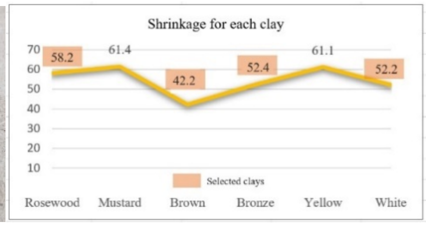


Fig.8. Clay test.

After analyzing the samples, the following clays were selected: rosewood, bronze, brown and white. They are the ones that had the least shrinkage, cracks and fissures, after combining them with wheat and barley fibers. After preparing the mixture, it is poured into the corresponding molds, where it is allowed to rest for a period of four days to ensure adequate and complete drying. Table 5 shows the results obtained by mixing the barley and wheat fibers with the clay. The rosewood clay had a contraction of 66.90 when combined with the barley and presented cracks of 0.1 cm,however, when combined with the wheat fiber, wheat had a contraction of 61.26 and 0 cracks, in the Brown clay a contraction of 42.59 and 0 cracks was obtained with the barley fiber, later when mixing it with the wheat fiber a contraction of 59.05 and 0 cracks was observed. On the other hand The bronze clay had no shrinkage when combined with the Barley fiber and no cracks, but when combined with the wheat fiber the shrinkage was 56.40 and 0 cracks.On the other hand The bronze clay had no shrinkage when combined with the barley fiber and no cracks, but when combined with the wheat fiber the shrinkage was 56.40 and 0 cracks. With respect to the white clay, a shrinkage of 58.34 and 0 cracks was obtained when combined with barley fiber, meanwhile when combined with wheat fiber, a contraction of 52.97 and 0 cracks was observed; compared to these results shown in the table, it was decided to use wheat fiber because it presented a better aesthetic and favorable finish have less shrinkage and absence of cracks. For this analysis, the same measuring instrument was used. This evaluation allowed us to choose the best fiber for the coating.

Table 5. Results of clays with plant fibers.

	Barley		Wheat	
Clays	Contraction (V)	Cracks	Contraction (V)	Cracks
Rosewood	66.90	0.1	61.26	0
Brown	42.59	0	59.05	0
Bronze	0	0	56.40	0
White	58.34	0	52.97	0

In Fig. 9 shows the results of the tests carried out with wheat fiber, which did not present cracks and had the least contraction. The coating process with the different clays and wheat fiber consists of four layers (See table N°6). In Fig. 10 shows the graph where it is seen that the mixture of clay with barley fiber had better results, however it was not chosen for its aesthetics in its finishing and subsequent drying.

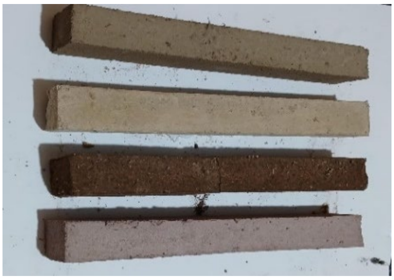


Fig. 9. Weighting results for clay and plant fibers.

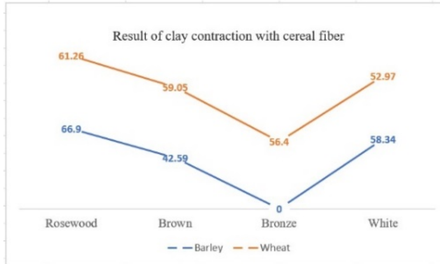
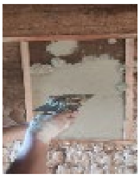
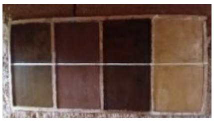


Fig. 10. Clays tests.

Graph 2 shows the results of the tests carried out with wheat fiber, which did not present cracks and had the least contraction. The coating process with the different clays and wheat fiber consists of four layers (See table N°6).

Table 6. How to apply the coating layers.

Layers	Materials	Dosage	Application Form	Figures
1°Coating Layer/ leveling	Clay Water Cow dung Sand Chicken wire	10 Kg. 4 L. 3.30 Kg. 4 L. 4 M.	To begin the coating process, a mesh was placed to reinforce and provide stability to the coating, then the mud mixture (clay, sand, cow dung and water) was applied homogeneously to the wall. After three days of drying the first layer, a wooden frame was placed to delimit the work area. The purpose of this first layer was to level out any malformations that the wall may have.	 Fig. 11 first layer.
2° Touch up layer	Clay Sand Wheat fiber Water	3.53 Kg. 4.26 Kg. 940 G. 1.5 L.	After three days of drying of the first leveling layer, the base layer was moistened so that it could adhere, then the next layer was applied, already combined with the following materials: clay, sand, wheat fiber and water. The mixtures are applied in each corresponding box.	 Fig. 12 application of the different mixtures.
3° Finishing layer with fine clay	Fine clay Water	700 G. 200 Ml.	The application of the last layer began by wetting the previous coating so that they have better adhesion. The last layer was coated with the fine clay that was previously strained with a fine cloth to obtain a mass without impurities. It is applied evenly throughout the work panel.	 Fig. 13 layer with fine clay.
4° Waterproof layer with additives	Teak oil Abroad Bella Laja Carnauba wax	3Free hands 3Free hands 2Free hands	The application of the additives was done gradually: first, the panels were divided into two equal parts for the application of the different additives. On the lower half the Bella Laja Exterior additive was applied (3 free hands), and on the other upper	

			half the teak oil was applied (3 free hands). In both cases it is left to dry until the next day and then reapply the same additives. Finally, the carnauba wax was applied to the panels that already had teak oil previously.	Fig. 14 finishing with additives.

4 Results

The effectiveness of the combination of different clays and wheat fiber is presented, as well as the effectiveness of waterproofing with the applied additives. It is contemplated that each type of clay reacts differently towards additives.

Table 7 shows the results of the coating. where the brown clay has the greatest number of deep cracks that range between 1.70 and 2.50 mm. On the other hand, bronze-colored clay, and rosewood-colored clay present superficial cracks between 1.50 and 2.00 mm. Finally, the white clay presents the least amount of cracks, with dimensions of 0.1 and 1.2 mm. The latter has a smoother finish as illustrated in Figure 11.

Table 7. Crack analysis.

Crack Analysis			
Clay/Color	**Width (mm)**	**Depth**	**Continuity**
Rosewood + wheat	1,5 - 2,00	Superficial	Yes
Brown + wheat	1,70 – 2,50	Deep	Yes
Bronze + wheat	1,5 – 1,70	Superficial	Yes
White + wheat	0,1 – 1,20	Superficial	Yes

Table 8. Waterproofing analysis.

	Teak Oil			**Beautiful Exterior Flave**		
Clay	**Application (in hands)**	**Amount (ml)**	**Texture**	**Application (in hands)**	**Amount (ml)**	**Texture**
Rosewood	3	500 ml	Smooth	3	500 ml	Smooth
Brown	3	500 ml	Smooth	4	500 ml	Smooth
Bronze	4	500 ml	Roungh	3	500 ml	Smooth
White	5	680 ml	Roungh	4	600 ml	Smooth

In Table 8, a comprehensive analysis of the waterproofing of the coating was conducted, using two types of additives: Teak Oil, applied in three layers on coatings of different colors, resulting in a smooth and shiny surface. The second additive, Bella Laja Exterior, was also applied to the coating, providing a smooth, shiny, and waterproof finish, as seen in Figure 11.

As an alternative, Bella Laja Exterior was used as the second additive, applied in three layers on rosewood and bronze clays, resulting in a smooth finish. The brown clay, with some cracks, received four applications, resulting in a smooth surface. Finally, the white clay was treated with four applications to achieve a smooth finish, as it absorbed the additive in the first application, as illustrated in Figure 12.

These additives not only prevent water absorption, preserving the aesthetic properties of clay surfaces against discoloration and water-induced wear but also reduce moisture in the wall, decreasing conditions for mold and fungus growth. However, it is crucial to carefully consider the selection and application of additives, adapting them to local climatic conditions and specific characteristics of the adobe wall [27].

Considering the porosity of the clay and local climatic conditions, along with application according to best practices, ensures effective and lasting protection. Furthermore, the incorporation of clay as a primary component in the coating, along with the addition of fibers as additives, helps reduce waste generation, thus contributing to the preservation of non-renewable resources.

5 Discussions

According to the results from the analysis of the coating properties of soil with plant fiber and waterproofing agents, it is observed that the proportion of fiber (barley and rice husk) reduces relative humidity, and the correlation with shrinkage decreases as the size and percentage of the fiber increase [13]. Additionally, Quiñonez [1] emphasizes the almost infinite variety of dosages and additives experimented with for building coatings but notes that errors in their application are also common. The results indicate that the samples underwent slight deformations due to the mixture with fiber (wheat), improving workability and flexion. Regarding waterproofing additives, they involved wrapping the clay in an impermeable layer to make it more stable and resistant to water or other fluids.

6 Conclusions

It was determined that applying a soil coating with additives to an interior surface improves soil properties, which cannot be achieved solely with untreated soil. In this study, it was observed that the incidence of soil cracks is significantly reduced due to the stabilizing properties of wheat fiber, which played an important role in absorbing some of the water and reducing shrinkage during drying. It was also noted that the dosage of fibers in the mixtures influences the result, with an optimal ratio between mass and fiber being crucial.

The total cost of the clay coating for an area of 1.20 wide by 2.50 (m2) long amounted to $25.00. This calculation includes all materials necessary for the preparation and application of the coating, as well as the costs associated with labor, the additives used, and any other expenses related to the application process. It is important to note that this cost may vary depending on geographic location, local material prices, and labor rates in different areas.

Regarding the appropriate choice of waterproofing agents, the porosity of the clay and local climatic conditions, along with application methods, ensure effective and lasting protection. The incorporation of clay as the primary component in the coating, along with the addition of fibers as additives, results in a reduction in waste generation and contributes to the preservation of non-renewable resources. This presents a significant advantage in terms of local availability and economic viability.

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