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An integrated design approach to the development of a vegetal-based thermal plaster for the energy retrofit of buildings

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ABSTRACT

Novel vegetal-based thermal plasters have been developed, in the framework of a joint research project involving manufacturers and research centers, adopting an integrated multi-objective design process. The adopted methodology, here specifically implemented for vegetal-based hydraulic lime thermal plasters for energy retrofitting purposes, has pointed out the importance of a multi-criteria optimization when studying the development of materials to be used in a retrofitting process, where true sustainability implies that many different aspects need to be tackled contemporarily.

The most effective plaster blends have been identified and tested, through an iterative process, which has involved moving from the material/component level to a real building application and taking into account environmental, technological, energy and comfort related issues.

1. Introduction

The energy retrofitting of existing buildings is one of the key issues the EU is currently fostering through a number of actions aimed at supporting the renovation and refurbishment process of the highly energy consuming building stock.

Within this framework, it is known that there is a large energy saving and CO_2 emission reduction potential in Italy, since more than 60% of the building stock is over 45 years old and more than 25% of the total number of buildings are in the 160–220 kWh/m^{2}y consumption band [1]. No renovation policy has been introduced for most of these buildings over the last 20 years, and an extensive renovation is therefore needed, combined with a functional refurbishment and an enhancement of the Indoor Environmental Quality. Nowadays, two thirds of the investments in the building sector are related to renovations of existing buildings, thus showing a by now well-settled trend towards the recovery of the building stock [1].

Interventions on the building envelope represent an energy and cost effective solution, and also play an important role in achieving better conditions for the users, as far as thermal, visual and acoustic comfort as well as indoor air quality are concerned. Nevertheless, the identification of the right strategy to adopt on an existing wall is quite a complex task, since compatibility (from the aesthetical, physical and technological points of view) and edge effects (i.e. thermal bridge) need to be evaluated carefully. In this context, thermal insulating plasters represent an interesting solution, as they are constructive elements that have been used for thousands of years, which show high versatility and increasingly higher technical performances. The growing and renewed interest in this material is pointed out by the high number of researches that have been carried out in this field over the last few years. Some keywords dominate R&D in this field and respond to reflect market trends: high energy efficiency (low thermal conductivity); low environmental impact (low embodied energy); natural origin (as opposed to synthetic materials); low pollutant emissions (VOC and formaldehyde emission control).

A relevant part of the current research activity is focused on the development of highly insulating plasters, such as aerogel based blends, which show very low thermal conductivity and result in a noticeable reduction of the layer thickness [2–5]. Even though the cost of these plasters is much higher than that of conventional plasters, they represent one of the most promising and worthy to be investigated types of novel plasters.

As far as low environmental impact and natural origin are concerned (issues which are often dealt with together, even though

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Nomenclature

λ_{cop}	Centre of panel thermal conductivity [W/mK]
d	Thickness of the specimen [m]
θ_{low}	Lower surface temperature [°C]
θ_{up}	Upper surface temperature [°C]
$\dot{q}$	Specific heat flux [W/m^2]
U	Thermal transmittance [W/m^{2}K]
Δ_t	Temperature difference between indoor and outdoor air [°C]
U^*	Thermal transmittance of the plastered wall [W/m^{2}K]
U_{ref}	Thermal transmittance of the reference benchmark solid wall [W/m^{2}K]

they are not necessarily related), the studies have mostly been aimed at assessing the performance of plasters that incorporate vegetal or mineral lightweight aggregates (LWA), such as perlite and vermiculite [6,7] cork [4,8], and hemp [4].

As for VOC emissions, it is well known that interior building materials can be sources of significant pollutant emissions and can therefore affect the quality of the indoor air. A number of investigations on emissions from indoor sources have shown that interior architectural coatings, such as paint and varnishes, contribute to indoor air pollution, in particular during the installation process [2,10]. However, there is a lack of documented investigations on the contribution of some products that are commonly used as substrates, i.e. plasters, even though they appear to be an integral part of the assembly. Only a few studies are available on this topic, such as that of Kwok et al. [11], which demonstrates the influence of the type of substrate on VOC emissions from paint and varnishes.

Although great efforts are being made, at a research level, to develop more and more performing plasters, most studies have focused on the optimisation of a single aspect and, moreover, technological/industrial issues have not been taken into consideration. An integrated vision and a multi-objective approach, geared towards optimisation, which takes into account the various aspects that are involved, is the best way to develop viable market solutions. In fact, it is known that the market for construction products requires novel products characterized by high energy/environmental performance and, at the same time, by high market competitiveness (in price, energy efficiency, installation features, etc.) and by a long expected service life [12].

Within this framework, a joint project, involving manufacturers and research centres, was started in 2011, with the aim of developing novel vegetal plasters, characterised by a high thermal performance and a low environmental impact. The innovative aspect of the research was the integrated approach that was adopted, since the research centres played a supporting role throughout the design process, by identifying raw materials and testing the developed blends from different points of view. In this paper, the adopted methodology is described and the main results pertaining to two vegetal plaster blends, one of which integrates corncobs and the other cork, are discussed.

2. Methodology

The research project carried out by the authors, which was aimed at developing a novel vegetal-based thermal plaster blend, was characterised by the opportunity of both the research and industrial teams working together, from the very first stages of the design process. The raw materials were selected in an integrated and synergistic way, in a life cycle perspective, in which the know-how on energy performance, as well as on environmental and technological issues, was crossed with the specific experience of manufacturers concerning industrial production and technical feasibility. Thus, an iterative process was progressively developed, starting from the design/formulation and going on to the characterisation and implementation, which was carried out at both a material/component scale and at a building scale. The feedback from the different analyses served as a starting point to tune the prototypes, and were considered up to the identification of the optimised market viable products. The opportunity of operating synergistically from the moment of the raw materials were selected, and then identifying formulations with waste materials derived from industrial and agricultural local processes, triggered a typical Circular Economy process [13]. New prototypes were then compared with conventional products, already present on the market, in order to set the performance that was to be achieved or exceeded.

Fig. 1. Plaster samples, from left to right: Bioart cork, VGT_001, Thermocalce, Cork_001, VGT_014, Thermointonaco.

2.1. The plaster blends under investigation

Two different vegetal lightweight aggregates were identified on the basis of a short supply chain rationale: granulated cork, derived from recycled bottle caps, and granulated corn-cob derived from the waste of local agricultural processes. A set of formulations was thus implemented and, following a cascade process, the plaster blends to be tested, were identified through lab and in situ measurements. The basic criteria used to tune the proper blends and identify the viable formulations were constituted by technological and environmental aspects. Once these new plasters had been defined, a series of tests was then performed in order to characterize their thermal properties as well as their VOC and formaldehyde emissions. In the first phase, the experimental characterisation was carried out in a laboratory, at a material/component scale. Merging the results achieved from different perspectives made it possible to obtain an overall picture of the plaster behaviour and to converge on the most effective solutions. As a final step, the identified products were applied to a real building, assumed as a test case, in order to evaluate the behaviour under real operating conditions.

In this paper, a synthesis of the process is described and the results are reported for the plaster samples described in Table 1 (four new formulations compared with two conventional plasters, that is, thermointonaco and thermocalce,) and presented in Fig. 1.