Development of an ecological thermal insulation product for a regenerative design

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Although thermal insulation materials contribute to reducing energy demand, the most used materials have high embodied energy. Bio-based thermal insulation products stock CO_2 and therefore have lower embodied energy.

The research work aims to develop a modern bio-based thermal insulation product based on invasive species in Portugal. Its use has a positive impact on controlling the spread and creates a value chain for this resource.

Portuguese vernacular architecture uses reed as a raw material to develop insulation solutions, demonstrating the fibre's potential. This work intends to characterise the Cortaderia Selloana reeds in order to understand its possibilities as an insulation material.

Main objectives:

- ❑ to develop and study the manufacturing processes of two prototypes of insulation panels, in compliance with regulatory requirements: one with the whole sections of culms and the other using the waste of the first in a crushed reed agglomerate;
- ❑ to analyze the environmental and economic life cycle performance of the new insulation products, comparing them with conventional ones;
- ❑ to contribute to a circular economy by developing low environmental impact, low raw material processing, and low-cost and biodegradable products.

Recent studies show that despite the high thickness required by bio-based insulation, it compensates with negative CO_2 emissions, see figure 1.

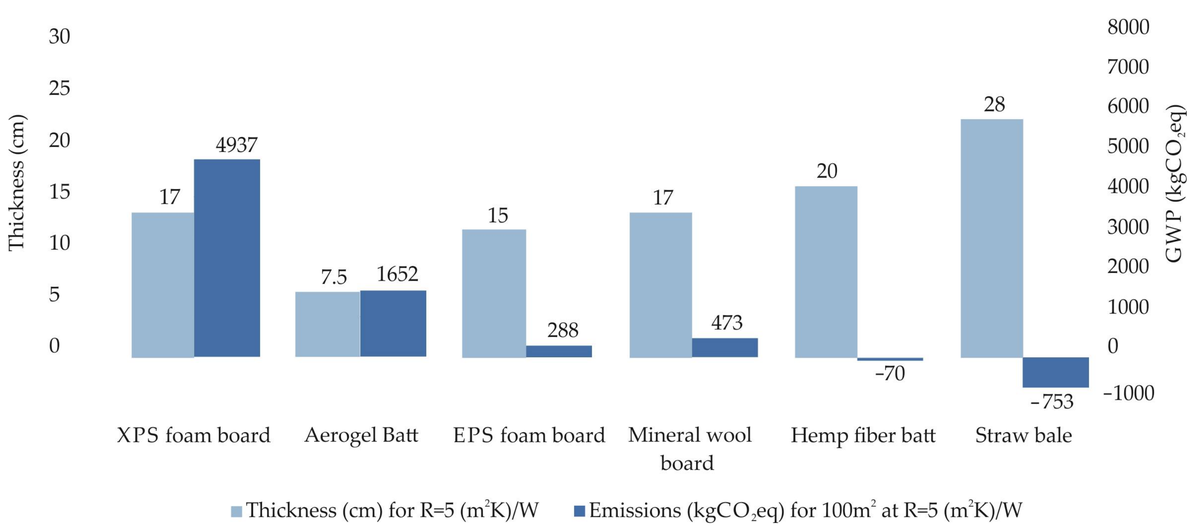

Figure 1: Comparison between insulation material thickness and carbon dioxide emissions for a 5 (m^2K)/W thermal resistance. Adapted from: Magwood, C., Bowden, E., & Trottier, M. (2022). Emissions of Materials Benchmark Assessment for Residential Construction Report.

Source: Cosentino, L., Fernandes, J., & Mateus, R. (2023). A Review of Natural Bio-Based Insulation Materials. Energies, 16(12). https://doi.org/10.3390/en16124676

The growing interest in bio-based materials and techniques for regenerative buildings is driven by several advantages, notably the low or even negative embodied energy. In this scope, fast-growing plants play an important role as they require less time to grow and consequently have a greater capacity to capture CO_2 from the atmosphere.

Limited research has been conducted on the environmental performance of bio-based insulation materials. By conducting comprehensive environmental studies, the benefits of using these materials will be highlighted and wider adoption will be encouraged. Ecological innovations have the potential to replace conventional materials while ensuring equivalent energy efficiency during the operation phase of buildings.

Among recent publications, a lack of characterization of thermal mass and thermal inertia, which can be characterized by heat capacity and diffusivity parameters, was also identified. This characterization can enhance the development of more effective construction solutions, especially for the renovation of vernacular buildings. Achieving a comprehensive characterization of both the existing and prospective materials allows straightforward and cost-effective building renovation, without encountering issues like excessive condensation and poor use of the passive energy potential offered by these materials.

Figure 2: *Cortaderia Selloana*.

Figure 3: *Cortaderia Selloana* stems (a) and experimental blocks (b).

In this scope, *Cortaderia Selloana* stems were evaluated on several physical and mechanical characteristics for a better understanding of the material.

The latest characterization tests show that:

- ❑ The found natural moisture content of around 9% is similar to other reed species.
- ❑ Water absorption is characteristic of this kind of plant, however, *Cortaderia Selloana* has a hydrophobic outer wall with a highly hydrophilic interior, especially at the nodes, probably due to its internal structure.
- ❑ Fourier-transform infrared spectroscopy (FTIR) showed a high composition of cellulose in the inner wall, while the outer wall was composed mainly of wax, as expected for a reed.
- ❑ The thermal conductivity of *Cortaderia Selloana* panels (figure 3) is similar to commercialized cork insulation panels.
- ❑ The first microscopic observations showed a fibrous internal structure with many voids (figure 4), explaining the low density of the material.
- ❑ In mechanical characterization, it was observed that the structure of the stem is quite elastic, as it does not suffer major ruptures and tends to return to its original shape after flexural strength tests.

Figure 4: Microscope images. (a) Node ampliation of 100x, (b) Stem section ampliation of 100x, (c) internal ampliation of 400x; (d) external walls ampliation of 400x.

The following work to be done will focus on creating panels with crushed reed and binders to evaluate performance and propose a commercialized insulation material.

The potential industrialization process of the products will be studied, and their economic and environmental performance will be evaluated and compared with the conventional insulation materials used.

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