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Nopal mucilage waterproofing applied to construction materials to reduce humidity in homes in Valle de Bravo, State of Mexico, Mexico

Impermeabilizante de mucílago de nopal aplicado a los materiales de construcción para reducir la humedad en las viviendas de Valle de Bravo, Estado de México, México

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Abstract

Nopal leaves (*Opuntia ficus*-indica) excrete a "viscous" substance called mucilage. Create and evaluate a waterproofing prototype made from nopal mucilage used in housing construction materials to reduce humidity and saltpeter. It was possible to verify an effective performance of the waterproofing of the mixture of test 1, based on nopal mucilage, water, alum stone, lime and soap, with an average absorption of 4.33%, test 3, includes mucilage, water , lime, and salt, which presented an average absorption of 6.83%, test 2 is the one that absorbed the most water since it only contains water, mucilage and alum stone, with a total of 7.50% absorption.

Mucilage, Natural waterproofing agent, Ecological prototype

Resumen

Las pencas de nopal (*Opuntia ficus*-indica) excretan una sustancia "viscosa" llamada mucílago. Crear y evaluar un prototipo de impermeabilizante hecho de mucílago de nopal utilizado en los materiales de construcción de las viviendas para reducir la humedad y el salitre. Se logró comprobar un desempeño efectivo del impermeabilizante de la mezcla de la prueba 1, con base al mucilago de nopal, agua, piedra de alumbre, cal y jabón, con un 4.33% de absorción en promedio, la prueba 3, incluye mucílago, agua, cal, y sal, el cual presentó un 6.83% en promedio de absorción, la prueba 2 es la que más absorbió agua ya que solo contiene agua, mucílago y piedra de alumbre, con un total de 7.50% de absorción.

Mucílago, Impermeabilizante natural, Prototipo ecológico

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Introduction

The project arises from the Inter-institutional Program for the Strengthening of Research and Postgraduate Studies in the Pacific (DELFIN Program), during the stay of the XXVII Summer of Scientific and Technological Research in the Pacific, at the Technological Institute of Higher Studies of Valle de Bravo (TESVB) , in the Architecture Program, with the participation of students, who helped design and build the prototype of ecological waterproofing with prickly pear mucilage, having as a line of research Alternative Materials and Technologies for Construction and Bioclimatic Architecture.

The UN General Assembly adopted the 2030 Agenda for Sustainable Development, an action plan in favor of people, the planet and prosperity, which also intends to strengthen universal peace and access to justice. The Member States of the United Nations recognize that the greatest challenge in the world today is the eradication of poverty and affirm that without achieving it there can be no sustainable development (ONU, 2015).

Within the 2030 Agenda for Sustainable Development, 17 objectives were established to be met in order to achieve sustainable development, and in this specific case it is intended to collaborate in the development of objective 11: Sustainable cities and communities, which establishes: "Ensure that cities and human settlements are inclusive, safe, resilient and sustainable".

Rapid urbanization is resulting in a growing number of slum dwellers, inadequate and overburdened infrastructure and services, which is worsening air pollution and urban sprawl (ibid.).

In the search to contribute to the solution to these problems, the aim is to innovate with products for the construction area that, in addition to being functional, also manage to reduce the impact in different aspects in order to be sustainable. In this specific case, one of the alternatives for the waterproofing systems that are currently used will be investigated.

The waterproofing used today usually contains additives, gases and volatile organic compounds that present a great environmental contamination in their manufacture, handling and subsequent permanence in the building. Its permanence in the building is dangerous as it releases volatile products from the film over the years and permanently, causing damage to both health and the environment (Alsina, 2007).

It has become essential to consider all development factors together to achieve sustainability when trying to meet the needs that society presents. Due to the fact that currently the main components of waterproofing agents are chemical compounds that produce a greater environmental impact than that which could be generated by natural components, alternatives have been sought that fulfill the same function that currently developed waterproofing agents intend to fulfill.

In addition, with the implementation of these alternatives, a decrease in investment costs for housing protection is achieved. In this way it is intended that these alternatives to industrialized products are a viable option for the user. Nopal mucilage-based waterproofing is usually one of the most effective natural alternatives, causing less environmental impact than conventional waterproofing.

The nopal has been an important part of the culture and history of Mexico, and not only in gastronomy but also as a fundamental part in the development of various products. Mexico is the world's leading producer of nopal, and for this reason it has been considered the main raw material in the development of waterproofing.

The properties of nopal mucilage have been used since pre-Hispanic times in the country. The mucilage has water retention capacity, interaction with fatty substances and a certain emulsifying power; These properties are still being investigated for their incorporation in food, medical, cosmetic or environmental remediation technology applications, among others (CIAD, 2021).

Three proposals for the preparation of a waterproofing agent based on nopal mucilage are presented, carrying out the corresponding analysis of each of the proposals to determine the efficiency that is achieved and define the ideal dosages, as well as the situation under which it is recommended. use each one.

Problem Statement

The affectations by atmospheric agents in buildings have been distinguished as one of the main causes that unleash the damage processes in construction materials. Humidity is one of the most important factors considered due to the seriousness of its impact.

Humidity is a measure that indicates the amount of water vapor in the air (Air Things, 2022). This factor increases or decreases its presence depending on the geographical place where the work is located, since it will also be affected by the current climatic conditions. Damage caused by moisture not only affects the safety of the building, but also the aesthetics and habitability of the place.

With the aim of reducing or eradicating the damage present in buildings due to humidity and with the advances that have occurred in the area of the chemical industry, innumerable waterproofing agents have been developed; however, the components of the waterproofing that are usually used today generate considerable environmental damage due to the chemical and toxic substances that make it up.

In ancient times, waterproofing agents of natural origin were already used, so, seeking to cover the need to stop deterioration in construction works and at the same time reduce the environmental damage that is generated, a waterproofing agent is proposed as an alternative to modern waterproofing agents. based on nopal mucilage.

A waterproofing based on natural components, such as nopal mucilage, represents a convenient alternative because it is easy to obtain and can even reduce economic costs for its preparation and application, but without neglecting the effectiveness of providing a coating. that protects from moisture leaks.

Justification

According to data from the National Financial for Agricultural, Rural, Forestry and Fisheries Development (2020), at the national level, the main producers of nopal cultivation are Morelos and Mexico City, who contribute 70.4% of the total volume of nopales; They are followed in level of importance by the State of Mexico, with a participation of 10.2%, and Jalisco, with 4.12%. Being that the place of study, which in this case is Valle de Bravo, is located in the State of Mexico, and taking into account the search for the use of the resources that are available in the region, a proposal is made for a waterproofing nopal mucilage base.

The application of nopal mucilage waterproofing will help reduce the deterioration of construction materials due to humidity, thus reducing maintenance costs.

In addition, it has become necessary to look for alternatives that have the least possible environmental impact, and that in the same way represent an economically sustainable cost. The use of nopal mucilage is usually the most effective natural alternative, since thanks to its origin it does not pollute the environment as conventional waterproofing agents do, in addition to generating lower costs.

Background

As soon as the human being begins to have stable settlements, the need arises to find ways to protect constructions against present damage. This is how waterproofing began to make its first appearances, although not in the industrialized way in which they are known today. Those first waterproofing systems consisted of using less permeable minerals in very inclined positions to deflect rainwater from the roofs (Endurpol, 2022).

The job of waterproofing is the third oldest in the world, dating back to about 13 thousand years, when men had the need to take refuge from the humidity at the end of the Paleolithic. The Egyptians were the first to build monolithic structures by waterproofing them with layer-applied reed fiber-reinforced tar emulsions 3,600 B.C. (Rivera & Benitez, 2022).

With the need to offer better protection alternatives, other types of waterproofing have been developed. Around the 1920s, petroleum derivatives began to be used as a waterproofing method, the most primitive of this type would be known as chapapote. Along with these waterproofing systems, flat roofs began to be created. With the discovery of fiberglass in the 70s, waterproofing membranes began to be manufactured. The breakthrough in chemical research brought about by the space race gave rise to discoveries of more durable and weather-resistant plastic materials (ibid.).

Considering the damage that current industrialized waterproofing can cause, various alternatives have been proposed, among which a natural waterproofing based on nopal mucilage stands out.

According to Gómez (2002), cited by the National Institute of Statistics and Geography (INEGI), 2013:3), the use of nopal dates back more than 25 thousand years ago, when man settled in what is now Mexico. It is probable that, being hunters and gatherers, they included the nopal as part of their diet.

In excavations carried out in Tehuacán, Puebla, prickly pear seeds and shells and fossilized prickly pear fibers were found. It is known that since pre-Hispanic times, Mesoamerican cultures found nutritional and medicinal qualities in the cactus on which they based many of their customs (Saravia, 2022).

Currently the nopal has given rise to the development of innumerable products, thus leading to numerous crops established both for food and medicine and for the development of various products. It has been taken to both the national and international markets and represents a source of income for the rural communities where it is grown.

The Ministry of Agriculture and Rural Development (2020) states that: “The nopal is an endemic product of Mexico where, in addition, it has diversified: of the 200 species of nopales, 101 live in our country. In Mexico, nopal is used in food, livestock, art, construction, the pharmaceutical and cosmetic industry, and more.”

Nopal mucilage and alum are some of the ingredients of the pre-Hispanic conservation and waterproofing techniques that Mexican archaeologists use to prevent the deterioration of ancient convents. The mixture of these materials dates from 900 to 1,500 years before our era in order to waterproof historic buildings (Milenio, 2011). For the restoration of the National Museum of the Viceroyalty, they have been made flattened with nopal slime and lime (Barrera, 2012).

Nopal mucilage is used in the production of ecological paint; At the INAH (National Institute of Anthropology and History), restorers, archaeologists and architects have recently applied prickly pear mucilage as a waterproofing agent for walls and roofs in archaeological zones and historical monuments. The Ministry of the Environment recommends the nopal mucilage as a natural waterproofing agent for walls and roofs of historical monuments (Torres, et al., 2015).

Within the framework of the Engineering Expo 2018, organized by the Technological Institute of Querétaro (ITQ), the Higher Technological Institute of Huichapan (ITESHU) and the Autonomous Metropolitan University (UAM), José Francisco Badillo, José Juan Carranza, José Alfredo Pérez, Jorge Luis Mendoza and Michael Mejía, ITESHU students, presented proposals for waterproofing from nopal slime.

The students noted that:

> “In this first stage we wanted to show the low-income population an alternative to make a waterproofing that could be effective in protecting their homes in the next rainy season. The nopal slime is emptied into a container, then the white cement is applied until it has a thick consistency and then the glue is added to obtain a uniform product. For one liter of waterproofing we use 800 milliliters of nopal slime, 240 grams of pegazulejo and 280 of white cement. It is applied like any waterproofing that exists on the market” (Excelsior, 2018).

In Mexico, nopal mucilage has been used in combination with lime because it increases its adhesive properties and improves its resistance to water. Because of its adhesive properties, it has been used similarly to plaster on adobe and brick walls and also as a water barrier in stucco. A pre-Hispanic technology that contributed to the persistence of Mayan, Aztec and Toltec architectural complexes to this day is in the sights of scientists and it is the use of nopal slime in construction (Cruz, 2014).

Some architects and builders noticed that, in some buildings, mainly tenements, there was humidity in the rest of the house except for the ceilings. They had no water leaks despite the custom of locating the sinks on the roofs. What was found as a common denominator in all cases, were some products used both in the removal of dirt, and to protect the colors of the fabrics, the main components of these being laundry soap and alum (Cordero, 2007). The combination of the mentioned materials supposes as a result an efficient waterproofing to use on surfaces.

Cahuana (2022) in his research determined the variation of the physical and mechanical properties of concrete blocks modified with waracco mucilage. The main results of the investigation tested at 28 days, the absorption percentage reached an optimum value of 3.79% with the addition of 3% waracco mucilage, then the compressive strength reached a value of 80.52 kg/cm2 with the 3 %, which represents an increase of 69.52% more than the resistance of the standard block, finally the permeability with a value of 20.00 ml with 3%, which represents a decrease of 55.65% less than the pattern, as a conclusion it has to be 3% The incorporation of waracco mucilage considerably reduced the absorption and permeability, as well as increased the compressive strength to 76.73% compared to the standard concrete block.

Céspedes and Rivera (2022) point out in their research an average compressive strength in artisanal bricks with nopal mucilage as a natural additive is 98.1083 kg/cm2 while artisanal bricks without additive have an average resistance of 92.0 kg/cm2, which is minor, in comparison of these two results, the handmade bricks with nopal mucilage as a natural additive have greater resistance to compression.

Chávez (2022) studied the effect of adding linseed mucilage to concrete in proportions of 0.5% and 1%, to evaluate its behavior on compressive strength and permeability. Manipulating the flaxseed mucilage, in a seed to water ratio of 1:20. The results of the test tubes with the mucilage, provided an increase in its resistance, where the addition of 0.5% for 7, 14 and 28 days increased by 7.56%, 6.12% and 9%, while with the addition of 1% it increased in 15.02%, 12.94% and 20.62% respectively, in addition the permeability tests also denoted a favorable change, where as a result the samples with the mucilage of 0.5% and 1% yielded values of the permeability coefficient 1.27E-10 and 8, 98E-11 m/s and a penetration of 32.97 and 24 mm, where it was concluded that the mucilage has a positive effect on resistance, increasing up to 23%, and on concrete permeability a favorable reduction was determined for the addition of 1 % considering low permeability concrete.

Ordaya (2022) affirms in his research that with the addition of nopal mucilage in self-compacting concrete in the fresh state are: Improvement in spreading, reduced resistance to blocking, improved self-leveling in relation to the standard sample, concluding that it meets the function of natural plasticizer, on the other hand it was observed that in concrete hardened with the addition of mucilage for all ages in dosages of 0.3%, 0.5% and 0.7%, the resistance decreases in a small percentage compared to the standard sample, but higher to the established design, this natural additive fulfills the function of plasticizer up to a dose of 0.3% and superplasticizer up to 0.5%.

Padilla and Romani (2022) in their research managed to find out that the vast majority of homes are self-built and that people lack economic resources to invest in their construction; This also confirms that the use of bamboo and construction techniques such as thatch are the most suitable for this project.

Prickly pear

The nopal is a succulent plant that measures on average between 1.5 and 3 meters in height. The stems (cladodes or "shovels") are flattened and grayish-green. The flowers are yellow and the fruits vary between yellow, red and purple and contain small seeds that are usually consumed together with the flesh of the fruit.

The plant reproduces by seed, but can also be propagated relatively easily vegetatively from detached stems (FAO, 2022).

The nopal belongs to the family of cacti, genus Opuntia. Among the cacti, there are plants such as organs, nopales, pitayos, garambullos, biznagas, peyotes, candelabra, cardons, reeds and cardenches, among others (INEGI, 2013).

Geographic location

In the genus Opuntia, 377 species are classified, all endemic to the American continent (that is, they are only found there), of which Mexico has 104 wild and 60 endemic. Cacti grow mainly in arid or semi-arid areas, but can also be found in areas with cold or temperate climates (Novo, 2007).

In Mexico, the genus Opuntia has a wide distribution. The regions with the highest species richness are the center and north of the Altiplano, the northwest, the Bajío, the Neovolcanic Axis and the Tehuacán-Cuicatlán valley. In the dry tropical regions and the northern deserts there is less richness, but endemic species of great importance are usually found. Brought to Europe by the Spaniards, the dispersion of the nopal around the world is very haphazard since the sailors used to take with them a good supply of prickly pears to avoid scurvy (a disease caused by vitamin C deficiency).

Subsequently, selected varieties were brought to establish plantations for various purposes such as stopping the desertification of the soil or producing fodder. Today, in many semi-arid regions of the world there are already naturalized and cultivated wild prickly pears. Some countries even have larger plantations than those of Mexico and with genetic resources that have diversified there (CONABIO, 2021).

Morphological characteristics

Nopales have developed characteristics that allow them to adapt to areas with little water availability and extreme temperatures.

Among others, succulence is its main morphological characteristic, it accumulates large amounts of water in short periods of time and the thick cuticle that they have makes them more efficient to avoid evaporation-transpiration. Due to its crassulacean acid (MAC) metabolism, it carries out a photosynthetic process through which the stomata are closed during the day and open at night, preventing water loss through transpiration.

Nopal mucilage

Nopal leaves excrete a “viscous” substance called mucilage (Opuntia ficus-indica), this is one of the most important components since it is part of dietary fiber. Nopal mucilage is a highly branched, fibrous polysaccharide with a molecular weight of around 13x106 g/mol. It contains approximately 35-40% arabinose, 20-25% galactose and xylose each, and 7-8% rhamnose and galacturonic acid each. Nopal mucilage is considered important for the food industry due to its viscosity properties. It has the ability to form molecular networks and strongly retain large amounts of water, as well as modify properties such as viscosity, elasticity, texture, water retention, in addition to being a good gelling, thickening, and emulsifying agent (Rodríguez, 2019).

Humidity

The author Martines (2007) in his article "Definitions of humidity and its equivalence" says that "Humidity is a property that describes the content of water vapor present in a gas, which can be expressed in terms of various magnitudes. Some of them can be measured directly and others can be calculated from measured magnitudes.

Humidity in the houses

According to Ortega (1994), in his book “construction pathology: dampness in the building”, he exposes four peculiar properties of water that are interesting for the study of dampness. The first is that water has a facility to change state at affordable temperatures; The second, when it solidifies, increases its volume and that causes its density to decrease, so it has the ability to float on its liquid state, acting as an insulating material.

The third, thanks to its polar character and its chemical structure of which it is composed, can be called water, as a universal solvent. And the last characteristic is the surface tension it possesses. Through this characteristic, the water is capable of wetting or bathing the surface, and by modifying its viscosity it can dissolve salts and transport them and deposit them in another place under totally opposite conditions.

Being an element that can easily change its volume, it can cause deterioration or even destruction of various materials, either due to freezing or its solvent capacity, which can cause washing of any surface of the material. In this way, the material is exposed to atmospheric components that, together with water, can cause chemical reactions between them and the particles of the material. The damage is not only superficial, but when the water is in its liquid state it can penetrate any surface, thus deteriorating the material or a construction element, from the inside, such as, for example, reinforced concrete.

It can be said that external humidity is subdivided into three types of humidity: absorption, infiltration and penetration. The three humidities have a different origin, but the same cause appears, which is water.

Absorption humidity occurs when vapor transfer is generated between the external atmosphere and the pores of the materials that make up the enclosure, when these are in the process of reaching equilibrium humidity.

Infiltration dampness originates from water seepage through fissures or cracks in the façade, with the combined or individual action of rain, wind and capillary suction. They usually manifest in the form of spots both externally and internally.

Penetration dampness is the result of poor building maintenance, which allows water to enter freely through unclosed gaps, open joints, etc. which often causes flooding inside the building and causes serious material damage. But they are not usually frequent since with good maintenance and good execution they are avoided without great effort (Pipiraite, 2017).

Saltpeter

One of the main consequences of hygroscopicity is called efflorescence. Saltpeter is a commonly used word to refer to what is technically called efflorescence. Efflorescence or saltpeter is a crystalline deposit on the face of a natural or artificial rocky surface that affects stone walls, brick, block, architectural concrete, plaster and stucco. Saltpeter is an old problem where the immediate affectation is the disfigurement of the stucco or plaster and the spoilage of the finishes.

Additionally, there is the damage caused by the growth of crystals on the surface of the wall. Efflorescence or saltpeter normally forms shortly after construction. New brick soon develops white spots that eventually cause the brick itself and other materials used in construction to disintegrate.

It frequently appears on the surfaces of the walls, both in stone and in brick and concrete block masonry, in plaster and plaster. The causes of these stains are the soluble salts contained in the materials of the wall, the masonry or the nearby ground and the presence of humidity. The water dissolves these salts and carries them with it through the wall. Upon reaching the surface, the water evaporates, leaving recrystallized salts as a residue. These are mostly alkali and magnesium nitrates and sulfates and, less frequently, carbonates. If there are iron salts among them, the spots will appear colored with a yellowish tone (Torres, 2011).

Natural waterproofing

It is an organic compound used as a protector on various surfaces whose characteristic is to prevent the passage of water. They are mainly used in the construction area to protect any property from humidity, waterproofing is used for the insulation of foundations, roofs, slabs, floors, walls, swimming pools, cisterns and deposits. Its effectiveness lies in its proper placement according to the specifications of each product and surface.

Waterproofing is the process that is carried out in all construction to give the elements that compose it the properties of preventing the passage of water through them; that is, it is a system or a series of stages. From the above we can understand that even new constructions must be waterproofed in order to prolong the useful life of the property. In addition to reducing costs by performing preventive maintenance instead of corrective (Valero, 2018).

Hypothesis

The waterproofing made from nopal mucilage will reduce the percentage of absorption in the construction materials of the houses.

Objectives

Create and evaluate a waterproofing prototype made from nopal mucilage used in housing construction materials to reduce humidity and saltpeter.

Materials

The materials that were used for the construction of the prototypes were from the region of the Municipality of Valle de Bravo, State of Mexico.

- Prickly pear.
- Nopal mucilage.
- Hydra lime.
- Alum stone.
- Neutral soap.
- Salt.
- Water.
- Annealed red clay brick (7*14*28) cm

Tools

- Weighing machine
- Test tube
- Brush
- Mesh #8
- Mesh #100
- Gloves
- Cutter
- Plastic buckets

Methodology

The empirical, quasi-experimental quantitative methodology, with a descriptive approach. Rodríguez et al. (2021) in their article "Waterproofing system based on mortar and nopal mucilage (Opuntia ficus-indica)" presents by empirical method the following quantities in table 1 shown, to develop a dosage of waterproofing which was used as guide to subsequently carry out the dosages of this research:

Material	Unit	Quantity (Grams)
Nopal mucilage	Grams	70
Sack lime	Grams	30
Alum stone	Grams	20
Neutral soap	Grams	15
Purified water	Grams	250
	Total	385

Table 1 Base dosage
Source: (Rodríguez Uribe, 2021)

The dosages made of natural waterproofing were applied to construction materials such as annealed red clay bricks, in which absorption tests will be carried out according to standard NMX-C-037-ONNCCE Construction industry - Masonry - Determination of absorption total and the initial absorption of water in blocks, bricks or bricks and bricks - Test method, this in order to know the amount of absorption and later tests are carried out to know the amount of humidity.

Experimental development

The experimental process consists of four stages which allow the elaboration of the waterproofing, from the extraction of the nopal mucilage to the realization of different dosages and mixtures of waterproofing, as well as analyzing the behavior of the bricks before absorption.

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Stage 1. Mucilage extraction

- Figure 1 shows the selection of nopal leaves from which the thorns and impurities were removed to later rinse and leave them clean.

- When weighing the nopal leaves on the scale, 3,141.5 grams were obtained.

- The leaves were cut into squares, later they were deposited in a bucket with water at room temperature. The amount of water is with a Nopal-Water weight ratio of 1:2, leaving the mixture to rest in a container for 48 hours.

- After the time, with the help of a number 8 sieve, the leaves were separated from the mucilage. Finally, to remove any solid that the mucilage had, a sieve was used again, this one was number 100 and thus the mucilage was obtained free of impurities and ready for use.

Figure 1 Nopal extraction process
Source: Own elaboration

Stage 2. Preparation of waterproofing mixtures

For the design and realization of the different mixtures, different dosages and materials were used, 3 different tests were elaborated in which 750 ml were obtained in each one, these will be described below:

- **Test 1.** Figure 2 shows that this consists of 300 ml of water, 200 ml of mucilage, 100 grams of lime, 70 grams of alum stone and 60 grams of neutral soap. The alum stone and neutral soap were diluted with the aid of boiling heat with 100 ml of water in each case of the 300 ml mentioned.

Figure 2 Process of elaboration of test 1
Source: Own elaboration

- **Test 2.** Figure 3 shows that it contains 300 ml of mucilage, 400 ml of water and 70 grams of alum stone. It is worth mentioning that the alum stone was diluted with the 400 ml of water contained in this mixture.

Figure 3. Process of elaboration of test 2
Source: Own elaboration

- **Test 3.** Figure 4 shows that it contains 300 ml of mucilage, 400 ml of water, 150 grams of lime and 60 grams of salt.

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Figure 4 Process of elaboration of test 3
Source: Own elaboration

Stage 3. Absorption analysis of bricks

In order to analyze the behavior of the bricks against absorption, the following tests were carried out:

- Before applying the waterproofing to the bricks, they were left to dry in the sun for 3 consecutive days in which they would be in the sun for 4 hours each day, this allowed us to minimize the humidity that they already contained. Subsequently, figure 5 shows the bricks that were left to rest in water, the 9 bricks as follows: from 1 to 4 12 liters were used, from 5 to 7 in 8 liters and from 8 to 9 in 8.5 liters, these amounts were determined to fully cover the faces of the brick. With this, it was possible to obtain the amount of water absorbed by each brick in relation to its weight.

Figure 5 Bricks immersed in water for absorption test.
Source: Own elaboration

Stage 4. Application of waterproofing tests

Figure 6 shows the three tests carried out that were applied to 3 annealed red clay bricks each, therefore we work with 9 bricks to observe the behavior and if there is any variation between bricks even with the same test. For its application, the following procedure was carried out:

- First, the bricks were dried in the sun to work with them with the minimum amount of moisture that they could contain.

- Each test was applied with a brush, covering all the faces of the brick, in order to fully cover the brick with the waterproofing mixture.

- It was left to dry for 10 minutes in the sun, being that way, it is a first layer. Finally, a second layer of waterproofing was applied, which was subsequently taken out in the sun to dry.

- The placement of tests was carried out as follows: from brick 1 to 3 test 1 was used, from brick 4 to 6 test 2 was used and finally, from brick 6 to 9 test 3 was used.

Figure 6 Application of waterproofing in brick
Source: own elaboration

- With the application of the waterproofing in each brick, a test is carried out to determine the percentage of absorption that each one has and thus be able to evaluate which waterproofing is more effective. Figure 7 shows the test that consists of placing 1 liter of water in a bucket and leaving each brick for 10 minutes, so what it managed to absorb in that time is taken into account to see the amount of water absorbed by each brick with its respective waterproofing.

Figure Absorption test process with waterproofing
Source: Own elaboration

Results

It was possible to obtain the amount of water that each brick absorbed in relation to its weight, these data are before applying the waterproofing, in Table 2 the amounts corresponding to each brick are presented, it can be observed that brick 6 with the difference of weighing 97.2 gr, it is the one that absorbed the least water and brick 8 with a weight difference of 180.2 gr, is the one that absorbed the most water.

Brick	Initial dry weight (gr)	Wet weight (gr)	Weight difference (gr)
1	1937.9	2092.1	154.2
2	1946.8	2103.8	157.0
3	2001.3	2129.1	127.8
4	1983.5	2102.5	119.0
5	1998.8	2127.4	128.6
6	1980.1	2077.3	97.2
7	1932.5	2055.2	122.7
8	1854.5	2034.7	180.2
9	1937.1	2069.8	132.7

Table 2 Registration of brick weights.
Source: Own elaboration

To determine the effectiveness of the tests carried out, the test with the waterproofing applied to the bricks was taken into account. Table 3 shows the (ml) of water absorbed by the bricks, with 1 and 2 being the ones with the least absorption of 40 ml and the one with the highest absorption being 5 with 85 ml.

Brick	Test applied	Water absorption in (ml)
1	Test 1	40
2	Test 1	40
3	Test 1	50
4	Test 2	70
5	Test 2	85
6	Test 2	70
7	Test 3	55
8	Test 3	65
9	Test 3	85
10	No test	130

Table 3 Water absorption of each brick
Source: Own elaboration

The percentage of absorption was calculated with the following equation:

Absorption = ((wet sample weight - dry sample weight)) / ((dry sample weight)) x 100

Table 4 shows the results obtained from the absorption percentages of the different tests applied to the bricks.

Brick	Test Applied	Absorption percentage
1	Test 1	4%
2	Test 1	4%
3	Test 1	5%
4	Test 2	7%
5	Test 2	8.5%
6	Test 2	7%
7	Test 3	5.5%
8	Test 3	6.5%
9	Test 3	8.5%
10	No test	14%

Table 4 Absorption percentage of each brick
Source: Own elaboration

With this, it was determined that test 1 is the most efficient, since it is the one that yields the best results in terms of water absorption. This result is due to the fact that tests 2 and 3 contain greater amounts of water and the absence of alum stone as well as neutral soap that works as a waterproof rubber, it is worth mentioning that test 1 was the only one that was not allowed. apply a second layer, unlike the other tests, since the mixture slips and does not allow its adherence.

In the same way, brick number 10 that does not contain a waterproofing mixture was put in the test in order to have a reference regarding the function that the waterproofing would have, this gives us as a result that there is a great difference in absorption between the application of waterproofing and the use of a brick without it, since the table alludes to how it counteracts absorption by using some natural waterproofing agent, the difference between a brick without water and with the waterproofing agent that presents the least percentage is 10%.

In graphic 1, it can be seen that the first waterproofing test is the one that presented the lowest absorption on average in the three specimens, with a value of 4.33% absorption, followed by the third test with a value of 6.83% and finally the second with a value of 7.50%.

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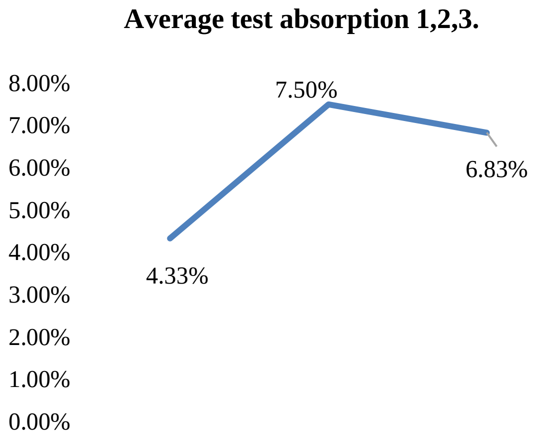

Graphic 1 Average of absorption tests
Source: Own elaboration

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Conclusions

The problems of water filtration and humidity are related and their causes are usually natural aspects, even economic ones, helping to solve this problem leads to the creation of a protection system, however, from an economic point of view, Many times there is not enough budget. For this reason, this research was carried out to analyze the economic differences and effective alternatives to moisture treatment and the implementation of natural, traditional and environmentally friendly waterproofing.

It was possible to verify an effective performance of the waterproofing of the mixture of test 1, based on nopal mucilage, water, alum stone, lime and soap, the pores of the brick were better sealed, which reduced the filtration of water in the bricks. , test 3, includes salt in the mixture but does not contain alum stone, which was the second best waterproofing agent, test 2 is the one that absorbed the most water since it only contains water, mucilage and alum stone.

Of the 9 bricks to which 3 different tests were applied with the nopal mucilage and without the inclusion of mucilage, it is concluded that, in the face of water exposures that can occur in constructions such as: rains and other external agents, it is verified that the traditional annealed red clay bricks that are frequently used today have a high vulnerability to humidity.

Finally, it was possible to demonstrate the previously proposed hypothesis which states that "The waterproofing made from nopal mucilage will reduce the percentage of absorption in the construction materials of the houses of Valle de Bravo, Mexico". Obtaining in the future bricks covered with natural waterproofing with less absorption capacity and more resistant to erosion caused by prolonged exposure to water. Waterproofing is essential for the protection of buildings against climate change.

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