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Advanced Design for Experimental Optimisation of Physico-Mechanical Characteristics of Sustainable Local Hemp Concrete

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Abstract: The meaning of technological progress is to produce economic development and to increase the level of personal comfort. Sustainability can only be achieved if, at the microsystem level as well as at the macrosystem level, the secondary effects of the activities undertaken by people on the environment are in a state of neutrality compared to the impact they can produce on natural conditions. This neutrality can be intrinsic or can be achieved through coercive and compensatory measures. If we take into account the production of carbon dioxide that accompanies a product from the stages of conceptualisation, design, procurement of materials, execution, operation, maintenance, decommissioning and recycling the waste produced at the end of use, then nothing can be sustainable in pure form. Nevertheless, there are products whose production, both as a raw material and as a technological process, can be neutral in terms of carbon emissions. Moreover, they can even become carbon negative over time. This is also the case with eco-sustainable hemp concrete, whose capacity to absorb carbon dioxide starts from the growth phase of the plant from which the raw material is obtained and continues throughout the existence of the constructed buildings. Not only does it absorb carbon dioxide, but it also stores it for a period of at least 50 years as long as the construction is guaranteed, being at the same time completely recyclable. However, in order to obtain an optimal mixture from the point of view of raw material consumption, represented by industrial hemp wood chips and the binder based on lime and cement, multiple experiments are necessary. The study presented in this work is based on the use of an advanced method of experimental planning (design of experiments method), which makes possible the correlation between the values obtained experimentally and the algorithm that generated the matrix arrangement of the quantities of materials used in the recipes. This approach helps to create the necessary framework for parametric optimisation with a small number of trials. Thus, it is possible to obtain the mathematical law valid within the minimum and maximum limits of the studied domain that defines the characteristics of the material and allows the achievement of optimisation. The material is thus designed to satisfy the maximum thermal insulation requirements that it can achieve depending on a certain minimum admissible compressive strength.

Keywords: local hemp concrete; design of experiments method; advanced optimisation

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1. Introduction

More than 36 years have passed since the first officially mentioned use of hemp concrete [1]. Studies on this bio-composite material [2,3] are continuously developing, so there are important works presenting applications [4–8] of this material in the field of construction [9–12]. It can be used to build insulating walls using self-supporting bricks or as infill in lost formwork and for the plastering layer both in new construction and the renovation of traditional buildings. It is often used to insulate floors, walls, and roofs. It is also used for casting leveling layers due to its low specific weight. Due to the natural porosity of hemp, it can be used successfully in sound-absorbing insulation or for vibration damping. By modifying the grain size and using automated mixing technologies, constructions can be obtained using 3D printers. However, the versatility of this eco-sustainable material [13–16] continues to be surprising, with the possibility of its use in more and more industries [17–19].

Previous studies have shown the thermo-mechanical performance of hemp concrete [20–26] with the limitations of being a non-structural material [27–30], but at the same time, it excels when it comes to heat transfer and the thermo-regulating capacity of ambient humidity, which makes it recognised as a very good thermal insulation material with a decisive role in increasing the hygro-thermal performance of sustainable constructions [31–33]. The fact that it is obtained from natural sources as a by-product of agricultural activities qualifies it in the race for the best products with potential in the circular economy [34] while contributing to the reduction of carbon emissions [35–38]. Today's society, in the midst of the changes imposed by climate change, is forced to adopt a different way of life. It has to learn to repress its previously acquired routines and change its habits in order to develop new, environmentally friendly reflexes. Despite the benefits that hemp concrete and hemp, in general, can offer, the media coverage, adoption, and application of technological solutions that implement this plant-based concrete are mainly reduced by the reluctance created due to the industry producing dedicated and traditional conventional building materials, which facilitates the application of easy-to-use installation technologies by anyone with minimal skills. The placing of hemp concrete, although it has various technological variants [39,40], involves greater attention and an additional workload both for the mixture and installation, as the material has a different consistency from any type of mortar mixture or conventional concrete.

Hemp concrete mixtures are differentiated by the construction element for which the mix is made. Depending on the ratio of hemp, binder, admixtures, and water used, selective thermo-mechanical properties can be obtained for both the heat transfer coefficient and compressive strength. The possibility to design the material according to the energy efficiency requirements, the advantage of being obtained from sustainable raw materials, and the ability to be used at the end life cycle as recycled aggregate concrete [41,42] have contributed to our attempt to optimise the physico-mechanical performances using an advanced method of conducting experiments. The method is based on statistical computation used both for the design of laboratory trials and for the interpretation of test results, hereafter referred to as design of experiment (DoE). This is an advanced experimental design technique discovered by Sir R. A Ficher in the 1920s, an English statistician who introduced it in Europe to the major prestigious universities with which he was associated through the book *The Design of Experiments* [43,44], published in its first edition in 1935. This book was based on a first work by the author in 1925 [44], which was in fact a laboratory guide presenting this revolutionary method. Used in agriculture for the first time by Fisher, the method was developed by statisticians Box and Wilson [45] in the era of the first industrial revolution between 1950 and 1970, who introduced the concept of response surface modelling for non-linear phenomena and helped users to optimise industrial processes, especially in the chemical industry at that time, by identifying the combination of parameters that could influence a process so as to obtain a desired optimum on a physical or mechanical characteristic of the process.

The second industrial revolution between the 1970s and 1990s was mentored by Taguchi [46], a Japanese engineer who introduced the concept of quality quantified by S/N (signal-to-noise ratio) and the robustness of industrial processes by decreasing the variability of the multiple responses of such a complex system. This industrial era, also known as the quality revolution, contributed to the development and consolidation of robust products that had, as an essential characteristic, greater durability over time and, as a result, much-improved customer satisfaction.

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