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SCIENTIFIC AND INTERDISCIPLINARY METHOD AS SUPPORT FOR THE RESTORATION PROJECT. THE BALUSTRADE STEPS OF VILLA CERAMI.

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Abstract

In this work an interdisciplinary study of the weathering forms of the Villa Cerami balustrade, was carried out with the aim to identify the type and causes of these and to plan conservation measures. The studied balustrade adorns and protects the steps of Villa Cerami garden, which is a suggestive example of 18th century 'urban villa', located in the very core of the Baroque Catania.
Sadly, these stunning steps, whose magnificence and placement characterises the out-door environment of the building, at present suffer from bad degradation conditions, and the decorative details adorning the baluster are affected by irreversible damage. The causes of this ongoing degradation process are: material features, humidity, pollution and the consumption caused by the activities performed in the building. Since 1957 it has been the location of the Faculty of Law of the University of Catania.
In this study, three balusters affected by the main weathering forms (biological colonization, black crust and granular disintegration) recognised in the entire balustrade, were selected. The lithological type and the weathering forms were defined on the basis of an *in situ* investigation, using respectively the comparison of materials, to identify the calcarenites type, and the Italian norm UNI 11182 along with the Fitzner formalism, to classify the degradation forms. A 3D survey of the selected balusters was performed with a time of flight Laser Scanner HDS300 of the Leica Geosystem with the aim to better define the volume and total surfaces of the material parts affected by erosion. The surfaces affected by black crust, were obtained by means of an image modelling technique. Data were used to calculate the damage indices through equations proposed by Fitzner and the limit at break for crushing.
The potentiality of this interdisciplinary approach (architects, engineers and geologists) is shown with the aim to apply it to the restoration of the entire monument. In addition, this interdisciplinary process has been useful to identify the strengths and weaknesses to assess the consequences of design choices with awareness.

Keywords

Interdisciplinary, limestone, pathologies, 3D survey

1. Introduction

In this paper an interdisciplinary method of analysis as a supporting for the critical approach to the restoration project was tested.
The new approach proposed by us provides for the study of the monument's degradation forms, the application of the Fitzner method supported by the detailed analysis of surfaces and volume by laser scanner.

The weathering form mapping has generally been performed through two-dimensional survey. Moreover, the element to be restored might not be easily attributable to Euclidean geometry, especially in the elements that are severely compromised by erosion. The laser scanner, in these cases, provides accurate data to evaluate the damage index in a short time and also to carry out static structura-type verification (for example the permissible loads, the eccentricity and bending moment calculations). In this paper the potentiality of these tools and methods were tested on a balustrade of the 18th century in a stately villa in the historic centre of Catania (Italy)

Fig. 1: Stairs and part of the villa

in order to carry out the right design choice with critical knowledge and scientific rigour.

2. Methodology

As for any restoration intervention applied to an architectonic element of cultural heritage, the study should be planned following a sequence of operating steps:

1) Historical survey: it is aimed at acquiring and evaluating all the existing information about the studied monument in order to understand its artistic and historical value. This survey is performed by archival and historical research.
2) Geometric survey: it can be carried out with direct and/or instrumental methods. In particular, the method of 3D survey by means of a laser scanner was tested in this paper with the aim to obtain the dimensions of the more degraded surfaces, the real amount of the lost material because of erosion, and information about the current granular disintegration.
3) Analyses of building techniques (materials, problems concerning building issues, etc.): they were performed through a direct method and by comparing materials and construction building solutions and coeval samples belonging to the same urban areas, whose physical and technology features had already been analysed in previous studies.
4) Analysis of damage: it was performed by means of both traditional and non-destructive surveys and mapping of the damaged areas.

For a complete description and evaluation of degradation forms, the Fitzner method analysis was followed in this paper, which takes into account the interactions among micro-climate, material, shape, construction techniques and technological system. The operation procedure consists of three different phases: the anamnesis phase allows one to acquire information about the monument; the diagnosis through in situ and/or laboratory analysis allows the obtainment of useful information on the type of building materials, material properties, state of deterioration, factors and processes of deterioration and need/urgency of preservation measures; and the therapy phase consists in the choice, execution and control of the preservation measures and in the long-term observation and maintenance of the monument.

3. Villa Cerami baluster case

An interdisciplinary study involving architects, engineers and geologists was conducted on the Villa Cerami baluster case with the aim to better investigate the construction techniques, the materials, the weathering forms and the causes of the degradation. The study was divided into four phases (anamnesis, pre-diagnosis, diagnosis, and therapy) described in the following paragraphs. In particular, the diagnosis phase was performed on three selected balusters which show the main weathering forms of the entire balustrade in detail.

3.1 Anamnesis. Knowledge as a tool for a correct operating procedure

3.1.1 Historical information

Villa Cerami in Catania lies at the heart of the historical centre of the town, on a hill ("Sperone del Penninello"). The main entrance faces Crociferi Street (via dei Crociferi), known for its line up of magnificent religious buildings (churches and convents), which flank the street with elegant and sinuous Baroque façades. The access to the villa is through a suggestive richly engraved portal, which represents an impressive example of the local Baroque style. Beyond the metal fence portal, and after a short gallery, there is the access to the large internal courtyard.

This is delimited: north-face by the stairs studied in the present analysis, whose first flight is in front of the main entrance; east-face by the former stables, today transformed into classrooms; west-face by the main building body. Finally, the north-face is delimited by a wall whose first part encloses the upper terrace, while its second part consists in one of the villa's fronts facing the Cerami street.

This front may have possibly been the first nucleus of the villa, while the remaining bodies should have been added subsequently, following the purchase of the villa by Domenico Russo Scammacca, Prince of Rosso di Cerami, around 1720 (Cosentino, 1993).

Historical sources hypothesise the presence, already prior to the purchase of the building, of external stairs. These were said to have successively been enriched with ornaments and the accessories interventions, aimed at adding magnificence, along with the portal, may have been made by Gian Battista Vaccarini (1702-

1768) the architect from Palermo who applied the formal and cultural principles of the Baroque style in Catania during the first period of reconstruction after the terrible earthquake of 1693. However, this hypothesis can be rejected on the basis of a careful critical-stylistical analysis and examined date in the archival records. In fact, some documents certify that the portal was completed in 1726, before Vaccarini's arrival in Catania. Moreover, the comparison with other portals and balusters of the same period in the historical centre, shows that the style is due to the movement of lapidum incisores (Fig. 2). In particular, having moved to Catania in the first decades following the earthquake, from Messina (the Amato family), Acireale and Palermo, these stonemasons were creators of most of the sculptural façades that characterise the monumental city.

Fig. 2: Benedectine monastery (CT): balustrade west façade on piazza Dante

Another hypothesis was advanced by Basile and Magnano San Lio (Basile & Magnano di San Lio, 1996), according to which the prince of Cerami acquired the prestigious ground in 1724.

The first building was an antiseismic half-timbered construction with a single level. Later, during the 18th century, the villa was expanded with new constructions: a second floor, a chapel, a large terrace with the elegant balustrade (here studied) and a monumental staircase.

Successively, at the end of the 1800's Carlo Sada (1849-1924) inserted a balcony that crowns the new building body of the basement entrance. Although doubtful, such modification gave to the building a new Neo-Renaissance façade, and enabled access to the building directly from the basement through a new entrance and inner stairs. A new restoration by Stefano Bottari and Giacomo Leone was carried out in 1957, when the villa became property of the Catania University, still now the location of the Faculty of Law. At that time, part of the façade built by Sada was removed and was restored according to the original style. In 1965 the rooms of the villa were enlarged following a project in line with the use of the time, i.e. to add new blocks built with a recent technique and modern materials, such as prefabricated aluminium and glass panels etc. The new building body, made by Salvatore Boscarino, hosts the Seminario Giuridico. It lies in the west side of the former Cerami property and is separated from the 18th century building by an inner courtyard which joins the new and old buildings. Successively, the Villa was consolidated (1992) in order to adapt to anti-seismic laws according to Fortunato Motta's project.

3.1.2 Geometric-formal and technical-constructive description

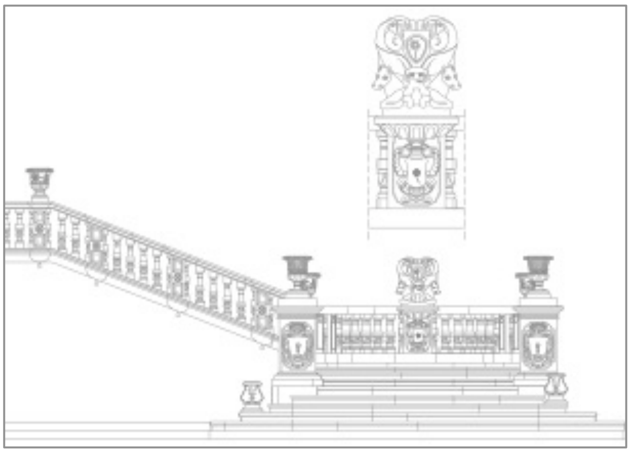

Fig. 3: Geometric survey; first flight with exedra

The survey of the steps was achieved using direct methods and with the aid of programs of laser scanner. The two-dimensional data were not considered sufficient for the purpose of locating and measuring the areas affected by the pathological conditions. For an exact determination of the areas affected by the deterioration and for its nature identification it is not possible to use of the traditional survey methods because of the eroded surface complexity. In fact, the elements to be examined do not have a two-dimensional prevalent extension, but they are solid with a complex volume. This configuration was greatly complicated because of the disgregating action of pathogens which have slowly transformed some of the balustrades into elements not attributable to any Euclidean geometrical figure.

For this reason the geometric study was performed by means of a 3D laser scanner which provided the volumetric data on the amount of degradation.

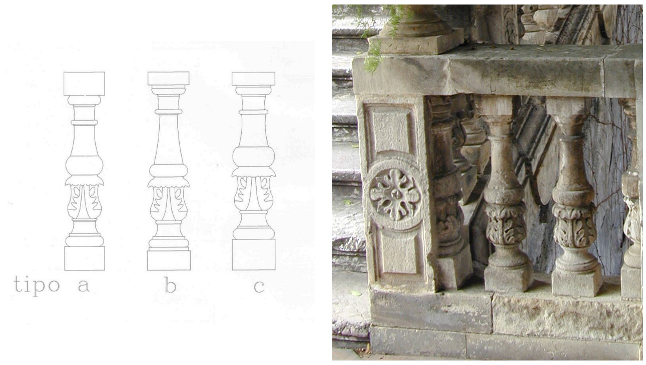

Fig. 4: Details: pilaster and the three kinds identificated balusters in the stairs

As for the construction system, the monumental stairs develop over three flights. Blocks of exquisite red Sicilian marble (*brecciato Rosso di Kumeta*) were beautifully worked out to build the riser and tread of these steps. The first flight, made up of eight risers, begins in the courtyard and leads to the first rectangular half and leans, through an exedra, over the roof garden of the north-face of the villa. The core of the exedra is highlighted in the baluster by a stone fountain engraved with motifs representing a crowned shield surrounded by valves. The pavement of both half spaces and of the first-floor balcony is of recent construction (1960's) and is made up of baked with inserts of green majolica.

The second and third flights are interrupted by a rectangular half space and they lead to the noble floor terrace situated.

Two stone pilasters, engraved with shields and valve, mark the beginning of the balusters.

They are surmounted by two impressive jars also richly engraved. The balusters are realised with tender limestone and they consist of a succession of small columns alternated by small pilasters decorated with flower motifs and that emerge in correspondence with each half space with jars engraved with various flower motifs.

The small columns, apparently identical, are actually slightly different: three typologies are identified that differ by form and decoration, as shown in Fig. 4. The three types of balusters are distributed along the stairs without a precise pattern. The only element that defines a common theme, and that appears more tiny and delicate, is badly conserved.

These elements concentrate into the apse of the first half space and are likely the remains of the original balusters. However, to confirm this hypothesis, accurate mineralogical and chemical analyses are necessary. On the stone surface we also noticed some traces of a refining layer that indicate a protective treatment likely made up of lime milk and calcareous dust.

The balustrade of villa Cerami likely originates from the Baroque balustrade that crowns the wall of the close monastery of Benedettini, rebuilt after the earthquake of 1694.

Both balusters show the same motifs, and follow the same inter-axe fuse cadence (20 cm).

The elements that characterise each baluster are nearly identical. In the monastery, in one of the inner courtyards, some remains of the original balusters are found. Thanks to an accurate compared analysis, coupled with a metric and photographic survey, we could understand how these architectural elements were made. Both at the base and at the abacus of the baluster the stone is moulded to the central part in order to ensure a link between the base and the handrail stone. They were then assembled by a male-female joining technique.

Fig. 5: Above: Benedictine monastery, link between plinth and the base of the baluster. Below: Villa Cerami; base of a yard with metal pin; link between plinth and the base of the baluster

The embedding made to host the fuses has a squared shape (in the monastery they have the size of 9cm per side, and in the villa 7cm per side). We could not find any piece displaying small holes indicative of the insertion of metal joints to ensure the base of the baluster, except for the jars on the small pilasters of villa Cerami (Fig. 5).

But in adjacent to the exedra, we observed, from the abacus of the collapsed baluster, that the frame with the handrail stone is secured by a wood pin (Fig. 6).

The technique of sewing stone blocks between them was common ever since ancient times although the joining material was usually consisting of lead or stone tiles. Clearly the wood is a material subject to sudden degradation, especially if in contact with moisture.

Therefore it is not suitable to perform the joining function for a long time. In addition, the soft limestone that powders because of pathogens does not provide a sufficient grip to trigger compulsions among the elements to be joined.

The stone blocks that make up the handrail stone have lengths ranging from 45 to 60 cm and they were also joined by a male-female technique.

In particular, the blocks on the small pilasters are smaller with both sides harbouring a central extrusion for insertion into the following block, and are alternated by female-shaped blocks.

Between the balusters and the two linear elements of the handrail stone and the basement lies a layer of mortar whose thickness varies presumably according to the size of the base or of the abacus. The mortar was likely employed to fill up the small differences in size between the fuses in order to obtain their stable joining and prevent voids.

Fig. 6: Abacus of the collapsed baluster, showing wood pin

4. *Pre-diagnosis. The stone balauster's calcarenities and main weathering forms: main causes and correlations between material, form and environment degradation*

The Villa Cerami baluster was probably made with different materials and so is affected by different degradation forms. However, to confirm this hypothesis it would be necessary to combine in situ investigation, laboratory analyses and weathering simulation. On the basis of in situ observation we performed the monument mapping (lithological and weathering form) of the three selected balusters. With regard to the lithological type a limestone attributable to the Palazzolo Formation namely ''Pietra di Noto'' was used. It is a yellowish-white calcarenite that extensively outcrops in the Hyblean Plateau and was widely used as building stone in the Baroque monuments of Catania. This formation was described by Rigo and Barbieri (1959) as a limestone and bioclastic limestone series, stacked in accordance with the marls of the Tellaro Formation.

It is divided into two Members, Gaetanì and the Buscemi Members, which are the lower and the upper part of the Formation respectively (Di Grande, Romeo & Raimondo, 1992). In particular the Gaetanì Member consists of an alternation of marly and yellowish limestones, while the Buscemi Member, shows a different colour, yellowish-grey.

Later, other authors (Carbone, Grasso & Lentini, 1987) identified two different lithofacies within the Palazzolo Formation so described: "fine-grained grey limestones and soft marly limestones alternating in layers of 20 – 40 cm; yellowish-white limestones outcropping in large bank levels".

The calcarenites of Palazzolo Formation have a high open porosity with a little size of pores which causes inside the circulation of rain water and capillary water rise and thus a widespread pulverisation of stone. In fact, in this typology of stone the loss of cohesion of the carbonate granules is frequent because of the chemical dissolution of the micritic portion (pulverisation).

Often the stone shows a gypsum and calcite surface film due to the phenomena of precipitation of dissolved salts in the water.

Fig. 7: Stone yard and fountain stone with black crust and biological layers

In agreement with what was said, the more frequent pathologies recognised in this study were: black crust, i.e. the external surface made of both biological layers and dangerous polluting substances; erosion, along with material detachment and loss, are instead concentrated on a few elements of the stair, such as the small pilaster on the left side of the first flight, on the small columns of the balusters and on the exedra at the level of the first half space. The extent and importance of the decay is linked to the features of the material, exposure and shape of the balusters. In fact, the deposit of polluting substances accumulates in the areas that are not reached by atmospheric agents, i.e. below the overhang and inside the bas-survey. For a Baroque balustrade, then, the more risky zones are the top of the small columns protected by the upper overhang of the stone handrail stone, and specifically, the inner parts of the elaborated engravings of the central fountain, the front sides of the small pilasters and their decoration jars.

The present study deals particularly with such a phenomenon since the villa is heavily exposed to an urban environment rich in carbon monoxide and various polluting agents, especially exhaust fumes from local traffic. In fact, villa Cerami is unfortunately placed at the heart of the historical centre of town, suffocated by public and private transport. The decay becomes worse in the north-face of the building, due to the effect of the ascending humidity coming up from the roof garden that has provoked the chromatic alteration of the stone material, the spreading of vegetal micro-organisms, and partial detachments over time.

In particular, in the portion of balustrade on the first landing, exedra shaped and located under a big ficus, the part of the exedra facing west appears more degraded. This degradation is favoured to a bad exposure, to the presence of the tree which gives shade and does not allows for the fast evaporation of water and promotes the proliferation of microorganisms; and finally to the presence of the adjacent fountain which over time probably caused phenomena of run-off and then rising dampness in the pillars.

Fig 8: View of the exedra of and the staircase

5 *Diagnosis*

5.1 The instrumental survey for 3D quantification of degradation

A 3D approach to the studied balusters' spatial and material data acquisition was performed with the aim to create a 3D model useful to the reconstruction and geological survey. At Villa Cerami we tested the integrated use of two survey methods: 3D Laser Scanner, for the survey of involved area and the extraction of volume data related to erosion and loss of material; 3D photo modelling for the survey of the patinas and the black crust. The integration between these two techniques was necessary because Time of Flight (ToF) laser scanner is not recommended for the acquisition of small geometric sculptural elements (Russo & Remondino, 2011) due to its accuracy (in the order of few mm) and the noise generated by the laser beam. Nevertheless, in literature there are studies that show the efficiency of ToF Laser Scanner used in limits conditions (Callieri, Cignoni, Dellepiane & Scopigno, 2009) and affirm the reliability of results under some conditions: to carry out scans at maximum sampling density allowed by the instrument without going beyond 3mm as minimum points distance. The redundancy of obtained data helps to refine the filtering techniques for noise removal. We will discuss filtering techniques for noise removal in Section 5.1.2. Instead, a polygonal surface (triangular mesh) is generated by image based modelling. Both techniques can quickly and accurately conduct the investigation on building products. The models obtained in this way are in effect the digital mould of the objects investigated. This allows us to "freeze" the situation at the time of scanning, examining the characteristics in order to define any necessary restoration, safety and monitoring interventions.

The method of operation involved two key moments:

–the acquisition of data in situ;

–the extraction and filtering of acquired data and their subsequent post-processing, through the use specific software.

5.1.1 Survey Project

Acquisition activities through 3D laser scanner technology provided a preliminary survey project. This must take account of operational and environmental factors that may affect 3D modeling and must be able to ensure the maximum possible coverage of the objects to be detected (Fig. 9). On the three selected balustrades (shown in Fig. 9 with the numbers 1-2-3) a volumetric study intent on establishing the extent of the material loss caused by erosion was performed. The equipment used is the ToF laser scanner model HDS300 of Leica Geosystems belonging to the Laboratory RDA (Survey and Diagnostics for Architecture) of the Department of Civil Engineering and Architecture, University of Catania. The technical characteristics of the Laser Scanner are the following: Accuracy: position 6 mm, distance 4 mm; Scan rate: 4,000 point/sec; Field of view: 360°x270°; Range: 300 m; Spot size: from 0-50 m, 4 mm (FWHH based), 6 mm (Gaussian based); Laser class: 3R (IEC 60825-1). Studies in literature (Benedetti, Gaiani, & Remondino, 2010). show that the instrument's performance should be evaluated through the resolution and accuracy parameters, paying particular attention to the working distance, the laser inclination and the type of surface and material. In presence of rough surface and deposits (as in our case) this creates a mattifying coating that reduces the deviation and noise, thus acting in favor of the scan results quality.

The software we used for the restitution are the following:

–Cyclone 6.0 (Leica Geosystem), for the phases of acquisition and alignment;

–CloudWorx (Leica Geosystem) and Autocad (Autodesk), for the processing in CAD environment;

–MeshLab (Visual Computing Lab, ISTI - CNR), system used for the steps of cleaning, filtering, editing and rendering the mesh model obtained, in order to calculate the volume and the lateral surface of the investigated balustrades.

The acquisition of the photographic sequences *in situ* turned out to be strongly dependent on the terrain and lighting conditions. The baluster chosen for the surface survey on the biological patina and the black crust is nº. 3. Because of the difference in elevation between the two sides of the balustrade and the difficulty of acquiring the entire element in a single shooting, it was decided to divide it into two parts, along the longitudinal axis that follows the handrail (Fig. 10).

The equipment used in this phase of survey is a Casio EX-Z1 camera. The types of software used for the restitution are as follows:

–123D Catch (Autodesk), software used to create the textured and poligonal model;

–MeshLab (Visual Computing Lab, ISTI - CNR), system used for some stages of cleaning, filtering, editing and rendering of the mesh model obtained, in order to calculate the surface area of the investigated baluster affected by the black crust.

The factors that most affect the recovery project are all linked: the lighting conditions of the environment; the material characteristics of the object to be detected; the proper focus in all the photo shoots; the correct shooting position of the operator and overlap of consecutive images;

and the scale of resolution required for the survey (Santagati & Inzerillo, 2013).

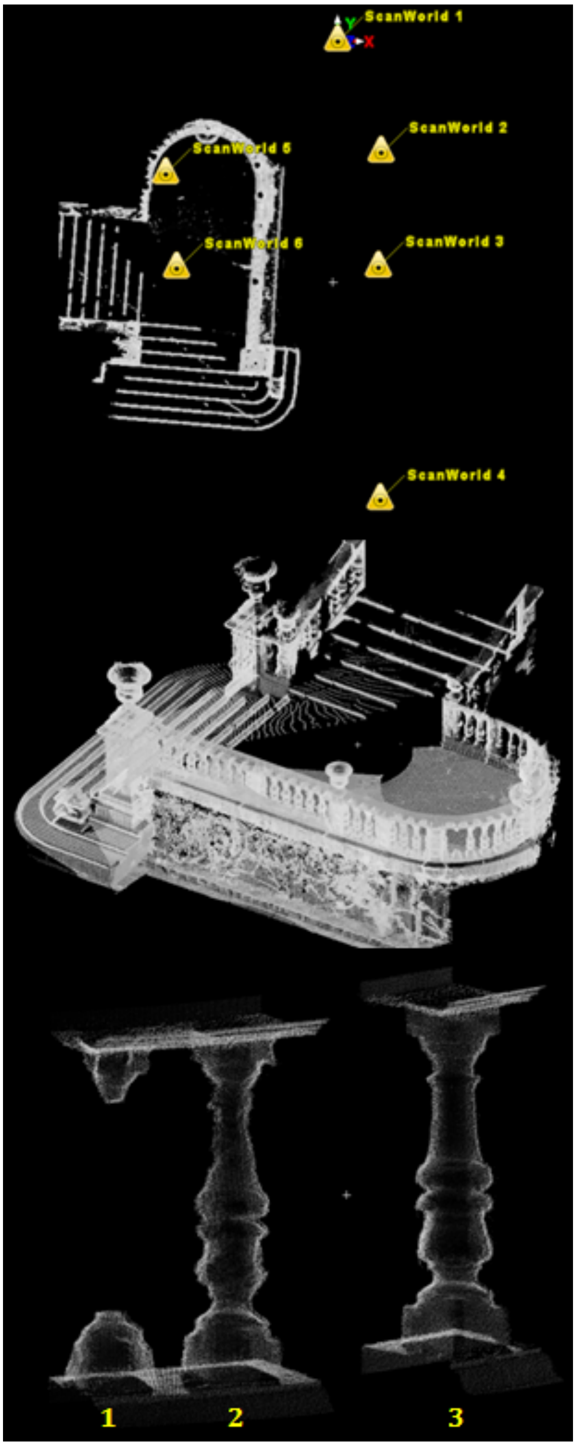

Fig. 9: Above, the survey project and point stations of survey through 3D Laser Scanner (6 shooting stations); at the center, the point cloud (13, 694, 137 points); below, balustrades studied

The table shown below (Tab. 1) provides the dataset of baluster 3, such as number of photos used, resolution images, resolution of the mesh, and number of triangles generated.

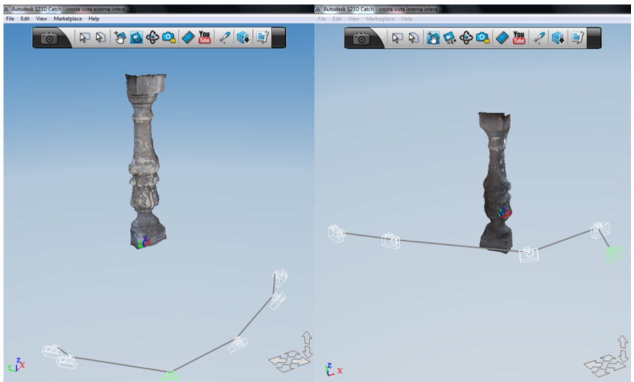

Fig. 10: Survey project relief through 3D photo modelling. On the left, outside view with respect to the landing; right, inside view. Reconstruction carried out with the software 123D Catch

Tab. 1

Object	**Baluster n.3 Outside view**
Number of images	6
Image resolution	3072x2304 pixels
Number of mesh polygon	92902
Object	**Baluster n.3 Inside view**
Number of images	6
Image resolution	3072x2304 pixels
Number of mesh polygon	84402

5.1.2 Volumetric data for the erosion and the loss of material

Importing the point clouds obtained from the laser scan on MeshLab it was possible to get individual polygonal models of the three investigated balustrades.

Because of the noise created by the use of a laser scanner time of flight, it was necessary to apply the smoothing filter (to be exact HC Laplacian Smooth - that is a improved version of the classical Laplacian smoothing and has a better behavior in respect to oversmoothing), for the calculation of volume and of the side surface to obtain the minimum possible error (Callieri et al., 2009). The dimensional verification was performed by comparing the models with a reconstruction solid, carried out in CAD environment, of a not degraded baluster (Fig. 11).

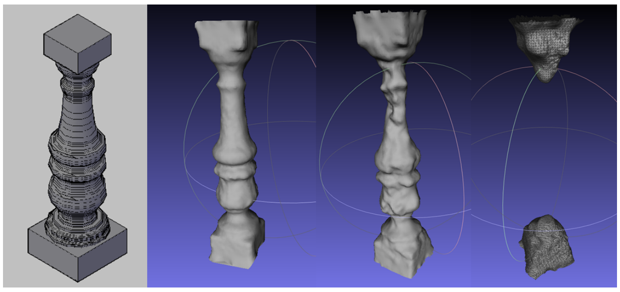

Fig.11: From left to right: baluster rebuilt through solid modelling; mesh baluster3; mesh baluster2; mesh baluster1

The table shown below (Tab. 2) provides volumetric and superficial data, extracted from 3D models, later used to study erosion and loss of material.

Tab. 2

Object	Baluster reconstructed
Volume	6900 cm^3
Side Surface	2880 cm^2
Object	**Baluster n.3**
Volume	6300 cm^3
Side Surface	2390 cm^2
Object	**Baluster n.2**
Volume	5600 cm^3
Side Surface	2200 cm^2
Object	**Baluster n.1**
Volume	2900 cm^3
Side Surface	1050 cm^2

5.1.3 Two-dimensional data for the assessment of patinas and black crust

The area of baluster 3 affected by the black crust was calculated using 3D photo modelling. Since the model contains the real colour textures, the healthy parts of the baluster have been lifted through physical elimination of mesh parts, within the software MashLab and the subsequent remaining area calculation (Fig. 12).

To better calculate the black crust thickness were performed in situ investigations. On these degradation forms will carried out the laboratory's analysis.

Fig. 12: On the left, polygonal model of baluster 3 reconstructed through 123D Catch; at the center, in red part of mesh selection not subject to degradation; right, final processing of polygonal model of the entire area covered by the black crust

The following table (Tab. 3) provides surface data of the black crust, derived from textured mesh.

Tab. 3

Object	Baluster reconstructed
Crust surface	2078.53 cm^2

5.2 The application of the Fitzner method: damage indices.

The classification of degradation forms was performed following the Italian norm UNI 11182 along with the Fitzner formalism.

In particular, Fitzner's approach (Fitzner, Heinrichs & La Bouchardiere 2003, 2004) is based on a hierarchical structure of the classification scheme divided into four levels:

- the first level describes four different degradation groups: loss of stone material; discoloration/deposits; detachment of stone material; fissures/deformation;
- the second level shows the main degradation forms;
- the third level specifies the main degradation form of the second level by means of individual weathering forms;
- the fourth level provides a quantitative estimation of the single weathering forms' intensity.

Fitzner, in his method, indicates six damage categories by increasing numbers: 0-no visible damage; 1- very slight damage; 2- slight damage; 3-moderate damage; 4- severe damage; 5- very severe damage. Each of these was defined on the basis of: weathering forms; the monument's historical value; proportion of degraded stone parts with respect to total structural element.

On the basis of this classification scheme the three selected balusters have been analysed with the aim to estimate the frequency and intensity of the degradation forms.

The weathering forms recognised in the balusters belong to the following classes: loss of stone material (group 1); discolouration/deposits (group 2); detachment (group 3); fissures deformation (group 4).

The laser scanning and photo modelling data have allowed to calculate the degraded volume and surfaces with respect to total structural element and define the damage categories.

The main degradation forms within the *loss of stone material class* (group 1) are:

- *back weathering* (W): uniform loss of stone material parallel to the stone surface.
  The second baluster is affected by frequent back weathering due to loss of crusts (cW) defined as a uniform loss of stone material parallel to the original stone surface due to detachment of crusts with adherent stone material. The estimated depth of this back weathering is < of 0.5 cm and damage category is equal to one.
- *rilief* (R): morphological change of the stone surface due to partial or selective weathering.
  The second and third balusters are affected by frequent alveolar weathering (Ra). The estimated depth of this weathering is in the range of 1-3 cm and damage category is equal to two.
- *break out* (O): loss of compact stone fragments.
  The third baluster is affected by a rare break out due to natural causes, such as intersection of fractures (nO). The involved volume is in the range of 500-1000 cm^3 and the damage category is equal to three.

The main degradation forms within the *discolouration/deposits class (group 2)* are:

- *soiling* (I): dirt deposits on the stone surface.
  The second baluster is affected by rare soiling by poorly adhesive particles from the atmosphere (pI), mainly grey to black deposits of dust, soot, fly ash etc. It shows a low intensity and a damage category equal to one.
- *biological colonisation to crust* (B-C): transitional form between biological colonisation and crust.
  The third baluster shows a frequent and uniform layer of a weathering transitional form between a microbiological colonisation (Bi) and dark-coloured crust which change the surface (diC). The intensity of this weathering form is high and damage categoy is equal to two.
- *loose salt deposits* (E): poorly adhesive deposits of salt aggregates.
  The third baluster shows, in the base surface, very rare poorly adhesive deposits of salt aggregates (efflorescences - Ee). The intensity is slow and the damage category is equal to one.

The main degradation form within the *detachment* (group 3) is:

- *granular disintegration* (G): detachment of individual grains or small grain aggregates
  The third baluster is interested by a rare high granular disintegration into powder such as to have caused the near total erosion of it. The damage category of this weathering form is equal to five. The second baluster shows the same deterioration but in a milder form (frequency: frequent; damage category equal to two).

The main degradation form within the *fissures/deformation class* (group 4) is:

- *fissures* (L): individual fissures or system of fissures due to natural or constructional causes
  The second and third balusters are affected by rare small fissures dependent on stone structure such as bedding, foliation, banding etc. (intensity equal to 2).

The Tab. 4 shows the assigned intensity and damage's category to some weathering forms with the aim to show as for the calculation of the damage categories is very useful know the degradation's depth and the amount of degraded surfaces.

Tab. 4: Intensities and frequency of some weathering forms and damage category

Intensities of characteristical weathering forms and their frequenty								
LEVEL I-GROUP OF WEATHERING FORMS								
GROUP 1: LOSS OF STONE MATERIAL								
Main weathering forms			Intensities					
			1	2	3	4	5	6
DEPHT OF THE BACK WEATHERING (cm)			<0.5	0.5-1	1-3	3-5	5-10	10-25
Back weathering	W	cW	frequent	-	-	-	-	-
Damage category			1	1	2	3	4	5
DEPHT OF THE RILIEF (cm)			<0.5	0.5-1	1-3	3-5	5-10	10-25
Rilief	R	Ra	-	-	frequent	-	-	-
Damage category			1	1	2	3	4	5

These data were obtained by means laser scanner, photo modelling and in situ investigations.

The histogram in Fig. 13 shows the total percentages of the several degradation forms in the three studied balusters.

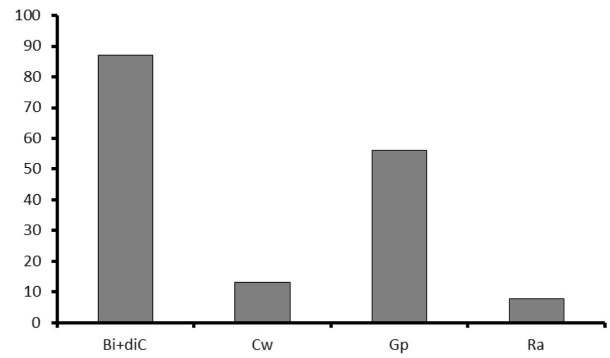

Fig 13: Histogram with percentages of the main degradation forms

With the aim to perform a quantification and rating of the degradation damage to the main considered weathering forms, the damage indices (linear and progressives) were calculated with two equations:

$$DI_{lin} = \frac{(A*0)+(B*1)+(C*2)+(D*3)+(E*4)+(F*5)}{100}$$

$$DI_{prog} = \frac{\sqrt{(A*0)^2+(B*1)^2+(C*2)^2+(D*3)^2+(E*4)^2+(F*5)^2}}{100}$$

A = Area (%) – damage category 0

B = Area (%) – damage category 1

C = Area (%) – damage category 2

D = Area (%) – damage category 3

E = Area (%) – damage category 4

F = Area (%) – damage category 5

These indices must be ranged from 0 and 5 and in particular, the linear damage index provides an average damage category, while the progressive damage index emphasises the proportion of higher damage categories.

The table 5 shows the calculated indices to the main weathering forms for each studied baluster.

Tab. 5: Damage indices of the main weathering forms

AREA	DAMAGE CATEGORY	% AREA
Bi+diC (baluster n.1)		
C	2	86,96
linear damage index		0<1,74<5
progressive damage index		0<1,86<5
Cw (baluster n.1)		
B	1	13,03
linear damage index		0<0,13<5
progressive damage index		0<0,36<5
Gp (balusters n. 2-3)		
C	2	7,95
F	5	56,07
linear damage index		0<2,96<5
progressive damage index		0<3,78<5
Ra (baluster n. 2)		
C	1	92,05
linear damage index		0<1,84<5
progressive damage index		0<1,91<5

The bar diagram in Fig. 14 shows a total damage indices very high to the third baluster, a high damage to the second baluster and finally a moderate damage to the first baluster.

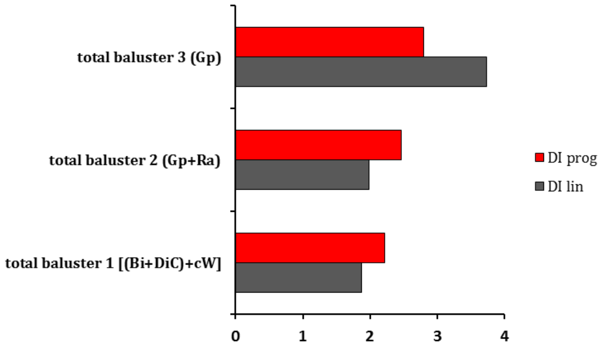

Fig.14 Calculated damage's indices for each studied balusters. Prog= progressive; lin= linear; total baluster #= total indices to the each baluster

5.3 Calculations of the breaking limit caused by crushing

Some elements of the balustrade were classified on the basis of their conservation state:
1) the first baluster has collapsed losing its stem;
2) the second baluster is so eroded that both decorative carvings and its shape are irremediably lost;
3) the third balauster still retains its shape but shows very frequent and severe incrustations.

-In the first case the baluster does not exist anymore and then it can't absolve its structural and aesthetic function. Moreover, this gap, although not very evident in relation to the entire staircase, creates a vacuum dangerous for the user.

-In the second case, part of baluster' s material and of its shape has been lost, but is important to monitor even though its structural function is compromised.

The carried out laser scanner survey provided the volumetric data and the 3D image of the baluster allowing us to verify if the element, despite the large loss of material and the consequent reduction of its section, will resist the compressive stresses due to the its weight and of the handrail above. Known less resistant section (DD=12,63 cmq), known volume of the elements imposed on it (8.520cmc), we calculated the weight P and σ_{am} (23kg / 12,63 = 1,82). The calculated data, despite serious reduction in section (from 35,15 cmq 12,63cmq), show values much lower than the minimum resistance to compression, the dry state, for the Palazzolo Formation limestone.

-Finally, in the third case, it could be sufficient to carry out a cleaning intervention to remove the black crust and deposits of biological nature; in this way, the baluster could continue to perform its aesthetic and structural function.

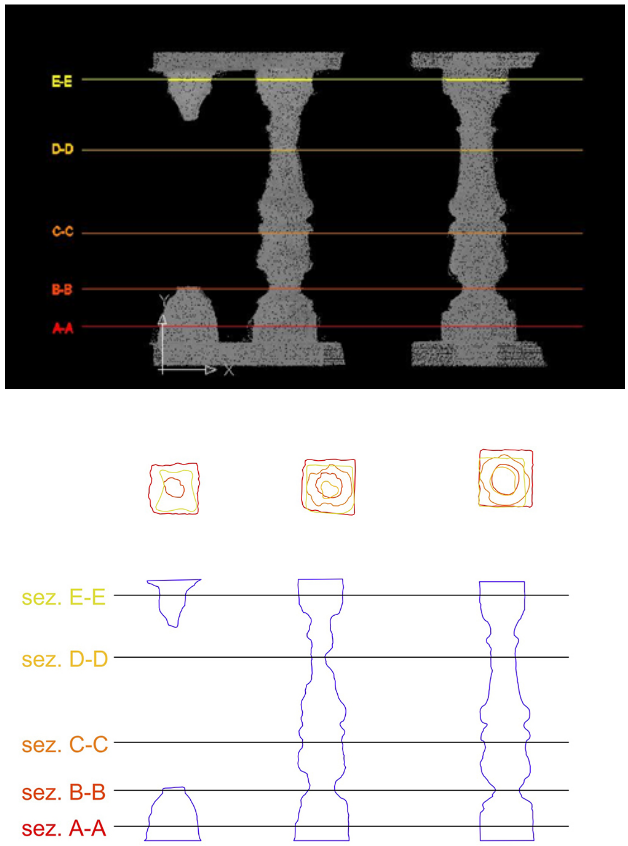

Fig.15 Scheme of sections and planes of balusters 1-2-3

6. Results. Scientific awareness for plane choices. From subjective creativity to objective practice

In the apparatus stone of the historical monument the "structure and shape" are articulated in several aspects: aesthetic on the basis of its artistic expression; composition; functionl; and static-structural (the shelves of the balconies, balustrades, columns, architraves etc. sustain other horizontal elements and live loads).

The reintegration, in this case, becomes a "relative necessity" which is closely related to the partset of the role of the element.

Moreover, often the stone blocks, decorated with fine low-surveys, lose their potential unit without compromising the whole.

The erosion of a shelf or a cornice or a baluster could compromise the aesthetic aspect of the single element but not the architectural unity of the whole.

This creates the hierarchical conflict between the Opera and its component parts, which should be resolved through critical value judgment (Brand, 2000).

The stone balustrade of a valuable monumental staircase is an integer which may be compromised by the absence of one or more balusters.

6.1 Therapy: Criteria and intervention techniques in methods and practices: preserve or restore?

In this paper we have studied three elements with several damage indices and located in sequence in the area of the balustrade area which is most exposed to weathering: from the less severe, which does not show loss of material, to the extreme case of collapse.

As regards to the "intact" balusters characterised by no longer perceptible carvings and colour because of the layer of pathogenic substances, the intervention can only be conservative.

The cleaning operation should be aimed at "liberating" the image from black crusts and biodeteriogens; also because these degradations damage the stone material.

The natural patina is instead identified and maintained.

In the lacuna case, it could be reintegrated, with different material than the original because it affects the entire compositions unity. In fact, "the authenticity of the monument still remains the primary objective of any modification of the building" (Charter of Venice 1960). The remaining fragments may be reintegrated into the new composition.

However, the design solution is problematic for the severely eroded baluster. In this case, its artistic value has been lost, but its function is still active. In fact, the carried out calculations have shown that the element's stability is not yet compromised. It can continue to perform both tasks of structural performance (parapet). But its image, distorted by disintegration, has to be related to the composition of the whole to which it belongs (the staircase); the compositive instance, in this case, is in competition with the artistic instance fragment (the baluster). The difficulty of interpretation of the instances and critic evaluation encourages the critics reflection about whether to keep (conservative intervention) or replace the fragment. The reconstruction using a similar stone material, but more durable, should be made with simple geometries without any carving sculptures so as not to be confused with the original balusters.

A second solution might be to remodel the lost form with plaster. In this way, however, the original materic essence would be lost.

At the end, the third way could be pure conservation, leaving the natural state of the element of deformation. The balustrade's image, in its entirety, would not be compromised but in time, the disintegration would gradually increase until its collapse (as happened to the baluster on the right) of the element. The project aims to stop this degenerative process. Besides, the evaluation of cultural reasons has to look for answers based on scientific and technical analyses in order to identify the most efficient protective substance.

The treatments of protection should have the following requirements: minimum influence on the optical properties of materials; stability to chemical pollutants and radiation, water resistance, vapor permeability, reversibility, and,

Fig.16: Three stages of decay: on the left photo of 2001; in the centre, the baluster without spindle (February 2015) and on the right, collapse of the capital and of the handrail overlying (May 2015)

above all, compatibility. The use of the protective nanoparticles, such as titania should be considered. Laboratory tests carried out on Noto, Comiso and Modica stones highlighted the good performances in term of self-cleaning action and protection against water and salts (Bergamonti, Alfieri, Lorenzi, Montenero, Predieri, Barone, Mazzoleni, Pasquale, & Lottici, 2013).

7. Conclusion

Not even today there is a unique line of reasoning on the issue of gaps in restoration projects. Cesare Brandi (1906-1988) gave a key contribution with the introduction of *Unità Potenziale dell'opera d'arte* tracing, along with Roberto Pane (1897-1987) and Renato Bonelli (1911-2004), the path of critical choice based on instances of cultural content.

The case study shown here wants to be a stimulus to the debate that is still open to every solution, be it creative, pedantic or timid, as long as it is obtained through a rigorous scientific process. This process is intended to focus all its strengths and weaknesses to assess the consequences of design choices with consciousness.

The described methodological approach shows how the new technology and the cooperation between interdisciplinary competences can strongly influence the restoration project. The aim is to extend the proposed method to the case with the similar technical and cultural issues in architecture and in archaeology.

The stone equipment that conforms historic buildings, in fact, contains within itself historical, aesthetic and material value. These instances are strongly connected to each other, but in the case of functional architectural elements, they depend on the persistence of their static efficiency over time. The restoration project can not and must not be added to a specific operational case study; however, the path experienced on the balustrade of villa Cerami certainly deviates from the creative approach to weighted design measures that are heavily dependent on technical-scientific assessments.[1]

[1] Giulia Sanfilippo is the author of paragraphs: 1, 2, 3, 4, 5.3, 6, 6.1 and 7. Erica Aquilia is the author of paragraphs: 4 and 5.2. Graziana D'Agostino is the author of paragraphs: 5.1.

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