3D-printing for Cultural Heritage. Structural Recovery and Monitoring Applications of Architectural and Decorative Elements

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Introduction

In the last decade, 3D-printing technologies are spreading in various fields. One of these is certainly that of cultural heritage as illustrated in the recent work (Acke at al., 2021, Xu et al., 2017) From this study it is clear that the main use of 3D printing in the field of cultural heritage is in the physical reproduction of archaeological and sculptural finds for the purposes of study, conservation and dissemination. A recent application concerns the field of restoration, or at least of the preliminary and intermediate phases of the process, and in particular the physical reproduction of decorative/architectural elements and/or components for filling gaps or reconstructing parts. In fact, the so-called addictive manufacturing technology on which the 3D printing is based (Chacón et al., 2017), allows a freedom of reproduction and design of the shapes and, at the same time, a precision of the details that make it much more versatile than the traditional techniques; indeed, compared to the latter, additive manufacturing technology has the advantage of a reduction in time thanks to an industrialization of the processes.

The use of 3D-printed materials instead of traditional ones also introduces greater environmental sustainability due to the possibility of using eco-sustainable materials, reusing components made and saving raw material. In the face of these advantages, additive manufacturing technology is still in an experimental phase both on a technical-scientific level and on a conceptual-application level on which it still has a limited implementation.

Design and modelling with innovative eco-sustainable 3D-printed elements

The aim of the research, carried out within two research projects H-S3D and 3DH-Solutions funded by Regione Lazio, is to provide a contribution on a technical-scientific level on the development of an innovative design and production process which, thanks to the use of eco-sustainable materials with high mechanical performances, creates architectural components able to accommodate the geometric irregularities of the gaps of historic buildings, with structurally optimized characteristics that can also be instrumented to carry out a permanent post-intervention monitoring.

This process will be validated from the point of view of experimentation, modelling and realization of these elements starting from the level of the material until that of the final product with particular attention to the whole process. The activity of the project, therefore, consists in the design and modelling of structural elements and architectural components with innovative eco-sustainable materials where the design of the material and the 3d-printing process will be central to the realization of the required performances. As part of the project, the design of the connections between printed elements and existing construction will be also analysed from both theoretical and experimental points of view.

Further, the project provides the possibility of making "smarts" the 3D-printed elements, by using them for permanent monitoring of the architectural asset with the housing of sensors in the body of the printed element.

The realization of the specimens and the experimental tests that will be carried out on them, are gradually designed in synergy with the phases of survey and digital representation of the architectural heritage and its gaps, of design of the material and of the structural elements, and the design of the monitoring system. The realization of the elements to be installed in the gaps of the architectural heritage, as well as the connections of these elements with the existing structure, represents the final product of the project together with the monitoring process to be activated in the post-intervention phase.

Another important and innovative aspect of the project is the experimentation of innovative nanomaterials in order to improve the characteristics of the 3D-printed elements. Indeed, a proper choice of nanoparticles of ceramic materials can increase the mechanical properties of the matrix in which they are dispersed and can give to the material interesting functional properties, such as hydrophobicity, self-cleaning and biocidal properties and also the ability to reduce polluting atmospheric agents. The construction of the elements to be installed takes place downstream of a design that takes place on two levels, that of numerical modelling and that of experimental validation, favouring the aspects of environmental sustainability. The entire production process always takes into consideration the requisites necessary for interventions on the architectural heritage and therefore tends to obtain greater reversibility, durability and distinguishability of materials and interventions.

The project analyses two types of applications: the partial reconstruction of masonry elements and / or the filling of gaps in order to restore the complete or partial usability of an ancient building; the reconstruction of decorative elements, such as the cornices of historic buildings or the battlements of other architectural works, which represent one of the most widespread and common situations of decay of the Italian construction heritage. In the context of the first type of applications, the case study chosen for the development of the activities is Rocca Janula, located in the municipality of

Cassino (FR), one of the most significant monuments for the local community and the Land of San Benedetto since the 10th century.

The H-S3D project is currently underway. The activities developed until now have essentially concerned three aspects:

- phase of knowledge, survey and digital representation of Rocca Janula; Fig. 1 shows the digital representation of Rocca Janula, in its current state with the gaps (left) and in the possible post-intervention condition of insertion of 3d printed elements;
- experimental tests on small printed elements in order to obtain the mechanical characteristics of the materials through tensile and bending experimental tests (Fig. 2);
- geometric/dimensional design based on the development of advanced optimization processes based on genetic algorithms which, in the design of the 3D-printing elements, allow to optimize the structural performances of the elements (Fig. 3).

Fig. 1. Digital representation of Rocca Janula, in the current state with the gaps (left, photogrammetric survey processing by drone) and in the possible post-intervention condition of insertion of 3d printed material (right, textured model).

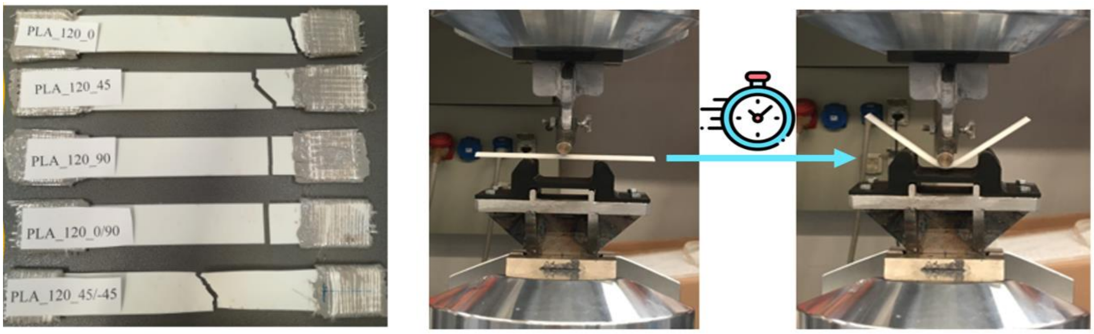

Fig. 2. Experimental test on 3D-printed elements: tensile test on the left, bending test on the right.

The project, thanks its interdisciplinary nature, favours the interaction between the worlds of research, industry and professional activities in the field of cultural heritage, thanks the transfer of skills and technologies in the context of integrative recovery practices of both architectural and structural elements, in order to allow the restoration of ancient buildings with a fundamental benefit for the enjoyment of the architectural heritage.

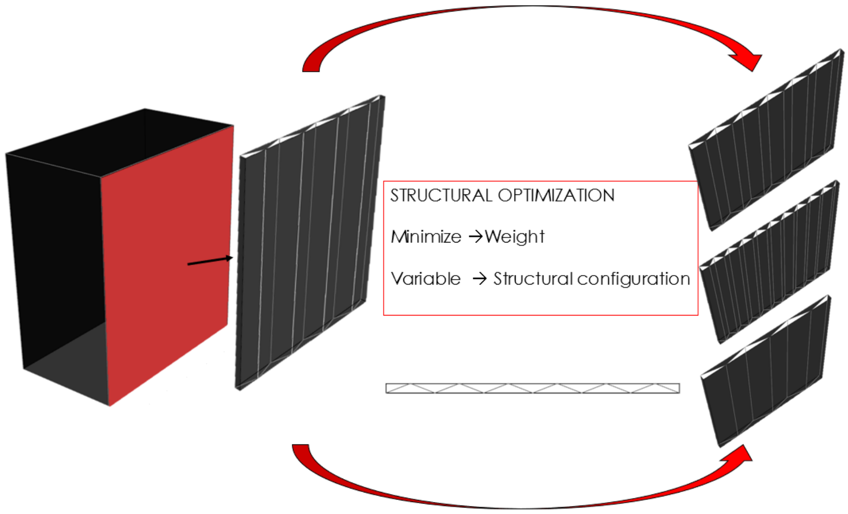

Fig. 3. Structural optimization process for the design of 3D-printed battlements for the Rocca Janula.

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Conflict of Interests Disclosure

Please disclose any financial or personal relationships with other individuals or organisations, such as sponsors, that could make your work appear biased or influenced.

Author Contributions

Please list the contributions of the project participants here, according to the CRediT system. See specific descriptions of the role here: (http://credit.niso.org/). **Please omit non-applicable roles**.

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