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FABRICATION OF INSULATING PANELS WITH BIOLOGICAL MATERIALS: HAZELNUT SHELLS AND POTATO STARCH

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ABSTRACT

The production of biocompatible materials in the construction industry is necessary for several reasons related to human health, environmental sustainability, and quality of life. The primary reason is undoubtedly human health protection, as many traditional building materials have been found to release harmful substances that can cause various diseases, respiratory problems, allergies, or chronic illnesses. Unlike biocompatible materials, which are known to not release toxic substances and are safe for those who live or work in buildings, biomaterials reduce pollution: these materials affect air, water, and soil. Reduced impact on climate change: they produce less CO_2 and greenhouse gases than traditional materials. Conservation of natural resources: Many eco-friendly materials are recycled, recyclable, or derived from renewable sources. Benefits for human health, Fewer toxins: They are less harmful to those who produce them, use them, or live in contact with them (e.g., in construction or food packaging). Improved air quality: Some eco-friendly materials release fewer harmful volatile organic compounds (VOCs). Long-term economic benefits. Resource savings: Durable or recyclable materials reduce production and disposal costs in the long term. Innovation and competitiveness: Companies that invest in sustainability improve their image and can access new markets and financing. Increasingly stringent regulations. National and international laws and regulations are pushing for sustainability, rewarding companies that adopt responsible practices. Social pressure and consumer awareness. Consumers are increasingly aware of the environmental impact of products and reward those who adopt sustainable solutions. Using biocompatible building materials means building in a way that's safer for people, more environmentally friendly, and more cost-effective. It's a fundamental choice for modern and sustainable construction the variant is the binder, which is a vegetable, such as potatoes, which will be used as a binder due to its properties. Tests were conducted by combining different eco-friendly materials, modifying their heat exchange ratios, and measuring their thermal conductivity. The thermal conductivity coefficient γ or K is a physical property of a material that measures how easily heat passes through it. It is calculated using Fourier›s law, observing how much heat passes through a material as a function of its geometry and the temperature difference. Conduction is one of the ways heat is transferred from one area to another within a solid body (such as a wall), without movement of the material. Example: if you touch a heated metal spoon on one end, the other end will also heat up over time: this is heat propagating by conduction between 0.030 and 0.070 kcal/(h·m·K; Potato starch is a polysaccharide (a long chain of simple sugars) found in many vegetables, including potatoes. It is composed primarily of amylose and amylopectin, two components that give it gelatinizing and adhesive properties. Its properties emerge when starch is heated (for example, by grating a potato and heating it with water). Its molecules absorb water, swell, and form a viscous gel. This gel can hold solid particles together, acting as a glue or binder. This work has led to a practical use of starch as a binder. In sustainable construction, starch has been used to compact natural fibers or eco-friendly insulation materials (such as peanut shells). It has been proven that it can be used in the production of natural biocomposite insulation panels. It should be noted that in the green building sector, it's already used to prepare natural glues and non-toxic adhesives, suitable for crafts or eco-friendly building materials. Among the advantages of using starch as a binder, natural and biodegradable, it is non-toxic, inexpensive, and easy to obtain, as the

potato crop is widely cultivated, these thermal conductivity coefficients are like those of other materials commonly used as thermal insulation in the construction industry. Walnut or hazelnut shells could therefore be used, valorizing this natural waste, in the production of insulating panels for buildings.

KEYWORDS: Thermal insulation Bio-waste hazelnut shells
Sustainable materials Potatoes

INTRODUCTION

This study extends previously published work by author. [1] It is very important to pay attention to the climate changes that are currently taking place, global warming causes torrential rains in some places and droughts [2] in others, even the melting of glaciers causes the ocean waters to rise consequently [3], all this also represents damage to the health of all of us [4]. All the climate changes that are taking place are directly linked to pollution, this has caused a greater attention of all the nations towards this problem, Europe with the '2030 agenda' wanted to involve all the countries so that they work to reduce this pollution, therefore it is of notable importance to reduce CO2 emissions and as we know the construction sector is one of the most responsible, therefore it is asked to intervene already from the raw materials used up to the whole production process [5], the risk deriving from human activities dangerous for the environment and life involve a notable total CO2 emissions [6] as well as the energy consumption for daily activities represents 15It is necessary to pay the utmost attention to the construction sector, it is very important to pay attention to energy efficiency because in existing buildings that are not thermally insulated in an adequate way, overheating occurs in the summer seasons and very cold in the winter seasons [8,9], which is why the problem of thermal insulation of buildings becomes of fundamental importance, currently said insulation is carried out by installing insulating panels, unfortunately polystyrene panels are constantly used which are derived from petroleum and therefore very polluting for the environment, this is the reason why it becomes of fundamental importance to create panels with ecological materials that respect the environment. design [10,11]. to obtain comfort in homes it is necessary to keep an eye on the internal temperature which is often guaranteed only by openings or by air conditioners, it has been found instead that a good thermal insulation with appropriate materials can have a positive effect on the internal temperatures of the home and also to create an adequate comfort. the insulating panels currently used are derived from hydrocarbons [12,13], polyurethane [14] or polystyrene [15,16], in a few cases those of natural origin such as glass fiber, mineral wool or cork are used [17–19]. There are also other natural materials available in nature such as clay, hemp fiber [20–22], derived from the fibers of the hemp plant, it has excellent thermal and acoustic properties. It is resistant to mold and insects and has low emission levels. It's grows rapidly and improves soil quality, the silkworm [9] It's potential as a thermal insulator, It's a Natural Fiber with a Porous Structure, Silk fiber (composed primarily of fibroin and sericin) has a porous structure that retains air, and air is an excellent insulator. This gives silk natural insulating properties, which are exploited in technical clothing (e.g., thin thermal underwear). The silkworm's cocoon serves to protect the chrysalis from changes in temperature and humidity. It is made up of overlapping layers of silk that partially block heat loss, hydrangea [23], or tree bark [24] Bark as a Thermal Insulator, It has Insulating Properties, It has a fibrous and porous structure that traps air, reducing heat conduction. It offers good thermal insulation (λ values between 0.04 and 0.06 W/m K on average, similar to those of other natural insulators). It also offers reasonable acoustic insulation.

Resistance to External Agents, It is resistant to humidity, insects, and decay, thanks to its natural tannins and resins.

Naturally fireproof in some cases (like cork bark). Sustainability, It is a by-product of forestry or the wood industry, 100% natural, recyclable, and biodegradable. It can be compacted into panels, mixed with other natural materials, or used in granules, even sheep wool [25], fibers obtained from the pineapple plant [26] or corn [27] and waste wood fiber [28,29], all materials studied from the thermal profile and characteristics, with the present work we wanted to create an insulating material but 100% biological and biocompatible and moreover made with recycled materials. Examples of Use, in some cases, pine, larch, or fir bark is used in insulating panels. Expanded cork bark is one of the best-known and most widely used examples in green building (thermal, acoustic, and vibration insulation). It can be used as thermal insulation, especially when processed (panels, granules, or composites). It is natural, eco-friendly, and offers excellent performance, although it is not yet widely used compared to other more well-known materials like wood wool or hemp. As mentioned, in this work prototypes of insulating panels are made, the design, analysis and evaluation from a thermal point of view are carried out, the raw materials used were peanut and walnut shells and potato starch was used as a binder. Good thermal insulation can reduce or even eliminate the need for air conditioning and heating systems, with both energy and environmental benefits. In winter (heating): A well-insulated building retains internal heat (produced by systems, people, and appliances). Reducing heat loss to the outside means less energy is required for heating. In summer (cooling), insulation prevents external heat from entering, especially through the roof and walls exposed to the sun. This keeps the interior cooler, thus reducing the need for air conditioning. In practice, insulation acts as a "thermal cap" that keeps the internal temperature stable, reducing the need for active systems to compensate for the external climate. Furthermore, waste material (agricultural waste) is used for their production, reducing production costs. Finally, the construction of these ecological panels will reduce CO2 emissions, and the energy used.

MATERIALS AND METHODS

MATERIALS

In this second project, the materials selected to make the insulating panels were hazelnut shells; the glue was made from potatoes with the addition of water. Hazelnut shells were chosen as the primary material for the insulating panels, as they are readily available in the Mediterranean region. This time, the binding agent was a vegetable, the potato. some examples of experimentation with walnut and peanut shells come from Morales et al. [30]. Activated carbon from hazelnut shells. In Pretreatment and Carbonization, the shells are dried, ground, and carbonized at high temperatures (typically 600–900°C), often in an inert atmosphere (nitrogen) or during chemical activation. As the carbonization temperature increases (up to ~900°C), increasingly higher values of specific surface area (SBET) and microporous volume are achieved. Also from Serafin et al. [31] Chemical or physical activation, consists of impregnation with agents such as KOH, H_3PO_4, Na-amide, followed by heating to create pores. Physical activation: treatment with steam or CO_2 at high temperatures (600–1000°C) to increase porosity; this vegetable contains potato starch, which has binding properties that make it an excellent thickener, for example, and has long been used in cooking. When heated in water, the starch gelatinizes, forming a structure that retains the liquid, creating a thickening effect. This property is due to the starch granules' ability to absorb water; it is excellent for use as a binder. Walnut shells can be successfully transformed into cellulose nanocrystals (CNC) using a biorefinery process that includes hydrothermal extraction, delignification, chemical/mechanical isolation of the cellulose, and hydrolysis/oxidation. The residue can also generate lignin and useful oligosaccharides. The yield and final properties make this raw material promising for applications in packaging, pharmaceuticals, or composite materials. also used for the production of biomethane or biogas [32]. Gasification and Syngas, hazelnut shells have proven to be excellent candidates for gasification processes, which produce syngas rich in CO and H_2 but little direct methane. Experimental prototypes (e.g., 30 kW electric) have confirmed the ability to effectively convert the shells into syngas usable as a fuel. The shells and wastes of walnuts and peanuts have also been used as compost for crops [33] and Ozipinar et al. [34] instead used these shells for the synthesis of activated carbons. Typical values indicate that activated carbon from hazelnut shells has a bulk density between 0.25 and 0.4 g/cm³ (even up to 0.55–0.65 g/cm³ in commercial products), while the actual density is approximately 1.04 g/cm³. These properties make it a suitable material for adsorption, gas/vapor, filtration, or purification applications. The present work has used as raw materials the waste of hazelnut shells bound by a natural glue which is inside the potatoes, namely starch. These materials have been used for the production of thermal insulating panels. The selection of the mentioned raw material has led to obtaining a double advantage: firstly, a completely biocompatible and biodegradable material, not harmful to the environment, and secondly, the recycling of a waste material, thus avoiding the consumption of another material, which in turn would lead to further energy consumption. Both materials, as already mentioned, are biocompatible and have also been selected because, after careful analysis and experimentation, they have proven to be suitable for thermal use and to create thermal comfort in buildings without damaging the environment, thus improving environmental sustainability. In the various tests carried out, the intrinsic properties of the new material, such as mechanical properties, have also been identified and compared with other similar materials [35]. or even other properties of the binder always compared with different materials such as for example bamboo fibres [36], or others such as cork. The starch contained in potatoes is a natural product with added thickening value. Potato starch is obtained through special processes from the rhizomes, tubers and stems of various plants. Potato starch has the same nature and composition as starch and due to these properties, it can be used as a colander.

METHOD

To test heat propagation, an experiment was conducted using thermodynamics as a framework. Heat can propagate through three different processes: conduction, convection, and radiation. In this specific work, we used conduction. In this process, heat propagation is expected without the movement of matter (by conduction). Heat was applied through a 1500-watt hair dryer, raising the temperature of the external surface to 72°-76°C in a short period of time. The internal temperature was then measured, fluctuating between 31°-32°C.

The amount of heat Q transmitted in a given time interval, or the rate of heat transfer identified by the formula $Q/\Delta t$, is:

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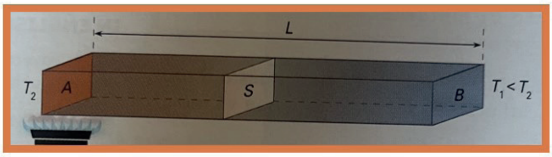
- directly proportional to the propagation surface S;
- directly proportional to the temperature difference ΔT between T_2 and T_1;
- inversely proportional to the length L;
- related to the type of substance, through the thermal conductivity coefficient λ (or K); From the formula:

$$\frac{Q}{\Delta t} = \lambda \cdot S \cdot \frac{\Delta T}{L}$$



Substance	λ (W/m · K)
Silver	429
Gold	315
Aluminum	247
Bronze	116
Cork	0,03
Air	0,02
Humid Earth	0,8

Table 1: Table thermal conductivity coefficient

Some materials and their thermal conductivity: The physical phenomenon of heat propagation in solids, or conduction in solids, occurs through the transmission of heat by direct contact. For example, if we hold an iron bar in our hand by one end and place the other end over a flame, after a while the end we're holding will also begin to burn. In iron, the particles exposed to the flame acquire thermal energy, that is, they increase their state of agitation and, by moving and vibrating, transmit this agitation to nearby molecules. We know that in solids, molecules do not move freely; they do not shift, but always remain aligned with each other. However, they vibrate and transfer their agitation to nearby molecules, thus causing the propagation of agitation and therefore heat by conduction. We know well that a body's ability to transmit heat, or its thermal conductivity, depends on the material it is made of. As can be seen in the table, metals are, in general, good conductors of heat (especially silver, then copper, gold, aluminum, iron, etc.); on the contrary, glass, wood, plastic are bad thermal conductors, because they do not transmit the heat that receive well and for this characteristic they are used as thermal insulators. The analysis and quantification of the new material used as an insulating panel was carried out by measuring the temperatures on the hot and cold sides, and by measuring the temperature variation in relation to time considering a unidirectional heat flow. The results obtained showed that this material can be considered a thermal insulator.

T1 = temperature of the wall in direct contact with the heat

T2 = temperature of the internal wall

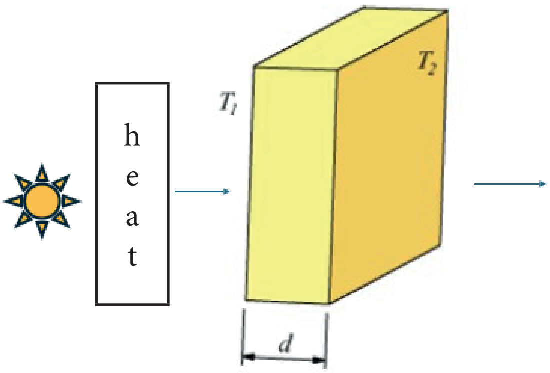


Figure 1: Test tube dimensions d=3 cm, h= 12cm, l=8cm

The experiment relating to the heat transfer equation according to Fourier's law aims to verify how heat is transmitted in a conductive material and to experimentally validate the heat conduction equation. [37]. To experimentally verify Fourier's law, we proceeded by measuring the heat flow in a conductor and comparing it with the temperature gradient. The material used was the heat source (hair dryer), a cold water bottle or heat sink at the opposite end, a thermal imaging camera to measure the temperature, a stopwatch and instruments to record the data.

The procedure first involved

Heating: One end of the panel is placed next to the water, while the other is kept at a lower temperature (or cooled).

$$\mathbf{q} = -k\nabla T$$

Regarding the heat transmitted, $\vec{q}$ represents exactly the local heat flux density [kcal/(h m2)]; k (or λ) is the thermal conductivity of the material [kcal/(h m K)]; and ∇T is the temperature gradient calculated and related to rectangular surfaces [K/m]; the quantity of heat Q transmitted in a time interval represents the rate of heat transmission determined by Q/delta t and is directly proportional to the propagation surface S, directly proportional to the temperature difference T2 -T1, inversely proportional to the length L, and is also linked to the type of material, which is characterized by its own thermal conductivity coefficient K. when referring to thermal comfort, residential thermal comfort refers to the sensation of thermal well-being a person experiences within a living space (such as a home, office, or school) when they feel neither hot nor cold and therefore do not desire to change the room temperature. According to the (Italian) standard UNI EN ISO 7730, thermal comfort is: "That state of mind in which an individual expresses satisfaction with the thermal environment." Therefore, the goal is to achieve maximum well-being with minimum energy consumption.

SPECIMEN PREPARATION

The raw materials, the shells, were combined with potato starch, and and water, the concentration of each component was varied to understand the effect on the measured thermal conductivity.

Figure 2 presents the results of the prototypes built. As in the experimentation described in the previous article [1], six different prototypes were selected. The table reports the composition and the ratio between the raw material and the binder.

Figure 3 schematizes the manufacturing process used to produce the prototypes. The process include several steps:

- Selection of crushed hazelnut shells to standardize the particle size distribution (granulometry);
- Weighing of the shell material (70,100,150 g of hazelnut shells);
- Mixing with the binder (70,100,150 g of potato starch);
- Water (70/100/150 g)
- Use of various ratios between components: (1:1:1), (1:2:1), (2:1:1),
- (1.5:1), (1:1.5), (2:2:2).

The shells and potato starch were manually mixed to form a compact compound. The resulting mixture was placed into molds of dimensions 12× 8 × 3 cm. After molding, the specimens were left to dry for 24 hours. Thermal conductivity was measured using two different methods:

1. **Open environment test**: one side of the prototype was heated; temperatures were measured on both sides over time, allowing for the calculation of ΔT.
2. **Enclosed environment test**: of size 12×8×3 cm was used, containing a 1500-watt heat and a water tank (70/100/150) mL of water in a sealed plastic bag). The prototype was placed between the light source and the water container. The temperatures of both sides of the prototype and of the water were measured experimentally.

Using the data collected and applying Fourier's law (considering heat transfer only in the X-direction), the thermal conductivity coefficient k of the material was calculated.

$$q^{(t)} = \frac{k \cdot A \cdot \Delta T}{L} \qquad q' = \frac{m \cdot c \cdot \Delta T}{t} \qquad k = \frac{m \cdot c \cdot \Delta T \cdot w \cdot L}{t \cdot A \cdot \Delta T}$$

k or λ [kcal/(h · m · K)] is the thermal conductivity coefficient; A [m^2] is the surface area

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Sample	Composition	Ratio (shells/binder)	Apparent Density (g/cm³)
1	Hazelnut/ potatoes/water	1:1:1	0.39
2	Hazelnut / potatoes/water	1,5:1:1,5	0.55
3	Hazelnut / potatoes/water	1:1,5:1	0.37
4	Hazelnut / potatoes/water	1: 1: 1,5	0.36
5	Hazelnut / potatoes/water	1,5: 1,5: 1,5	0.61
6	Hazelnut/ potatoes/water	0,8:0,80:0,80	0.30

Figure 2: Test specimens manufactured for possible use as insulating material.

of the sample; L [m] is the thickness of the sample; and ΔT [K] is the temperature difference between the faces of the sample (i.e., between the hot face on the bulb side and the outer face on the water bag side). $\mathbf{q}(t)$ [kcal/h] is the heat flux in the insulation panel.

For water:

q' [kcal/h] is the heat flow, m [g] is the mass of the water, c is the specific heat of water ($1 \cdot 10^{-3}$ kcal/g · K), ΔT_w [K] is the temperature rise of the water, and t [h] is the duration of the experiment.

The heat flow is equal in both cases because heat is transferred from the bulb side to the water bag through the insulation panel. Therefore, the thermal conductivity coefficient can be calculated.

By equating equations (2) and (3), expression (4) is obtained, from which the thermal conductivity coefficient of the material can be derived. Fourier's Law:

$$q(t) = \frac{k \cdot A \cdot \Delta T}{L} \qquad q' = \frac{m \cdot c \cdot \Delta T}{t} \qquad k = \left| \frac{m \cdot c \cdot \Delta T \cdot w \cdot L}{t \cdot A \cdot \Delta T} \right.$$

- q [kcal]: heat flow
- k [kcal/(h · m · °C)]: thermal conductivity coefficient

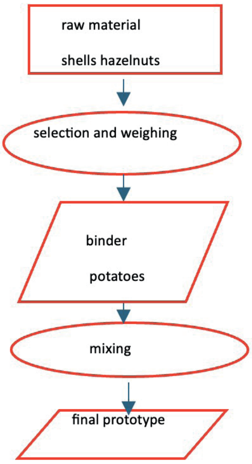

Figure 3: Scheme of the fabrication of an insulation panel specimen.

- A [m²]: surface area of the specimen
- ΔT [°C]: temperature difference between the faces of the specimen
- L [m]: thickness of the specimen
- m [g]: mass of water
- c [$1 \cdot 10^{-3}$ kcal/(g · °C)]: specific heat of water
- ΔT_w [°C]: temperature increase of the water
- t [h]: time

RESULTS AND DISCUSSIONS

In a building, energy efficiency is defined as the optimal use of energy to perform all daily functions, such as heating, cooling, lighting and the operation of household appliances. The aim of this category of research is to obtain maximum comfort and functionality in buildings with the minimum possible energy consumption; let's think for example of the study conducted by Hoppe P. [39] suggesting that the use of non-stationary methods such as the Universal Thermal Climate Index (UTCI) is preferable, suggests the use of non-stationary methods such as the Universal Thermal Climate Index (UTCI). This refers to an evolution of human thermal comfort assessment methods that consider the temporal and spatial variability of the environment, rather than assuming stationary and uniform conditions (as more traditional methods, such as PMV – Predicted Mean Vote, did). A non-stationary method, on the other hand, considers the dynamic variations of climate parameters (temperature, humidity, wind, solar radiation, etc.) over time and space, and considers the dynamic physiological and behavioral response of the human body. In other words, it simulates a real, evolving situation, not a static environment. Thermal comfort is also addressed in international standards [40,41]. The energy standard in European countries such as Spain is in accordance with the basic building code (Norma Basic building NBE-CT-79); in Italy, Technical Standards for Construction (NTC 2018) establish safety and design requirements. Furthermore, the energy efficiency regulations (Legislative Decree 192/2005) and the minimum environmental criteria (CAM). Regarding the heat transmitted, $\vec{q}$ represents exactly the local heat flux density [kcal/(h m2)]; k (or λ) is the thermal conductivity of the material [kcal/(h m K)]; and ∇T is the temperature gradient calculated and related to rectangular surfaces [K/m]; the quantity of heat Q transmitted in a time interval represents the rate of heat transmission determined by Q/delta t and is directly proportional to the propagation surface S, directly proportional to the temperature difference T2 -T1, inversely proportional to the length L, and is also linked to the type of material, which is characterized by its own thermal conductivity coefficient K. when referring to thermal comfort, residential thermal comfort refers to the sensation of thermal well-being a person experiences within a living space (such as a home, office, or school) when they feel neither hot nor cold and therefore do not desire to change the room temperature. According to the (Italian) standard UNI EN ISO 7730, thermal comfort is: "That state of mind in which an individual expresses satisfaction with the thermal environment." Therefore, the goal is to achieve maximum well-being with minimum energy consumption. The study by Pineda et al. [´ 42] analyses a multi-family house in a Mediterranean climate, as well as the study by Cerezo-Narvaez which elaborates answers on the energy impact, the impact on emissions in the environment and in the economy[43]. Similarly, the present work aims to give a contribution regarding the modern needs of living in a comfortable environment and respecting the environment by using biological materials. By analyzing the prototypes obtained, thermal conductivity values of k = <u>0.027</u> kcal/(h · m · K) were recorded, were recorded, the lowest recorded. This value is very similar not only to that obtained with other products of natural origin such as cork, but also to the prototypes from the first experimentation [1], which used a different binder. Furthermore, these values fall within The various thermal insulating materials currently used mostly concern materials such as expanded polystyrene which has a good thermal coefficient K equal to 0.033 kcal/(h m K), but it must be underlined that it is a material derived from petroleum. Similarly, in the building industry there are also some natural materials such as cork which is very widespread in construction and has a good thermal coefficient of 0.041. Nevertheless, it is necessary to make ever greater efforts to ensure that petroleum-derived products are replaced by biological materials. With this new material, the thermal coefficient obtained is quite good as it is on average around 0.030.

The thermal conductivity obtained in the new material was compared with that of a cork insulating panel. It was found that the thermal conductivity coefficient obtained with this method is k = 0.030 kcal/(h m K), the reference standards (UNE 5690, in Spain Basic Standard for Construction NBE-CT-79) and Technical Standards for Construction (NTC 2018), and Technical Standards for Construction (NTC 2018), in Italy, the consolidated Law regulates various aspects of construction and renovation, while the NTC. It is therefore demonstrated that "the use of the thermal box and the application of Fourier's law equations allow us to obtain a reliable thermal conductivity coefficient." This method was then applied to the insulating panels produced. The thermal conductivity coefficient was calculated for all the samples, comparing the results with data for other materials obtained from the literature. It is important to note that the material produced is completely natural, recyclable, and renewable, as it is of plant origin and therefore considered waste material.

Figure 4: Insulation panels made of biomaterials. Showing the top and the side of them.

Composition:
1. Hazelnut / potato / water: 1:1:1
2. Hazelnut / potato / water: 1.5:1:1.5
3. Hazelnut / potato / water: 1:1.5:1.5
4. Hazelnut / potato / water: 1:1:1.5
5. Hazelnut / potato / water: 1.5:1.5:1.5
6. Hazelnut / potato / water: 0.80:0.80:0.80

With regard to the binder used, a fairly good thermal conductivity coefficient was obtained, likely due to the elasticity observed in materials derived from potatoes.

The values of the thermal conductivity coefficient (k), expressed in kcal/(h· m · K), were determined by measuring the thermal conductivity of each prototype. The k values reported in the table represent the average of three measurements taken for each material.

The results are comparable to those of materials currently used in the market, such as expanded polystyrene (k = 0.029 kcal/(h · m · K)), cork (k = 0.038 kcal/(h · m · K)), or glass fiber (k = 0.040 kcal/(h · m · K)).

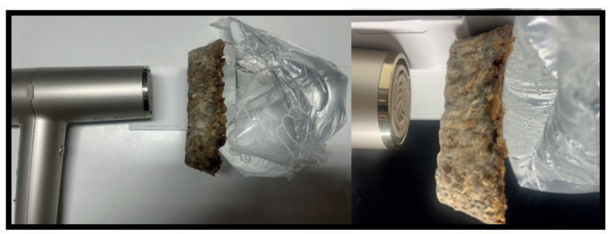

Figure 5: Schematic (a) and photograph (b) of the thermal box used.

Therefore, hazelnut and walnut shells can be considered as a promising material for the production of insulation panels, offering an environmentally friendly solution as they are biodegradable waste. In doing so, the principles of the circular economy are applied, contributing to improving the sustainability of the construction sector.

Further studies would be necessary to optimize the shell-to-binder ratio and quantify the environmental benefits. Nevertheless, this study demonstrates that hazelnut and walnut shells represent a valid alternative for the development of eco-sustainable insulating panels.

CONCLUSIONS

Continuing to analyze the work done previously [1] it was possible to demonstrate once again that the shells of walnuts and hazelnuts constitute an important natural raw material which, by using it in the construction of insulating panels, in this case the starch contained in potatoes was added as a binder (this too is a completely natural material) which, assembled in a panel way, works very well as a thermal insulator, therefore it was found that, by using these two materials further advantages are obtained, first of all the reuse of a waste material, such as the senda thing, it is a completely natural biomaterial, therefore the environmental impact is zero, secondly the potatoes which are a vegetable widely cultivated throughout the world and easily available; It's therefore important to consider that today, the entire world is called upon to work to reduce environmental pollution. Therefore, responsible and environmentally friendly choices are necessary, especially in the construction sector, which is one of the most polluting. Choosing to use organic and natural materials is crucial. This is why the raw material chosen was hazelnut shells, which are, moreover, a waste material and, through this production process, become a new organic material.

Hydrocarbon-based insulation panels are widely used in the construction sector. Furthermore, their life cycle is often optimal, which provides an advantage during disposal.

Beyond the environmental benefits, this study has verified that the thermal conductivity coefficients of the insulating panels produced are optimal and comparable to those of commercial insulating materials currently on the market. From the work done, we can conclude:

- The thermal conductivity coefficients obtained for the biomaterials are between 0.030 and 0.070 kcal/(h · m · K).
- The raw materials (shells) are biological waste products and can be effectively reused to produce insulating panels.
- These natural materials offer a sustainable alternative to more polluting options and contribute to reducing the environmental impact of the construction sector.

The inclusion of new materials—such as ecological waste biomaterials—in the construction industry is essential for improving the sustainability of the sector and reducing its overall environmental footprint.

Sample	Composition	Ratio (shells/binder)	Coefficient of thermal conductivity (Kcal/h·m·K)
1	Hazelnut/ potatoes/water	1: 1: 1	0.078
2	Hazelnut / potatoes/water	1,5:1: 1,5	0.052
3	Hazelnut / potatoes/water	1: 1,5:1	0.027
4	Hazelnut / potatoes/water	1: 1 : 1,5	0.063
5	Hazelnut / potatoes/water	1,5 : 1,5: 1,5	0.070
6	Hazelnut/ potatoes/water	0,8:0,80:0,80	0.075

Figure 6: Test specimens manufactured for possible use as insulating material.

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