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THE POTENTIAL USE OF GIANT REED FROM PORTUGAL AS A THERMAL INSULATION MATERIAL

Raphaele Malheiro[a], Aurora Morilla[b], Adriana Ansolin[c], Jorge Fernandes[c], Sandra Silva[c], Ricardo Mateus[c,*]

[a] *University of Minho, Department of Civil Engineering, CTAC, Campus de Azurém, 4800-058, Guimarães, Portugal*

[b] *Universitat Politècnica de Catalunya, Carrer de Jordi Girona, 31, 08034, Barcelona, Spanish*

[c] *University of Minho, Department of Civil Engineering, ISISE, Campus de Azurém, 4800-058, Guimarães, Portugal*

[*] corresponding author: ricardomateus@civil.uminho.pt

Abstract. The construction sector plays an important role in climate change. Thus, there is a pressing need to construct buildings that reduce heat losses, use natural and local materials, exploit renewable sources and ensure high comfort levels with a minimum environmental impact. Reed, considered carbon-neutral and a carbon dioxide sink material, has been used for centuries for diverse uses. Its properties and high availability made it a popular building material, as seen in Portuguese vernacular architecture. Knowing the properties of the reed is a crucial step to ensure successful heritage conservation, optimising these materials, and developing innovative solutions. This paper studies the potential of using giant reed from different Portuguese regions as a thermal insulation material. Giant reed board prototypes ($15 \times 15 \times 5$ cm, about $235\,\mathrm{kg/m^3}$) were built. Their thermal performance was tested in a hotbox, according to ASTM C1363 19. The results show that the giant reed harvested on the northern coast of Portugal has better thermal performance than reeds from other regions. However, regardless of the region of the country where the giant reed was harvested, it has a satisfactory thermal resistance (Re ≥ 0.30 $(\mathrm{m^2 \cdot {}^\circ C})/\mathrm{W}$), allowing its use as a thermal insulation material in the buildings.

Keywords: Giant reed, thermal insulation material, natural material, low cost, sustainability.

1. Introduction

The construction sector is one of the largest energy consumers. It is under pressure to improve its energy efficiency and environmental performance and reduce non-renewable resource use. The largest part of buildings energy consumption is related to the operation phase. Energy poverty is still high in the European Union (EU), and Portugal is one of the EU countries where the consequences of energy poverty are most evident. A large part of the Portuguese building stock was built before the first thermal regulation came into force DL 40/90 [1], resulting in reduced thermal insulation and inadequate adaptation to the climatic context.

The use of natural materials in construction can be a great advantage. Using these materials in construction can reduce the environmental impact compared with non-natural materials, reaching similar or better characteristics in some cases. Reed, considered carbon-neutral and a carbon dioxide sink material, has been used for centuries for diverse uses. Its properties and high availability made it a popular building material, as seen in Portuguese vernacular architecture. The Arundo donax, giant reed, has been identified in Portuguese vernacular architecture, mainly in walls [2] and roofs [3], to provide better thermal insulation to the buildings.

Several authors have studied the thermal insulation properties of natural materials (cork, reed, bagasse, cattail, corn cob) to assess the opportunity to use them in the buildings [4]. The potential of using reed as thermal insulation has also been investigated [5–7]. Some studies have evaluated the thermal potential of boards where the reed is the main material [6], and others have evaluated boards made only with reed [7]. Boards of giant reed harvested in Portugal were used in a prototype of a building solution based on earth and reeds (stem and fibres) [8]. The prototype, built in Lisbon, had its indoor and outdoor temperatures monitored during different seasons. The researchers concluded that the solution contributed to controlling the indoor air temperature, given the thermal amplitudes that were registered outside. Regarding boards made only with reeds harvested in Portugal, no results were found. The studies highlighted the thermal insulation potential of the reed around the world.

Since the properties of natural materials can be site-dependent [9], it is important to know the thermal insulation properties of reeds harvested in Portugal. The plant growth and development are influenced by several environmental factors, such as temperature and humidity [10, 11]. Thus, the origin of the plant can influence its characteristics. In this sense, this paper

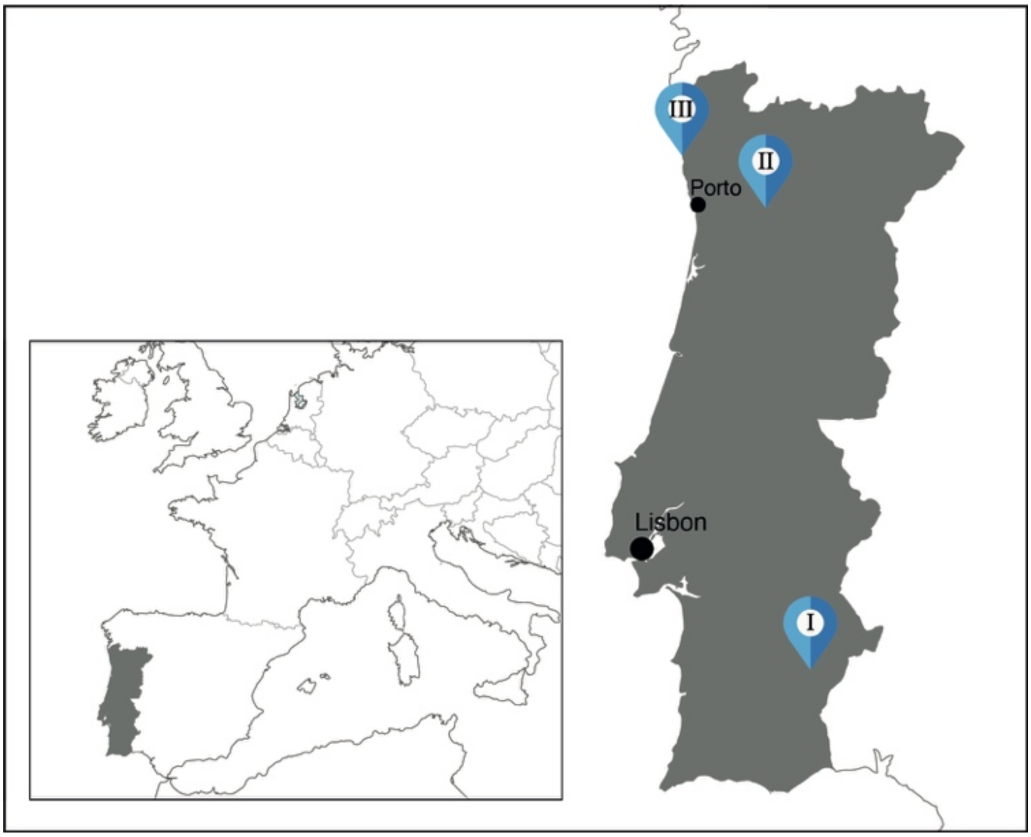

Figure 1. Giant reed harvest regions: Serpa (I), Santa Cruz do Douro (II) and Apúlia (III).

studies the potential of using giant reed from different regions of Portugal as a thermal insulation material. This investigation assessed the thermal behaviour of reed, aiming to produce knowledge that can be used to design new solutions for more sustainable construction and heritage conservation.

2. Reed: specie identification and climate characterisation of harvesting regions

Reed species studied is *Arundo donax*, also called as giant reed. This species is widespread throughout the Portuguese territory, being an invasive plant. Considering the country climatic differences, three different regions were chosen for harvesting the reed: Serpa (I), Santa Cruz do Douro (II) and Apúlia (III) (Figure 1).

Serpa is a city located at 200 m above sea level [12] and it is characterized for having a temperate climate – Type C – according to Köpp-Geiger Climate Classification, sub type Csa (temperate with hot and dry summer) [13]. Serpa is the least rainy and hottest region studied. The average total annual precipitation is 400 mm, and the annual average mean temperature is 17.5 °C. Regarding the extremes, the annual average minimum and maximum temperature are 12.5 and 25.0 °C, [13]. Santa Cruz do Douro is a Parish located at 400 m above sea level [12]. According to the Köppen-Geiger its climate is also Type C, sub-type Csa [13]. The average total annual precipitation is 800 mm and annual average mean temperature is 15.0 °C. Regarding the extremes, the annual average minimum and maximum temperatures are 10.0 and 17.5 °C, respectively [13]. Apúlia is a village on the northern coast of Portugal located at 10 m above sea level [12]. According to the Köppen-Geiger its climate is also Type C, but the sub-type is Csb (temperate with dry or temperate summer) [13]. Apúlia is the rainiest region studied. The average total annual precipitation is 1400 mm, and annual average mean temperature is 15.0 °C. Regarding the extremes, the annual average minimum and maximum temperatures are 10.0 and 17.5 °C, respectively [13].

3. Experimental program

3.1. Reed boards preparation

Three reed board prototypes were developed to evaluate the performance of giant reed harvested in different regions of Portugal as an insulation material. One board with 150 × 150 × 50 mm was built for each studied region (Figure 2). The giant reed board prototypes were prepared using a three stage process: cut the reed stems in parts with 150 mm length; steel wireframe preparation using the pre defined dimensions (Figure 3); accommodation of reeds cut into steel wireframe (Figure 4).

The wireframe was developed using steel wire only in the board's borders to minimise its influence on the heat flux during the tests. Furthermore, the se-

ID	Quantity of reed in the board [unit]	Steel wire mass [g]	Board mass (initial): reed + wire [g]	Final thickness [mm]	Density of board [kg/m^3]
I	41	19.50	295.1	55	237.1
II	33	19.50	260.5	50	231.6
III	29	19.50	287.9	50	255.9

Table 1. Characteristics of the reed board prototypes.

Figure 2. Reed board prototype.

Figure 3. Steel wire frame.

Figure 4. Accommodation of reeds into the frame.

lection of reeds was made considering their regularity along the length. It was also used different diameters of reed to achieve a better accommodation between them. The final thickness of the reed board prototype is related to the accommodation of reeds into the frame. Considering the reed as a hygroscopic material, the reed boards mass were verified before (initial mass) and after (final mass) the tests. The main characteristics of the reed board prototypes (including initial mass) are presented in Table 1.

3.2. Thermal performance

The thermal performance of giant reed board prototypes was evaluated considering their thermal resistance (*Re*) and thermal conductivity (λ). These parameters were determined using a calibrated hotbox designed and built at the Department of Civil Engineering of the University of Minho, based on ASTM specifications C1363 [14].

The hotbox is composed of two chambers, the cold and the hot one, and one mounting ring placed between the two chambers. The giant reed board prototype was placed in the centre of the mounting ring. It was enclosed between two Medium Density Fibreboard (MDF) boards to provide a flat surface for installing the flux meter and controlling the air permeability between the two chambers [15]. Since in a previous study, Malheiro et al. [16] concluded that geometric configuration has no influence on the thermal performance of the giant reed board prototype, it was tested in a vertical position. The variation of the giant reed board prototypes mass during the test was evaluated.

The tests were carried out considering the heat flow meter method, defined in ISO 9869-1 standard [17]. The heat flux is measured through a heat flux sensor installed in the giant reed board prototype's central

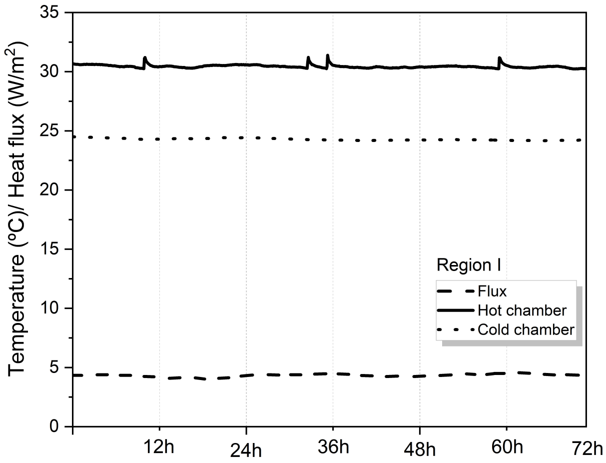

Figure 5. Region I reed board prototype: temperatures and heat flow.

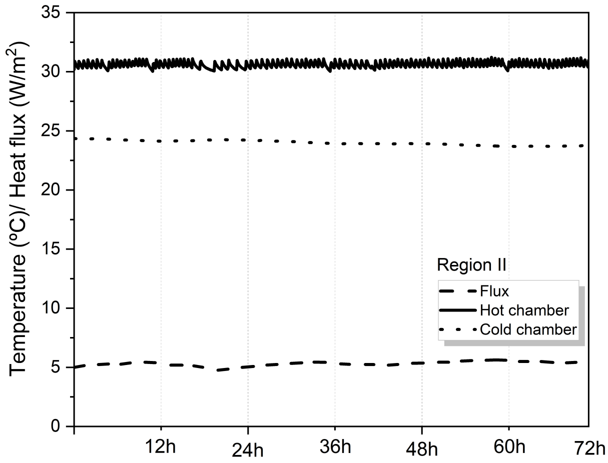

Figure 6. Region II reed board prototype: temperatures and heat flow.

part, and thermocouples measured the temperatures. With the values of the heat flux (q) and the surface temperatures (T), it was possible to determine the thermal resistance (Re) of the set of materials (giant reed board prototype + MDF), using Equation (1). ΔT is the difference between the surface temperature of the MDF in the hot and cold chambers. The thermal resistance of the giant reed board prototype was determined using Equation (2). The reed board prototype's thermal conductivity (λ) was assessed using Equation (3), where e is the board's thickness.

$$Re_{set}\ [(\mathrm{m}^2 \cdot {}^\circ\mathrm{C})/\mathrm{W}] = \frac{\Delta T}{q} \tag{1}$$

$$Re_{reed}\ [(\mathrm{m}^2 \cdot {}^\circ\mathrm{C})/\mathrm{W}] = Re_{set} - (2 * Re_{MDF}) \tag{2}$$

$$\lambda_{reed}\ [\mathrm{W}/(\mathrm{m} \cdot {}^\circ\mathrm{C})] = \frac{e}{Re_{reed}} \tag{3}$$

4. Results

4.1. Thermal performance of reed board prototype

Figures 5 to 7 represent temperatures and heat flow reached during 72 hours test [17] in the hotbox for each board studied.

From Figures 5 to 7, it is possible to see that temperature in the cold chamber and heat flow remained very stable during the test period, regardless of the giant reed board studied. Concerning the temperature in the hot chamber, a slight perturbation is observed during the test, being more evident in the giant reed board from Region III. This variation in the hot chamber temperature does not influence the heat flow during all test periods. The heat flow remained very stable, maintaining an average value of 4.36 W/m^2, 5.35 W/m^2 and 4.39 W/m^2 for Regions I, II and II, respectively.

Table 2 summarises the final mass of prototypes and the average values obtained for their thermal

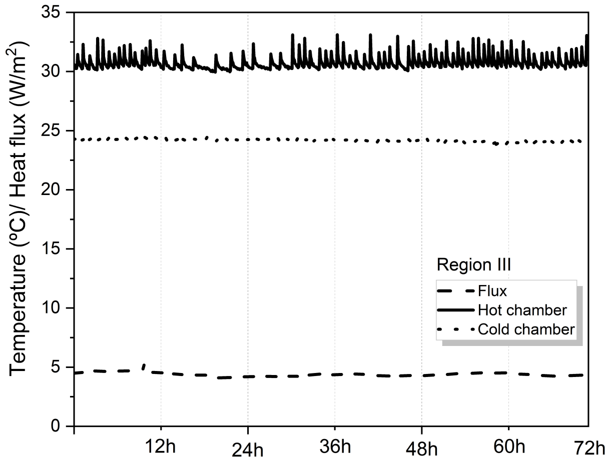

Figure 7. Region III reed board prototype: temperatures and heat flow.

properties. These values were calculated based on the results from Figures 5 to 7, using Equations (1) to (3).

Table 2 shows that the reed board prototype from Region III has the greatest thermal resistance and the least thermal conductivity between the board studied. The boards from Regions I and II show very similar values for the thermal properties studied. Comparing final and initial (Table 1) board mass, it is clear that the mass variation has no significance, being the loss always less than 0.70 %.

5. Giant reed board prototype as insulation material

The results presented in Section 4 show a satisfactory thermal performance for the giant reed board prototypes, regardless of the region from where the reeds were harvested. The values achieved for thermal conductivity are very close to the values presented in the current literature, 0.045–0.056 W/m · °C [23]. Furthermore, comparing the performance of boards made using only reeds, the thermal conductivity achieved in this study is lower than that achieved by Asdrulali et al. [5] using the hotbox test method, 0.065 W/m.ºC.

ID	Board mass (final): reed + wire [g]	Re_{set} [m$^2\cdot$°C/W]	Re_{MDF} [m$^2\cdot$°C/W]	Re_{reed} [m$^2\cdot$°C/W]	λ_{reed} [W/m $\cdot$ °C]
I	293.4	1.313	0.147	1.019	0.049
II	258.7	1.247	0.147	0.953	0.052
III	287.0	1.501	0.147	1.207	0.041

Table 2. Characteristics of the reed board prototypes.

Material	Thickness [mm]	Density [kg/m^3]	*Re* [m$^2\cdot$°C/W]	Reference
Rock-wool	60	25	1.60	[18]
XPS	50	32	1.40	[19]
EPS	50	20	1.30	[20]
Cork	50	110	1.25	[21]
Giant reed	50–55	237–266	0.95–1.21	This study

Table 3. Characteristics of the thermal insulation materials (adapted from [22]).

The board developed by Asdrulali et al. [5] has a similar thickness, 56 mm, a lower density, around 90 kg/m^3, and different reed species, *Phragmites australis* (common reed). The difference in the density is probably related to the reed species used and, consequently, the number of reeds used and accommodation between them. Common reed and giant reed have a marked difference in their average diameter: around 1.0–2.5 cm and 2.5–5.0 cm [24], respectively. In this sense, the comparison of results from different studies should be made with caution.

Considering the Portuguese thermal regulation, the thermal resistance and thermal conductivity values achieved are in accordance with the requirements defined for thermal insulation material, that is $Re \geq 0.30$ (m$^2\cdot$°C)/W [25]. Furthermore, when comparing the giant reed board prototypes studied with some insulation materials commercially used in Portugal, a similar performance is observed (Table 3). Considering similar thickness, the thermal resistance of reed board represents at least 60 % of the thermal resistance of rock-wool and 76 % of the thermal resistance of cork, for instance.

Concerning the giant reeds origin, observing Table 2 data, it is possible to say that the climate of the reed harvest region has no significant influence on the thermal performance of the giant reed board prototypes studied. Despite that, the board made with reed harvested in Region III, the rainiest region studied, has the highest thermal resistance and the least thermal conductivity. This behaviour may be related to the density of the board since the reed board made with reed harvested in Region III has the highest density. It is important to know that the reed board prototype III reached a highest density using fewer reeds than prototypes I and II (Table 1).

These results confirm the potential of the giant reed harvested in Portugal to be used as a thermal insulation material. In addition to the advantages in terms of insulation, reeds have other ecological benefits. They are considered a carbon-neutral and a carbon dioxide sink material and have the advantage of being biodegradable and low-cost.

6. Conclusions

An experimental investigation was carried out to evaluate the potential of using giant reed (*Arundo donax*) harvested in Portugal as a thermal insulation material. Considering the influence of climate in the plant growth, reed board prototypes were made using giant reed from three different regions from Portugal.

The results show a satisfactory thermal performance for all the reed board prototypes, regardless the region where the reeds were harvested. The values achieved for thermal resistance, 0.9–1.2 m$^2\cdot$°C/W, are in accordance with the requirements defined for thermal insulation materials in the Portuguese thermal regulation. Comparing these reed boards with some insulation materials commercially used, it is observed a similar thermal behaviour. Concerning the giant reed origin, the reed board prototype made with reeds from Region III shows a slightly better thermal performance than the others.

Analysing the results, it is possible to conclude that, under the studied conditions, regardless the harvesting region studied, the reed boards showed satisfactory thermal performance. However, it is important to consider different possibilities to contain the boards (wood boards, plasterboards, mortars). Additionally, as the reed is abundant throughout Portugal, its use is an eco-friendly and low-cost option that gathers all conditions to be used in the construction market.

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