SURVEY, DIAGNOSTICS, MONITORING METHODOLOGYAND DIGITAL TWIN FOR THE CONSERVATION OF THE FACADE OF THE CHURCH OF SANTA MARIA DI NAZARETH IN VENICE

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ABSTRACT:

This contribution aims to illustrate the experimental research linked to the restoration concluded in 2018 for the conservation of the façade of the Santa Maria di Nazareth church in Venice and the ongoing monitoring methodology for the evaluation of its conservation state over time. The baroque façade is unique in Venice as it is entirely made of Carrara marble, a limestone with a saccharoid structure which has proved over the centuries unsuitable for the aggressive lagoon climate, given the complex architectural conformation and the unfavourable environmental conditions in which the façade is inserted.
The state of conservation of the marble at the beginning of the last worksite showed widespread and worrying degradation in many parts, especially in the more protruding ones: in fact, the stone surface reached detachment and pulverization by simple contact. The ultimate goal was to achieve a compatible and retractable conservative restoration for a possible improvement of the conservative results over time and also to facilitate an effective retrieval of scientific data in case of future interventions. With this aim, once the construction site was completed, a survey campaign with the purpose of reproducing a digital twin through 3D modelling was planned, to monitor the façade to have an exhaustive knowledge of the possible vulnerabilities present, with the involvement of the VIDE laboratory of IUAV University of Venice. A data acquisition protocol has been developed for the preservation of cultural heritage, thus guaranteeing an uninterrupted knowledge of the material degradation and of the structural situation.

1. CONSERVATIVE RESTORATION PROJECT OF THE FAÇADE OF S. MARIA DI NAZARETH CHURCH IN VENICE

1.1 The façade of S. Maria di Nazareth church of Carmelitani Scalzi order in Venice: diagnostics for restoration project

The baroque façade of the church of Santa Maria di Nazareth (*vulgo* degli Scalzi), a work of the late seventeenth century by Giuseppe Sardi, besides being a monument connoting the city of Venice, located at the entrance to the lagoon city, is a unicum in the context of the city, as it is entirely made of Carrara marble (Bettini and Frank, 2014), a lithotype rarely used in the Venetian environment. Over the centuries, this saccharide-based limestone has proved unsuitable, in particular given its location on the outside which subjects it to the aggressiveness of the lagoon climate, in addition to the sudden rise and fall in temperature due to both radiation and frost, Figure 1.
The need for restoration work on the façade of the Scalzi church was born following an unexpected event in July 2013, when an acanthus leaf from a capital collapsed.
It soon became clear that with the passing of time and the succession of various interventions it was losing its physical consistency showing widespread and worrying phenomena of degradation.
In many parts, especially in the more projecting ones, the stone surface came to detachment and pulverization by simple contact, Figure 2-3.

The first diagnostic investigations revealed a vast and unexpected degenerative phenomenon affecting the entire marble decorative apparatus: it appeared very degraded and characterized by decohesion and in some cases by a pulverization of the material below an apparently compact cortical surface, for a depth varying up to 12 cm.

Figure 1. Facade of the church of Santa Maria di Nazareth, at the end of the restoration works in December 2018.

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Figure 2. Detail of the degradation, 2016. -- Detail of the head of San Giovanni Battista: the Carrara marble shows different states of decay, the main ones being erosion, pulverization, widespread craquelure and chromatic alteration.

Figure 3. Detail of a cherub placed in the string course of the second order of the façade, clear example of different states of degradation of Carrara marble.

As first step of the knowledge path, the reconstruction of the history of the conservation interventions was carried out, through archival research phase at the Historical and Contemporary Archives of the Superintendence for Architectural and Landscape Heritage of Venice and at the Archive of the Venetian Province of the Discalced Carmelites, paying particular attention to the iconographic material, materials and techniques adopted over time. It was discovered that an uninterrupted process of restoration began in 1743, only 50 years after construction, and that already five restoration interventions were already completed in the last century. These interventions, evidently, have not stopped the process of deterioration of the building materials of the façade of Santa Maria di Nazareth, also because they have always been carried out independently from each other. Particular attention was therefore paid to the materials and techniques adopted over time, aware that an approximate or incomplete knowledge of the history of the façade, from a material and structural point of view, would have favoured incorrect interpretations of both the construction model and the diagnosis of degradation and instability, thus preluding to operational choices distant from the actual needs of the monument.

1.2 Experimentation for heritage documentation and preservation

From the beginning of the construction site, several needs emerged:
• experiment with consolidating products capable of penetrating to considerable depth in order to reconnect the decohesion layer with the healthy one;
• use of consolidating products available on the market that would have guaranteed the supply of adequate quantities of material to cope with the consolidation of a large area;
• verification of the best consolidating effect down to the depth and at the same time use consolidating products with the greatest possible compatibility with marble without compromising retractability, if necessary.

As described, the surface condensation processes of humidity and mists have proved particularly harmful for Santa Maria di Nazareth façade. Since such a dramatic condition/precarious state of conservation of the Carrara marble (made explicit via the map tool, Figure 4) did not find match in existing scientific literature, an experimental research in collaboration with the CNR/Institute of Geosciences and Earth Resources of Florence was undertaken. Thus, a fundamental partnership for choosing the consolidation agents and the method of application as well as for validating the performance was established (Forti et al., 2021).

The choice was therefore oriented towards nanomaterials which, thanks to the very small size of the particles, would allow a good penetration of the consolidating agent, until reaching the healthy part of the marble.

For the in situ experimentation, 10 test areas were identified on which to carry out the chosen treatments. Everything about location, quantities, concentrations and application techniques was documented through appropriate forms, a tool to return the data in tables and contextually document each operational step photographically.

At the end of this consolidation phase, micro-cores were performed with recovery and analysis of the powders in the most degraded areas, to verify the actual quantity of product applied and above all the depth reached by it. They are detectable through a map, Figure 5.

Another fundamental intervention to reduce the degrading effects of water was the improvement of the gradient of the horizontal planes of the façade so that water could flow faster. This was achieved by tessellation and integration of some parts of the artifact that were incomplete or interrupted, with a lithotype similar to that of the façade, to avoid problems of mutual incompatibility.

Regarding the static-structural analysis, performed by a a structural engineer, the focus was on the problems that affected the sculptural apparatus of the entire façade. In summary, the interventions concerned the execution of steel reinforcements alongside the pre-existing supports and the strengthening of the columns through steel belts.

Figure 4. Mapping of degradation phenomena: erosion and decohesion

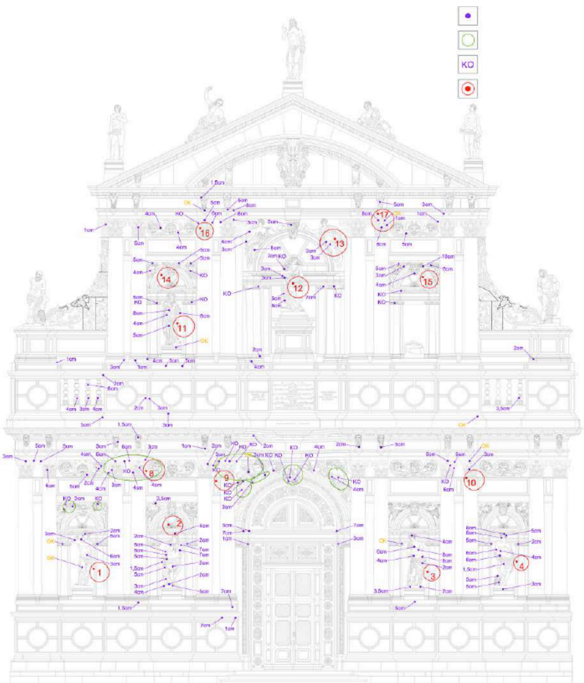

Figure 5. Mapping of tests drilling

2. DATA ACQUISITION PROTOCOL FOR CULTURAL HERITAGE PRESERVATION

2.1 Towards an Historical Digital Twin

The ultimate goal was to achieve a conservative restoration compatible and retractable for a possible improvement of conservative results over time and also to encourage an effective retrieval of scientific data in case of future interventions.

To this purpose, three years after the conclusion of the worksite, a survey campaign aimed at the façade monitoring also through a digital twin reproduced via 3D modelling was planned, in order to have an exhaustive knowledge of the possible vulnerabilities, with the involvement of the VIDE laboratory of IR.IDE research infrastructure of the Department of Excellence of IUAV University of Venice.

Thanks to this collaboration, a data acquisition protocol has been developed aimed at monitoring the preservation of cultural heritage, thus ensuring an uninterrupted knowledge of material degradation and static situation.

The protocol uses a survey implemented indirectly and with filming technologies such as laser scanners and drones with high-precision cameras, and data return technologies with point cloud processing. First of all, it aims to integrate the information gathered from the previous restoration and to make a comparison on the state of the artefact, following the concept of preventive restoration. Secondly, it aims to document the cultural heritage to support the maintenance activity. The returned 3D digital model (Figure 6) is in fact used to detect differences from the point of view of the kinematics, through crack pattern and detachments, of the chromatic alterations alerts, of the deterioration of the reinforcements and of the retainers inserted by the restoration interventions (e.g. supports for the statues or nets of protection). This 3D model can be defined a Historical Digital Twin (Figure 7), a project tool for carrying out analyses aimed at assessing the vulnerability of the facade, preparatory to possible interventions with respect to the possible worsening of the deterioration state. Moreover, it can be used as a versatile tool for operations to promote and enhance this important part of the Cultural Heritage, e.g. possibilities offered by digital technologies.

Figure 6. 3D digital model of the façade

Above all, it is considered essential to monitor the durability of treatments because they have not been tested previously and therefore there is no data in natural degradation situations for comparison, essential because the durability depends on the environmental conditions and the surrounding micro-climate. The possibility of carrying out an almost constant control on the evolution of the material degradation and the cracking

framework, through methods not impacting such as the developed one, allows to promptly intervene with regard to the damage aggravation with maintenance interventions, ensuring to management and maintenance offices the knowledge of the state of preservation and safety of the artifact, without having to undertake a future global restoration onerous and even traumatic for the preservation of the monument.
The architectural survey campaign was intended not as a mere restitution of the data to the "current state", but as a privileged reading tool of pre-diagnostic nature, as a non-destructive analysis of the composition, as a means of analysis and control of the entire conservation effort in order to proceed with the choice of the operating technologies to be used in the various construction phases.

The first step of the indirect monitoring protocol is therefore the digital survey. In particular, for operations of architectural survey through digital photogrammetry, the following instruments were used: Nikon D850 digital camera with 50mm f/1.4 lens, FARO focus s 150 terrestrial laser scanner, that allows to detect 976000 points per second with an accuracy of 1mm at 150m, and drone Mavic 2 Pro with video HDR 4K 10 bit (Figure 8). The use of the latter allows a properly detailed survey of geometry and damage present in portions otherwise not reachable because at height. The laser scanner acquisition is integrated with the 3D photogrammetric survey based on the automatic modeling of photographs, through the software Agisoft Metashape (2021). The detection technique is Structure from Motion, which through Computer Vision algorithms, extracts the remarkable points from single photographs, deduces their parameters and crosses points recognizable on multiple images, detecting their coordinates in the space, all through almost automatic collimation (Lucignano, 2021).
From the automatically oriented images a dense points cloud was obtained, which was scaled and roto-translated into the reference system, allowing integration with laser scan data. The following process of polygonal modeling occurs through creation parameters that follow a three-dimensional coordinate system and the obtained polygonal objects (meshes) return reality both as shape and as texture.

Figure 7. Digital Twin of the façade: 3D digital model representative also of the correct volumes

Figure 8. Close- up image from drone survey

The returned 3D model is therefore used to check criticalities from the point of view of kinematic mechanisms, through cracking and detachments, signals of chromatic alterations, decay of the reinforcements and retainings inserted by the restoration interventions (e.g. supports to statues or protective nets) and any demonstrations of poor performance of such interventions (Rocca et al., 2022). In fact, the drone survey allows to evaluate static risk factors such as material detachments, cracks, movements evolution (i.e. kinematic mechanisms) of the upper part of the façade and its projecting elements, such as the emblem and external statues, allowing a correct programming of possible direct interventions. The same risk factors can also be symptoms of risk of material consistency loss, if systemized with the previous conservation interventions reconstruction. This survey, together with the terrestrial one, returns, through the methodology just before stated, the 3D model, which, thanks to the high degree of accuracy, allows to quickly identify critical points even to non-expert users not aware of the artifact problems, and from these ones to interpret the structural problems.
It should be underlined that the more accurate the model is, the more detailed the knowledge framework is, allowing to achieve a geometric understanding of the façade, and consequently make assumptions about its structural functioning.
In the three-dimensional model of the façade it is possible to read the role of the individual parts that compose it, and it also serves as a basis for the construction of the numerical-mathematical model FEM (detailed finite element 3D modeling) of the façade, or of one of its constituent elements, for static or dynamic analyses that verify the structural safety of it, Figure 9.
In fact, as regards in particular the verification of the current static condition and of the seismic vulnerability of entire façade or single elements, the high-precision 3D digital model obtained is functional to security checks, both with expeditious (Berto et al., 2021) or advanced methods (FEM, in this case carried out with Midas Gen). Depending on the analysis detail degree to be carried out indeed the 3D model provides the necessary parameters for the application of "fast" methods, or it is the basis for the realization of numerical FE models to perform in-depth static and dynamic analyses.

2.2 Digital survey, 3D representation and security check of statues

Explanatory is the case of the façade sculptural apparatus, in particular the statues placed in the upper half, which needs an advanced and non-invasive monitoring as the one carried out by the presented methodology, as it has already suffered a fall and consequently a complete loss of one of its elements (the Speranza statue in 1920, SABAPV-AS). Through the indirect survey the sculptural and decorative apparatuses of the façade of the church of Santa Maria di Nazareth are discretized into the various constitutive elements.

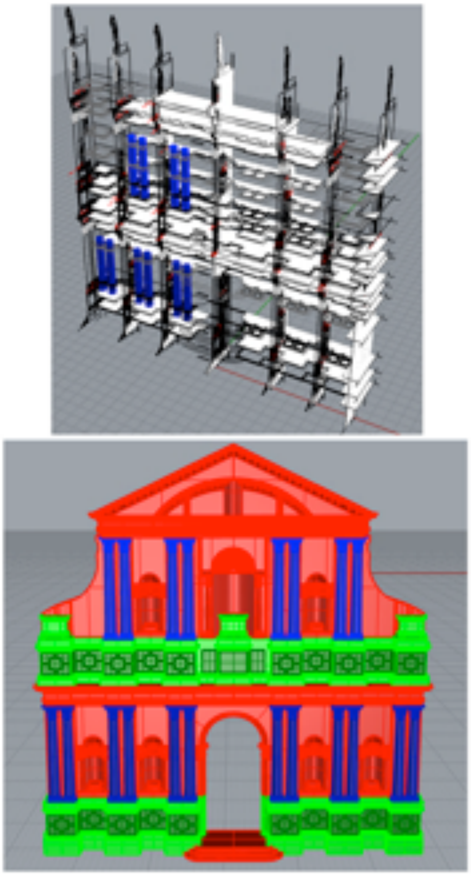

Figure 9. 3D model for static and seismic evaluations

Through the software for the creation of three-dimensional models and the process presented earlier, a 3D digital model of closed and controlled shape is obtained, for the control of the actual state and the predisposition of safety assessments, alias for the element preservation, both against the action of time and against any risks from external actions such as wind or earthquake.

On this model the FEM 3D mesh model was then built, in which, in a digital environment it was also possible to experiment and verify several hypotheses of restoration and structural-static consolidation. A punctual example is the analysis of the statue of San Girolamo (Figure 10) with the presence or not of metal retaining rods, intervention designed in the last restoration. These small metal structures are made of stainless steel and support the statue from the back, without being directly amortized in the marble. The above model, set up thanks to the innovative data acquisition methodology, provides a controlled representation of the geometric shape (Marra et al., 2021), which makes it possible to assess the statue stability when it is subject to the force of wind or earthquake, with and without metal retaining rods, thus verifying the effectiveness of the intervention. In other cases, as for the statues of San Sebastiano, San Giovanni and Santa Maddalena, the corresponding 3D digital models allow both to identify the most critical areas, namely where cracks for tensional concentrations are detected, and to carry out advanced FEM analyses to confirm the presence of such concentrations and to evaluate the adequacy of the installation of stainless steel bars in the statues as stitching of the deep cracks found before restoration.

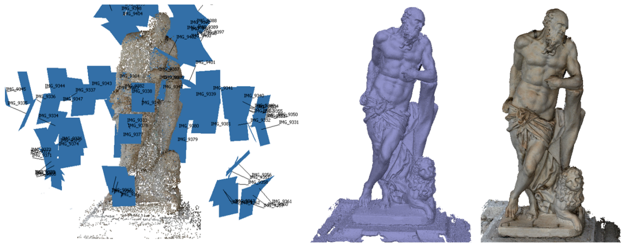

Figure 10. Step of 3D modeling of the statue of San Girolamo of the façade

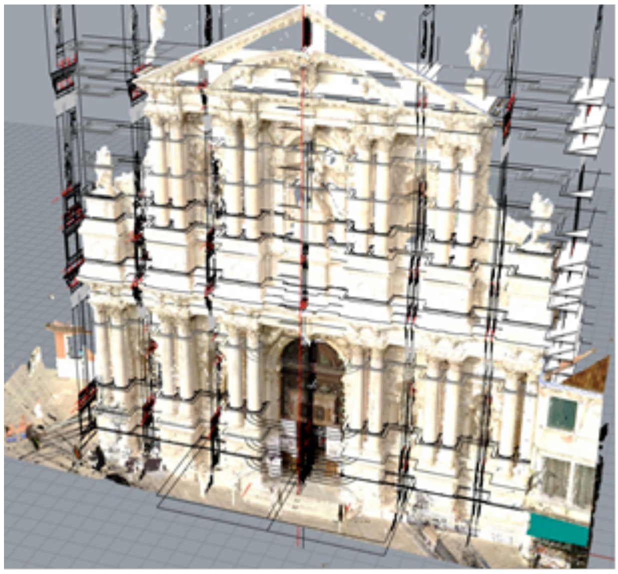

Figure 11. Overlay of section planes on the 3D model

3. CONCLUSIONS

Fundamental aspect of the conservation and enhancement of cultural heritage is monitoring, theme that is also addressed in "Linee guida per la valutazione e la riduzione del rischio sismico del patrimonio culturale con riferimento alle Norme Tecniche per le costruzioni di cui al decreto del Ministero delle Infrastrutture e dei trasporti del 14 gennaio 2008" (Linee guida, 2010).
The monitoring of the structure through a procedure indirect, non-invasive and that uses digital technologies is therefore an activity of fundamental importance in the context of monumental assets such as the facade of the church of S. Maria di Nazareth in Venice. Through this it is possible to obtain information on the state of the "façade system" and on the possible evolution of the criticalities found, Figure 11.
The proposal aims to refine and implement the methodology set on the research work related to the façade of Santa Maria di Nazareth that combines advanced technologies of survey and 3D representation with knowledge of structural engineering, finalizing it to the protection and enhancement of the venetian "facade systems" as a whole.
In particular, the aim of the procedure is to obtain an historical digital twin of the system, fundamental not only to allow to collect the relevant information for the knowledge of the artifact, aimed at its protection thanks to the combined use of digital technologies, but also as an aid to the definition of monitoring and maintenance plans, acting as a support to restorers and offices in charge. It is also intended to pay particular attention to the control of the artifact, functional to the over time monitoring of deterioration processes in relation to a changing environment, such as the lagoon.

In Authors' opinion, the effort, in terms of research, experimentation, operational, of Historical Digital Twin construction, made it possible to preserve the precious façade in its context, also generating an enrichment of unique knowledge in the field of restoration.

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