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PROGETTO RE-FRESCOS

Preservation, Safeguard and Valorisation of Masonry Decorations in the Architectural Historical Heritage of Piedmont

(D.D. 229/DB1300 del 12 Novembre 2008, S.O. n.2 al BUR 48/2008)

Responsible: Prof. Alberto CARPINTERI, Politecnico di Torino – DISEG

FINAL REPORT

April 6, 2013

1. Foreword

The research team involved in the present Project has found in the Sacri Monti of Piedmont (belonging to the UNESCO World Heritage List since 2003) different case-histories where develop joint multidisciplinary researches. The idea was that the proposed analysis could assume a key role for preservation and maintenance of these monuments.

The research activity was conducted by different subjects: the Politecnico di Torino, the National Research Institute of Metrology (INRiM), and involving the Special Natural Reserve of the Sacro Monte di Varallo as co-proponent.

In actuality, public awareness of the need to preserve, protect and enhance the Historical Heritage, on account of its intrinsic cultural value and its relevance to environmental concerns, is a well-established fact.

While the devastating, irreversible damage wrought by inappropriate intervention methods are right under our eyes, the experience acquired over a quarter of a century of strengthening and restoration works has led to the following conclusions:

(a) Repair and restoration interventions must be conducted on the basis of careful investigations into the composition of the materials, construction history, deterioration mechanisms.

(b) The investigation must focus on the relationships and interactions between the decorative apparatus and the supporting masonry, the microclimate and the soil in direct contact with the structure.

(c) In Piedmont, as anywhere, it is possible to identify a multiplicity of local practices in terms of masonry construction, finishing and decoration methods that are able to make use of local materials and resources.

(d) Each local technique gives rise to special problems of compatibility with some of the integration and bonding systems to be adopted.

(e) In designing rehabilitation and restoration works it is necessary to resort to systems that have been specifically tested for compatibility, durability, and, possibly, reversibility.

The co-proponent laboratories of the Politecnico di Torino and the National Research Institute of Metrology (INRiM), by conducting the research activities related to this project, developed integrated investigation, using non invasive methods, specially designed for dealing with the highly diversified historic heritage of Piedmont, with the aim to remedy current shortcomings in the identification of effective and compatible restoration and maintenance techniques.

The physical-chemical decay and the damage evolution of materials constituting the decorated surfaces and the support were found caused by infiltrations of water, thermo-elastic stresses, or seismic and environmental vibrations. The physical-chemical degradation was dealt by Materials Science and Chemical Engineering techniques.

The stability of the decorated surfaces was investigated by innovative Acoustic Emission (AE) and ultrasonic methods already experimentally tested in the field of artistic and monumental Italian cultural heritage. The ultrasonic investigation techniques allowed to assess separations, defects and damage phenomena regarding the decorated surfaces and the masonry supports. Innovative acoustic methods allowed to distinguish a well preserved artwork in comparison to a damaged one.

The data collected during the experimental tests conducted in situ were interpreted with Fracture Mechanics models and methodologies.

Finally, the research activity has shown how the design of the most appropriate technique turns out to be crucial as well as the selection of the most suitable repair products in terms of durability and compatibility.

2. **Duration of the Project:** 36 months.

3. **Work plan**

The project was divided in 6 Work Packages, the WPs Leaders are Professors and Researchers of the Politecnico di Torino and Researchers of INRiM; in each work phase, Researchers of the different Departments are involved. The WP indication is listed in the following:

- WP1) *Characterization of historical surface finishing and execution techniques. Study of materials and their mixing ratios. Definition of specific interventions*. WP Leader: Arch. Marco ZERBINATTI (from month 1 to month 36).

- WP2) *Damage analysis of decorated surface structural support by the Acoustic Emission technique*. WP Leader Prof. Giuseppe LACIDOGNA (from month 1 to month 36).

- WP3) *On site monitoring of mural decorative artworks using advanced ultrasonic techniques - Laboratory prequalification of injection grouts to be used in repair works*. WP Leader Prof. Pietro Giovanni BOCCA (from month 2 to month 36).

- WP4) *Upgrading and recovery of mural painting assets in Piedmont: the problem of reliability and durability of the media*. WP Leader Dr. Alessandro SCHIAVI (from month 1 to month 29).

- WP5) *Analysis of debonding phenomena in decorated mural elements by numerical models based on Fracture Mechanics*. WP Leader Dr. Marco Paggi (from month 13 to month 30).

- WP6) *Dissemination and diffusion of the results*. WP Leader Prof. Gianpaolo SCARZELLA (from month 12 to month 36).

4. Technical Scientific Objectives and Results

WP1: Characterization of historical surface finishing and execution techniques. Study of materials and their mixing ratios. Definition of specific interventions

Responsible: Dr. Marco Zerbinatti

The WP01 has worked to obtain the goals defined during the project phase with particular attention to the characterization of the materials which make up the surfaces (historical external renders) under investigation, their techniques of application and the possibilities of employment of innovative materials according to interventions of maintenance and/or restoration. Considered the vastness of the theme connected with the main subject of investigation (the architectural complex of Sacro Monte in Varallo Sesia), the job has been planned with a multidisciplinary approach, with the purpose of achieving results which turn out to be proved by the contribution of various scientific sectors. At first, it needs to be underlined that the attention addressed to the historical architecture surfaces is, nowadays, still often insufficient; beyond the decorated surfaces (like painted ones), the plasters are very frequently subjected to interventions of total substitution and remaking, without the proper attention to their importance as “material document”, to the executive techniques originally employed and to the inseparable relationship with the wall system. For these reasons, the research activity can usefully be described dividing it in different, consecutive phases.

PHASE 1 - KNOWLEDGE, SAMPLING AND CHARACTERIZATION OF MATTERS.

The first months of job have been spent to achieve a deep knowledge about artefacts of Sacro Monte of Varallo and their main phenomena of decay on external surfaces (in collaboration with technicians of the Ente Riserva Sacro Monte bureau); as a consequence, the WP01 has drawn a sampling planning on site to study characteristics of matters under chemical-physical and mineralogical- petrologic point of view. This study has been based on a high number of samples with similar aesthetic and behaviour properties; in this phase, the main interest has been focused on outdoor ancient plasters with dark grey-blue colour (in some cases, nearly black), applied on the west and north-

west façades, most frequently under the wind-rain aggressive action and featuring by the sequent characters:

- a very polished and dense surface,
- the grey-blue colour (from dark grey nearly black to light grey-blue),
- the application on façades exposed to the wind-rain action,
- the capability of lasting for a long time (through the centuries) despite the hardest climatic and environmental conditions.

Characterisation analysis of these surfaces have been developed in order to analyze now the reasons of their durability, recognise constituent materials and their ratio. Through chemical – physical analysis have been obtained the following information:

- employment of local sands like aggregates (their mineralogical composition correspond to Sesia river sand),
- employment of magnesic putty lime like binder,
- employment of a local black hearth like pigment (from Boca, with lignite as constituent).

Some data were obtained also by historic documents (in particular, on “ratio” for plasters used in these yard); these data have confirmed the results of instrumental analysis and have underlined the high skilfulness during the execution on the plasters. Indeed, the polished and dense surface on the sides under wind-rain action has preserved the façades and the indoor artefacts (wall paintings and sculptures).

PHASE 2 – RE–FORMULATION OF EXTERNAL PLASTERS AND INTERVENTION PROPOSALS.

On the base of the investigations and the decay survey, a production (or better, a “reproduction”) of plasters samples with smooth finishing was started in our laboratories, with mixing ratio apt to make maintenance interventions on lacunas.

The goal of this experimental phase has been to characterize the aptest mixtures according to employment of the materials today available, focusing the attention to the material constitution, to the finishing and grain of surfaces, to the chromatic yield and morphology. Sands have been withdrawn by Sesia river, while not being us more furnaces

of magnesian lime on the territory, it has been acquired an aged putty lime with a comparable composition of the original one used in the plasters of the Chapels. The pigment used for getting the grey-blue colour is the black earth of Boca.

Of the drawn samples realized in laboratory has been valued the chromatic compatibility in comparison to the chapels which have been take as references (through acquisition of data with spectrophotometer) and the behaviour of the plasters to the water on surface, through the measures of the contact angle and capillary absorption.

The superficial workmanship has underlined some problems about the execution, but through the comparison with a restorer, smooth and uniform samples have been obtained, thin and deprived of cracking, even if of limited ampleness (this aspect have to be further examined on site). We have been point out the formulations and the ratios of the components that can be considered some valid bases for possible interventions of restoration on the surfaces.

PHASE 3 – STUDY, APPLICATION AND EVALUATION OF NEW CONSOLIDANTS.

These experimental phase has been focused on the formulation and application of organic / inorganic hybrid materials for the superficial consolidation of disaggregates plasters. In fact, in the field of the maintenance through employment of materials with good consolidating capabilities, has been underlined a demand in conjugating an elevated mechanical ownerships (as the typical cohesion of the polymers) with the characteristics of stability and compatibility typical of the inorganic materials.

Besides, it must be considered that also in the sector of the restoration it‘s always increasing the necessity of employing products with a less quantity of solvents and deprived of toxic components for the man and for the environment.

For all these reasons two material hybrids have been studied, in which the organic matrix is the epoxy resin polymerized by cationic way with the employment of a base catalyst of ytterbium ; this allows to get to the meantime the condensation of the TEOS and the deposition of cluster of silica in the polymeric matrix. This method of space-lattice, never employed in the field of restoration, it was efficaciousness and compatible with a possible application in the yard.

Following the application of the two formulations, has been found a good re-aggregation of the binder, a reduction of the water absorption by capillarity, and of the total water absorption, to forehead of an unchanged transpiration of the water vapour on the treated plasters. Analyses have underlined that with both the treatments the porosities have been maintained, while the consolidating one doesn't form a superficial film. Obtained values by the colorimetric measures from results compatible both before and after the accelerated ageing of the samples with ultraviolet radiations. Finally, through the tests of salts solution ageing, a good compactness of the consolidated part has been verified and has not been found an incompatibility of the treatments as a consequence a differential thermal expansion among the treated zones and the not treated ones.

At the end of this phase, in the courtyard of the ISEG department has been built a stone shapes wall having similar characteristics to those of the masonries of the chapels of Sacro Monte. On the two faces of this wall plasters have been applied samples of plaster constituted by 2-3 layers of lime based on mortars, intentionally performed detached by the support in partial way.

This wall will be used for different experimental activities:

1. an evaluation test of the performances of consolidants studied in laboratory, into a situation of real ageing in outdoor space,

2. in collaboration with the INRIM, tests for the evaluation of performances of a portable diagnostic tool in phase of study, that will be used to evaluate in a non-invasive way the entity of the detachment of the layers of plasters through the employment of sonic waves.

PHASE 4 – INVESTIGATIONS ON THE DEGRADATION BY BIOFILMS.

Besides, thanks to the collaboration established with Daniela Pinna, researcher at Opificio delle Pietre Dure – Florence, biologist expert in restoration of stone monuments, a field of investigation has been developed to identify the most diffuse bio-films responsible of the degradation of many plastered surfaces, and natural stone too.

Through two days of study and a seminar activity (which have participate Ph.D. Students and Students of the School of Specialization cultural heritage), at Sacro Monte has been drawn some samples of natural (marble, granite) and artificial stone materials (mortars, plasters) in order to investigate the degradation causes by bio films agents, apt

to purpose correct maintenance interventions. This phase, as it has been the most recently started, it's still under completion and the results will be soon available.

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WP2: Damage analysis of decorated surface structural support by the Acoustic Emission technique.

Responsible: Prof. Giuseppe Lacidogna

The aim of this WP is to reveal by means of the Acoustic Emission technique the damage evolution in the support of the decorated surfaces of the Sacred Mountain of Varallo. In particular, the data coming from the “in situ” monitoring of the Chapel XVII were utilized in order to preserve the artworks from seismic risk and eventual collapses due to earthquake actions.

A complete diagnosis of crack pattern regarding not only the external decorated surface but also the internal support is of great importance due to the criticality of internal defects and damage phenomena, which may suddenly degenerate into irreversible failures.

A great deal of non-destructive techniques work by introducing some type of energy into the system to be analyzed. On the contrary, in AE tests, the input is the mechanical energy release generated by the material itself during the damage evolution, so that no perturbation is induced and the integrity of the system may be guaranteed. By monitoring the support of a decorated surface by means of the AE technique, it becomes possible to detect the occurrence and evolution of surface vs. support separation and of stress-induced cracks.

Cracking, in fact, is accompanied by the emission of elastic waves, which propagate through the bulk of the material. These waves can be received and recorded by piezoelectric (PZT) transducers applied to the external surface of the artwork support.

Objective of the research is to use the AE technique to assess the support of the decorated mural surfaces developing the application aspects of this technique, which has been widely studied from a theoretical and experimental point of view by some authors in the safeguard of civil and historical buildings. The AE technique makes it also possible to predict and localize the presence of cracks and analyze the damage evolution in supports such as decorated masonry walls and vaults.

As regards the structural integrity, the Chapel XVII shows a vertical crack of about 3.00 m in length and a detachment of frescos both on the North wall, which are the object of the

present monitoring campaign by means of AE. Six AE sensors are employed to monitor the damage evolution of the structural support of the decorated surfaces of the Chapel XVII: four are positioned around the vertical crack while two are positioned near the frescos detachment (Fig.1). For the sensor pasting on decorated surfaces, a suitable methodology is applied.

Moreover, the Chapel XVII shows another vertical crack on the South wall, symmetric of the previous one with respect to the pronao of the building. The monitoring period of the structural supports of the chapel began on April 28, 2011 and ended on June 4, 2011. The results obtained by the application of the AE sensors are presented in Figs. 2 and 3.

As can be seen from Fig. 2, the vertical crack monitored on the North wall of the chapel presents a stable condition during the acquisition period ($0.5 < \beta_t < 1.0$) and a clear distribution of cracks in a surface domain is proved by the b-value in the range (0.95, 1.10). The evidence for the presence of a large crack is offered by the low frequency signals registered (< 200 kHz): as a matter of facts, considering the velocity as a constant and applying the Lamb ratio, the wavelength needs to be larger than that of the maximum inhomogeneity in order for the wave to pass through without significant modifications in its waveform. It is reasonable to assume that for a high frequency wave it is possible only to propagate through a small inhomogeneity; on the contrary for a low frequency wave it is possible also to propagate through a large inhomogeneity. Concerning the monitored frescos detachment (Fig.3), the decorated surface tends to evolve towards metastable conditions ($0.5 < \beta_t < 1.8$) and the signals acquired show high frequency characteristics (< 400 kHz): therefore a distribution of microcracks in fractal domain near to a volume is assumed for the analysed region.

To complete the analysis, the Chapel XVII was also discretized exploiting symmetry with three-dimensional linear pyramid elements, accounting for the accurate geometry of the stone masonry structure. The shape of the cylindrical chapel, and of the above spherical dome are precisely discretized, taking into account the various apertures, the inside internal vault supporting the Mount Tabor installation, and the outside pronao with columns. On the contrary, the wooden roof structure was considered only as an external load. The mesh of the structure is shown in Fig. 4. The finite element model is discretized using 15400 nodes, connected by 64200 elements, and is characterized by 43064 degrees of freedom. The elastic properties assumed for the masonry, and the density, where respectively equal to: E = 2E+9 Pa; ν = 0.3; ρ = 20 kN/m^3. The elastic analysis, performed

with the commercial finite element code DIANA® allows for a preliminary assessment of the structure. Fig. 5 shows the contour of the principal compressive stress. In general, the level of compressive stress is quite low, compared with the expected strength of the stone masonry, and almost everywhere lower than 1 MPa. Nevertheless, the compression stress in the external columns of the pronao is greater, and equal to 1.03 MPa. The external columns are also subjected by environmental degradation of the stone.

Fig. 6 shows the contour of the principal tensile stress, reported on the deformed shape of the structure. The tensile stresses calculated on the internal wall of the chapel, justify the presence of the two symmetric dominant cracks. Fig. 7 shows the deformed shape of the structure compared to the initial shape. The deformation clearly shows the opening mechanism due to the effect of the pronao, as well as to the thrust of the internal vault that support the mount Tabor installation. A more detailed mechanical characterization of the masonry is currently under development to perform the subsequent nonlinear analysis.

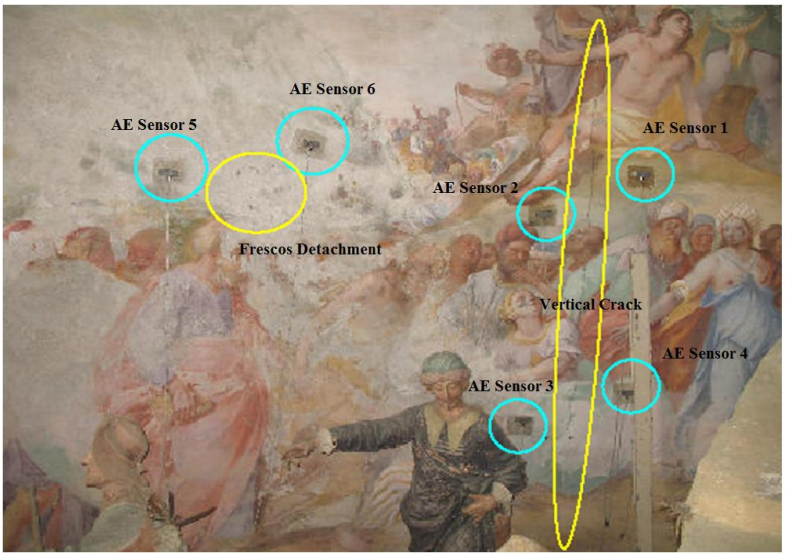

Fig. 1. Chapel XVII: View of the Monitored Damages and Position of the AE Sensors.

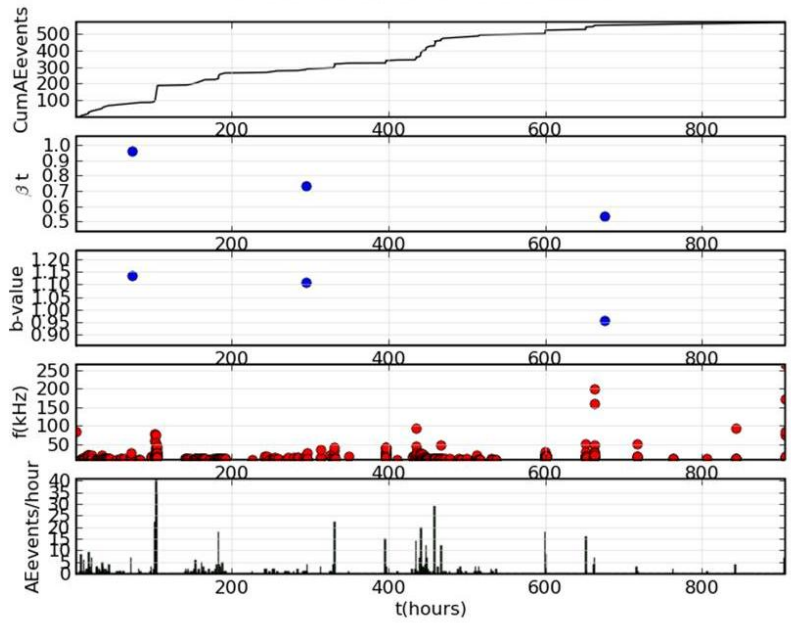

Fig. 2. Chapel XVII: AE from Vertical Crack Monitoring.

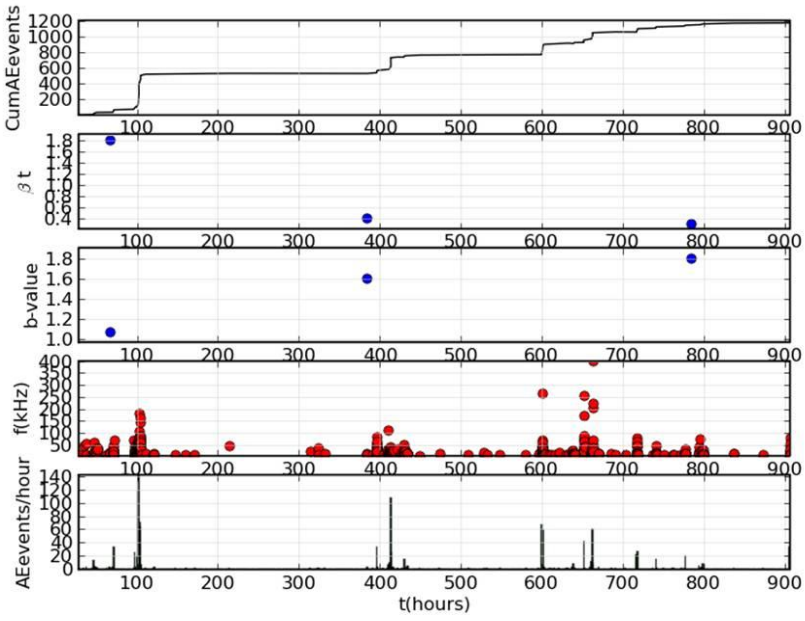

Fig. 5. Chapel XVII: AE from Frescos Detachment Monitoring.

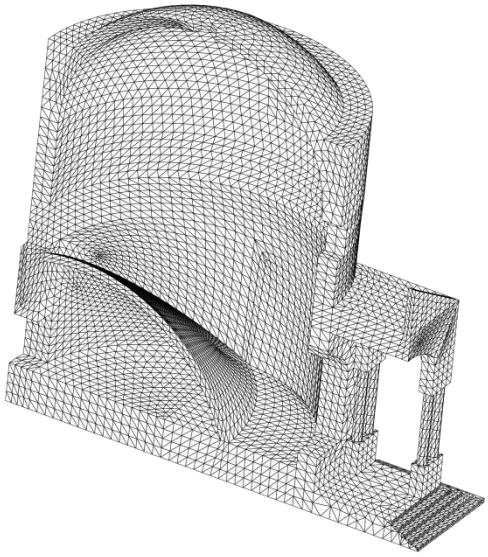

Fig. 4. Chapel XVII: Finite Element Mesh.

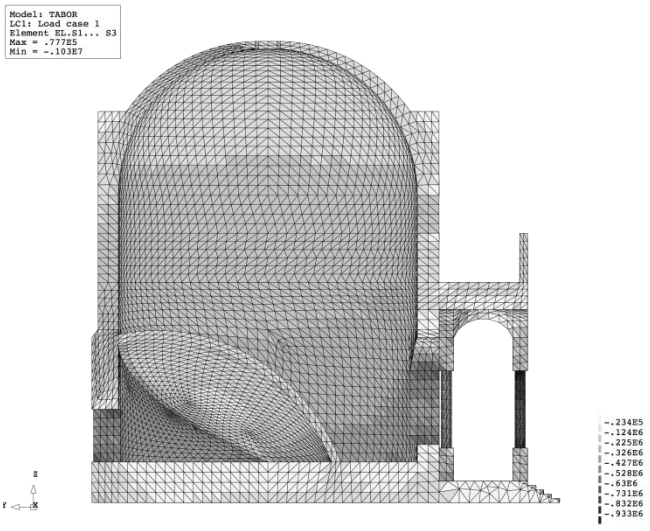

Fig. 5. Chapel XVII: Principal Compression Stress Contour.

Fig. 6. Chapel XVII: Principal Tensile Stress Contour.

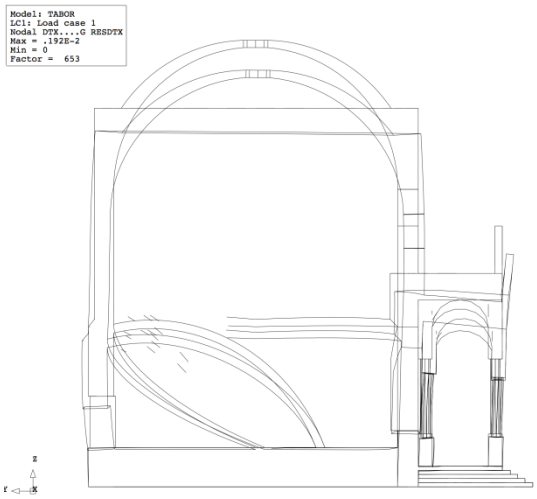

Fig. 7. Chapel XVII: Deformed Shape.

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WP3: On site monitoring of mural decorative artworks using advanced ultrasonic techniques. Laboratory prequalification of injection grouts to be used in repair works.

Responsible: Prof. Pietro Giovanni Bocca

In accordance with the objectives set at the beginning of the Project, Work Package 3 has been working in a threefold direction, with the ultimate aim of improving the state of the art concerning the early diagnosis and non-destructive monitoring of mural artworks and subsequently developing useful tools for the design of repair works (with selection of the most appropriate repair products, in terms of durability and compatibility with the pre-existing structures):

1. Theoretical development, experimental implementation and application of innovative diagnostic and monitoring techniques based on the observation of acoustic waves propagating through heterogeneous media, with special reference to a specific methodology referred to as *Scaling Subtraction Method*.
2. Laboratory development of novel material characterization techniques, based on the use of mechanical tests, performed with the aid of a specially conceived device in order to explore the ultimate potentialities of the materials considered and investigate in particular the strength and adherence properties of the interfaces between the functional layers constituting mural artworks. In addition, while subjecting materials to particularly high stress levels, these techniques make it possible to examine the mutual interaction between repair products and underlying support of mural artworks in severe conditions, and hence to define very strict and accurate prequalification criteria.
3. Accelerated lab simulation of natural degradation effects usually occurring in mural artworks, with the aim of evaluating the durability and structural compatibility of repair products under the effect of environmental actions. In particular, since it is known that major problems affecting brick or stone masonry structures, both modern and historical ones, are related to rising damp and to the presence of soluble salts into capillary water, that finally induce cracking and de-bonding of the external layers of mural artworks, specific attention has been devoted to the lab simulation of thermo-hygrometric fatigue phenomena, also in the presence of expansive soluble salts.

As far as the first and third points are concerned, very positive results have been achieved, as reported in references [1-4], with the definition of effective lab protocols for the evaluation of freezing-thawing and salt crystallization effects, in the presence of water. The experimental evidence revealed that this type of damage causes an increase in the nonlinear response of the system to an ultrasonic excitation, in a similar way as already attested in the scientific literature for different other forms of degradation. The use of a nonlinearity indicator such as the one based on the Scaling Subtraction Method proved to be very useful for the purposes of damage monitoring, since it showed a high sensitivity to the appearance of decay and was able to provide precursory indications with approaching rupture. Additional experimental methods based on acoustic techniques were also used in the framework of WP3 for the characterization of the occurrence of progressive degradation at the interface between material layers due to different damage mechanisms, with encouraging results detailed in references [5-7].

Finally, with regard to the second point listed above, laboratory procedures aimed at generating a progressive deterioration of the interface between brick/stone and mortar layers in controlled experimental conditions were developed at the Non Destructive Testing Laboratory of the Politecnico di Torino – see references [8-15]. They were intended as a preliminary stage in the design of a pre-qualification procedure to be applied to repair mortars for restoration of historical masonry buildings. Indeed, assessing the durability of repair products is a major concern because of the potential occurrence of de-bonding phenomena due to insufficient compatibility between original and repair materials, in terms of their mechanical characteristics. Therefore, the study of the long-term mechanical interaction between repair mortars and historical masonry substrate turns out to be crucial for the design of durable repair works. In this direction, the experimental campaign carried out in the framework of WP3 contributed to provide a better understanding of the damage mechanisms considered, thus shedding new light on the on site behavior of historical masonry artworks. Moreover, the evolutionary phenomenon of mortar de-bonding was analyzed also through the cohesive crack model. The numerical simulation of the laboratory tests was shown to be able to describe the experimental evidence correctly, thus allowing to characterize the mechanical behavior of the interface and substantiating the possible use of the analysis developed here to predict de-bonding phenomena also in problems with different boundary conditions, by changing the simulation parameters properly.

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WP4: Upgrading and recovery of mural painting assets in Piedmont: the problem of reliability and durability of the media.

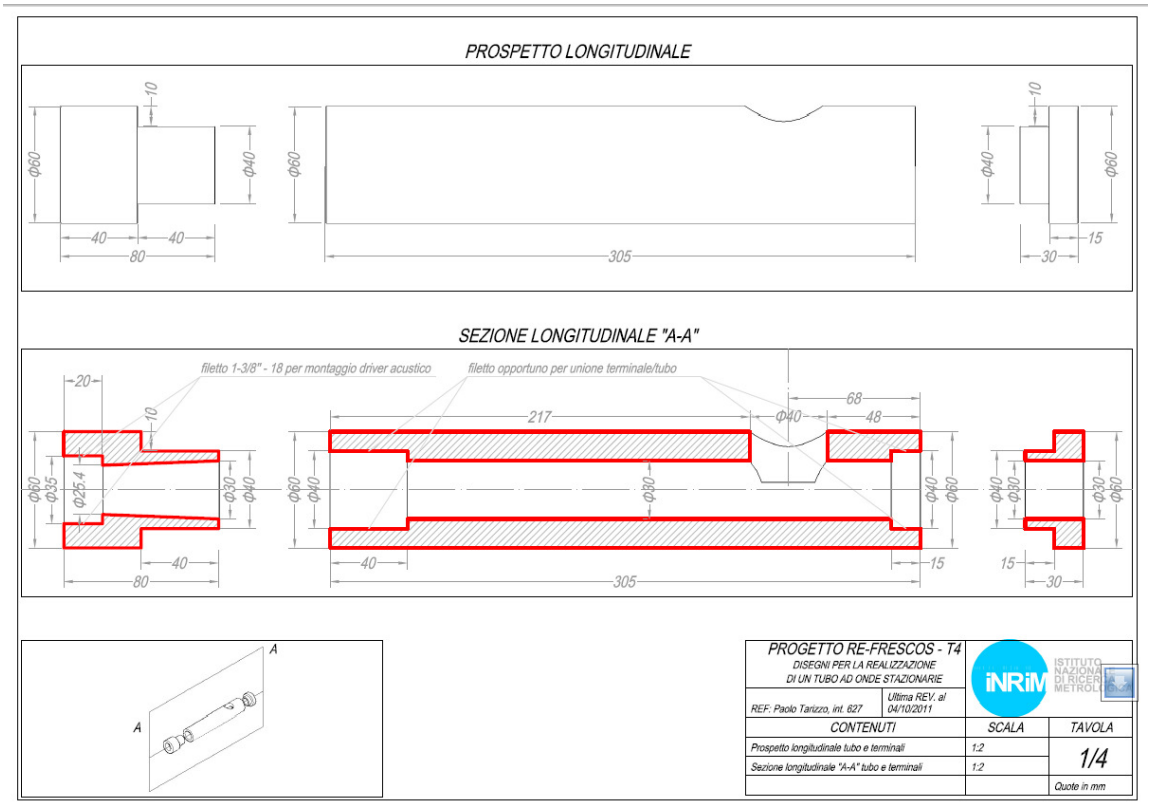
Responsible: Dr. Alessandro Schiavi (INRIM)

Endosuperficial Sonoscopy: Implementation of a diagnostic apparatus, based on acoustic techniques, for the monitoring and the evaluation of the state of conservation of frescoes.

Our research activity has been focused on the development of a non-invasive method, based on acoustic measurements, suitable to monitor the conservation status of frescos. Essential metrological requirements are good repeatability of the measure and a certain degree of practicality of the measurement itself.
The method here proposed is founded on the measurement of the acoustic energy reflection factor through the analysis of the plane waves field in a tube. More precisely, the idea has been to adapt the instrument used to measure in the laboratory the coefficient of absorption of absorbent materials, known as Kundt tube, to an in situ measurement [1-2]. The measurement device has been fully designed, developed and realized in the laboratories of INRIM.
The method for laboratory measurement of the absorption coefficient in Kundt tube is described by the standard UNI EN ISO 10534-2 [3] and is based on the calculation of a transfer function between the signal detected by two microphones placed inside tube [4-5]. The method is based on the assumption that the waves inside the tube are plane.

The Refrescos “handy tool” device consists in a Plexiglas tube of a nominal diameter of 50 mm (inner diameter of 30 m) with a total length of 360 mm. The fresco surface analysable is then of about 7 cm2. The absorption coefficient $\alpha(\omega)$ can be measured usefully in the frequency range between 500 Hz and 5 kHz.
In the Figure 1 the tube is depicted. This device is composed of functional divisible parts, so that it is easily modifiable if necessary. The acoustic driver is connected to the tube and in it a microphones holder is placed. The third and last module shown in Figure 1 constitutes the contact element between the measuring device and the frescoed surface, i.e. the head of the tube. Because of the possible irregularities of the surface and the

required non-invasivity, a 5 mm of synthetic rubber-like (closed cell) neoprene layer has been used. This material is particularly suitable for our purposes, because its deformability allows to fill the surface irregularities of the wall without damaging it and also the high flow resistance due to the internal structure causes the absorption of acoustic energy is known.



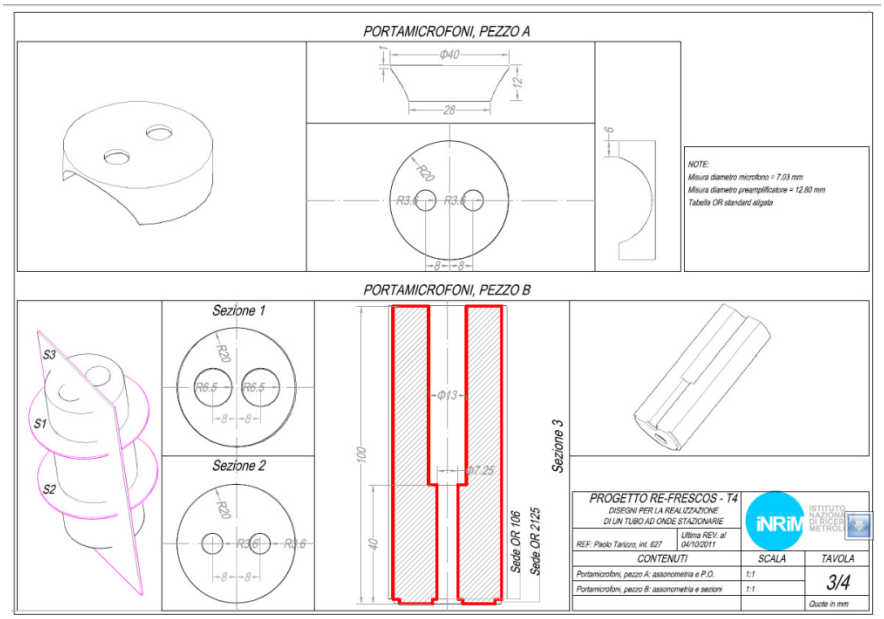


Figure 1: Drawings of the project of the tube.

Figure 2: The apparatus realized at INRIM.

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WP5: Analysis of debonding phenomena in decorated mural elements by numerical models based on Fracture Mechanics.

Responsible: Dr. Marco Paggi

The scientific results obtained within WP5 regard two main topics, in line with the aims of the research.

1. Development of a finite element model based on nonlinear fracture mechanics for the study of the phenomenon of debonding at the interface between heterogeneous materials.
2. Development of physical-mathematical models for the characterization of crack propagation due to repeated mechanical loadings (vibrations, cyclic loading, fatigue).

Regarding the first topic, a novel thermo-elastic cohesive zone model has been proposed for the study of decohesion of interfaces not fully bonded between materials with different thermo-elastic properties. In addition to the mechanical part regarding the relation between cohesive tractions and relative displacements between the adhered bodies, a law relating the heat flux and the temperature jump at the interface has been considered. The proposed relation, motivated by micromechanical contact considerations, considers a thermal conductance of the joint dependent on the crack opening displacement. Such a dependency of the heat flux on the displacements of the continuum leads to coupling between the elastic and the thermal fields.

Writing the weak form of the differential problem related to the static and thermal equilibrium of an infinitesimal plane element, the contribution of the interface has been suitably highlighted. The subsequent discretization and approximation of the weak form within the finite element method has required the implementation of an interface finite element in the research code FEAP. In addition to nodal displacements, nodal temperatures have been included among the problem unknowns. Since the field equations are strongly nonlinear, the solution of the problem at each time step has been obtained according to the Newton-Raphson technique. To this aim, a linearization of the thermo-elastic cohesive relation has been carried out in order to compute the consistent tangent stiffness matrix of the finite element. The proposed model has been applied to decohesion problems between two materials with a thermo-elastic mismatch. In particular, the effect of

cooling down a masonry wall on the debonding of a decorated layer from the substrate has been analyzed.

Regarding the second topic, the classic Paris and Wöhler fatigue laws have been generalized by considering fractal geometry concepts and dimensional analysis. Particular attention has been paid to the description of the fatigue behaviour of mechanically short-cracks. Experimental results have in fact shown how microscopical cracks have a higher velocity than the macroscopical ones. Hence, a significative fraction of the fatigue life of materials and structures is spent in the growth of such defects whose behaviour is difficult to be quantified. The new proposed laws, motivated by fractality of rough crack profiles, have permitted to characterize with a higher accuracy the anomalous behaviour of short cracks and to analyze size-scale effects on the fatigue life induced by the propagation of such defects.

Original contributions have been presented at conferences and published or submitted for publication on international journals (see the following list of publications).

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5. Conclusions

The research activity conducted by different subjects: the Politecnico di Torino, the National Research Institute of Metrology (INRiM), and involving the Special Natural Reserve of the Sacro Monte di Varallo as co-proponent, has combined and integrated different methodologies in order to correctly operate on the artworks of the Sacred Mountain of Varallo.

In this framework, a first social and economical impact regards those artworks which have been almost ignored until now: they will be able to go back to their original splendour and become cultural and touristic poles, as well as a good chance for territorial economy.

As matter of fact, in the last few years Turin and the Piedmont's territory have been slowly leaving back the industrial identity to acquire a new connotation, based on the presence of artistic and touristic centres of exceptional interest. On this base, the activities of the research team have been of primary relevance in the valorization and preservation of the historical and artistic heritage of Piedmont. In a social-economical context, a second impact regards the chance to optimize restoration costs through a careful diagnosis.

The innovative techniques here proposed lead to the individuation of the true degradation causes. As a consequence, all restoring interventions will be specifically thought for any specific problem with a consequent costs saving. In addition, the results of the highly qualified technical activity are a great contribution in the valorization of the territory and are able to satisfy the technical demands of the restoring subjects. The same results could be used by the Public Authorities for a better qualification of their activities and for an economic return on the territory. The outcome of the interdisciplinary activities are presented in scientific publications and in intervention guidelines, both at a national and international level.

Moreover, a complete website could be found at:
http://www.refrescos.polito.it/
where all the activities and the scientific results obtained during the 36 months of the RE-FRESCOS Project are reported.

The website also contains all the Proceedings of the Conferences that have been held at the Politecnico di Torino about RE-FRESCOS.

A Final Conference on the technical and scientific results of the RE-FRESCOS Project is planned for May 2013 in Varallo (VC).

April 6, 2013

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