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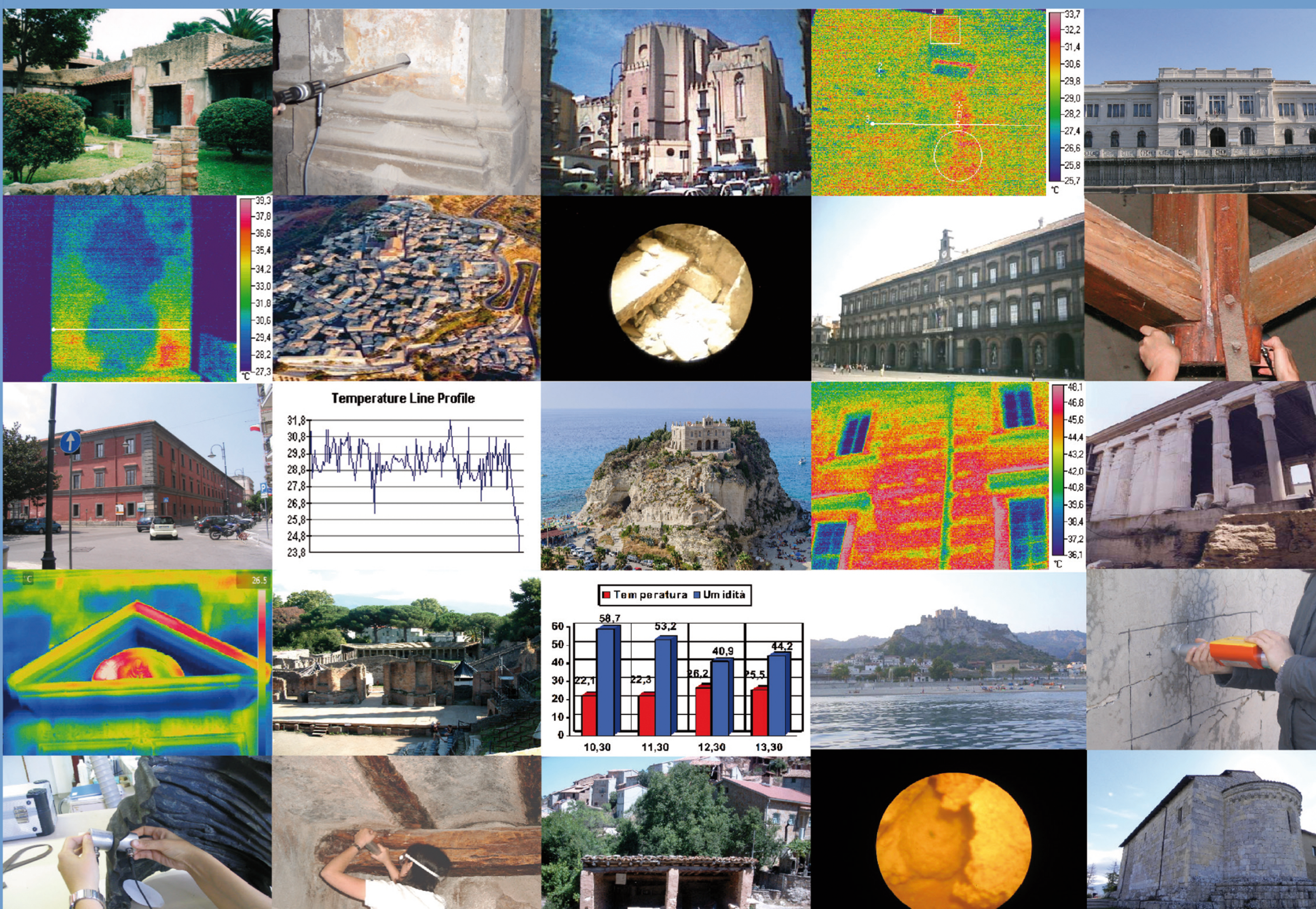
Alessia Bianco

ON SITE DIAGNOSTICS

FOR ARCHITECTURAL CONSERVATION AND RESTORATION



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Premise

The topic of on site diagnostics for historical, monumental and vernacular architecture is characterized by a twofold difficulty, partially due to a sort of hiatus between scientific community and professional system.

In fact, on one side universities and research centres produce advanced technologies, methodologies and procedures, but not always adequately disseminated among professionals and sometimes inconsistent with some relevant criteria, such as feasibility and cost-effectiveness.

On the other side, professionals, in the field of on site diagnostics for historical architectures, are holder of a heritage, made of experiences and practice, which often is not enough shared and sometimes is contrasting with the limited possibility to evaluate and verify the professionalism of operators, due to a professional training and certification system, which seems too heterogeneous, if compared to other high scientific and technical professions, as is the case, for example, of medicine or engineering.

Between the academic and the professional systems there are other intermediate levels: firstly the institutions, which sometimes act legislating with particular attention to the professional certification issue, as in the case of North American countries, sometimes with rather more primary interest in regulating the use of instruments through procedures, protocols and methodologies, as in the case of several European countries, considering, for example, the numerous and highly detailed UNI-EN norms.

The last actor in this scenario is the market in the field of diagnostic tools, which has the merit of setting up, at least partially, an effective connection between the scientific-academic community and technical-professional organizations, but of course following the instances of business, both in terms of proposed instruments and, above all, about the professional training market in the field of diagnostics for ancient architectures.

However this profession is very complicated, because it requires very specific skills, which have to concern, at the same time, two dimensions of knowledge that, in the least two centuries, have seen a mutual gap.

In fact, to properly plan and design a diagnostic survey on historic buildings, professionals must have solid background in history of architecture (often together with expertise in archaeology) and drawing documentation for historical buildings; but at the same time skills and expertise in the field of materials, chemistry, geotechnics and structural engineering of traditional buildings are required.

However, observing many of the not only European codes in the field of on site diagnostics or regulations for the professional training and certification on no-destructive controls, the focus is often placed on how to use diagnostic tools and operational and executive procedures; but the preliminary phase, i. e. the design of the diagnostic plan, although crucial for obtaining useful and reliable diagnostic results, is left to the discretion of professionals and not often subject to quality control procedures.

In fact, it is not rare to come across very extensive diagnostic reports, which include detailed results of numerous tests (diagnosis), but not introduced by equally detailed diagnostic plans, which should contain a historical and drawing documentation of the investigated building, together with its transformations and restorations, as well as endogenous and exogenous factors, related to its conservative and structural issues (anamnesis).

Finally, many of these diagnostic surveys omit to integrate the diagnostic results with their interpretive reading, that can be connected to emerging needs and interventions, to be proposed just simply in terms of methodological approach (prognosis).

This is one of the reasons why in this book[1] the diagnostic experiences are described, though, for logistical reasons, often briefly, following a systematic methodological approach, according to three of the main steps for the knowledge historical buildings: anamnesis, diagnosis and prognosis, obviously with particular attention to the specifically diagnostic issues (diagnosis), but framed in the preliminary diagnostic plan and interpreted in the light of the performance, prefigured in the preliminary stages and connected to the visual inspection.

The book faces another question, mentioned at the beginning of this introduction, which is crucial for on site diagnostics for architectural heritage, i.e. how to pursue a better osmosis between the scientific research and the professional practice; that is why this book regards not only some experimental, unconventional and innovative diagnostic surveys (about twenty) and diagnostic experiences, carried out on particularly valuable monumental buildings under the historical-architectural point of view (about fifteen), but also ordinary and simple experiences in the field of professional diagnostic practice (about sixty), where, however, it was possible to apply the methodology and the know-how, acquired and systematized in the performance of the experimental diagnostic surveys, often included in wider scientific research projects.

For these reasons this book is not exclusively addressing the scientific and academic community in the field of on site diagnostics for monumental and vernacular historical architecture, but it also pursues the aim of disseminating in the professional system a heritage of rather varied experimental researches and practical experiences, but methodologically oriented toward a culture, which considers the design of diagnostic plans as a regulation criterion for quality control of professionals.

[1] This book collects almost hundred experiences in the field of planning, implementation and validation of instrumental on site diagnostic investigations for monumental and vernacular historical architectures and archaeological ruins, carried out in in fifteen years:
-from 2003 to 2013 within the S.I.S. Section (Strumentazioni Investigative in Situ-On site investigative tools), directed by prof. arch. Giorgio Allegra from 2003 to 2005 and prof. arch. Vittorio Ceradini from 2006 to 2013, of the M.A.Re. Laboratory (Materiali ed Analisi per il Restauro- Materials and investigations analysis for restoration), directed by prof. arch. Enzo Bentivoglio from 2003 to 2005 and by prof. arch. Simonetta Valtieri from 2006 to 2013, of the P.A.U. Department (Patrimonio, Architettura, Urbanistica-Heritage, architecture, urban planning) of the Mediterranea University of Reggio Calabria-Italy. The investigations were carried out by the author from 2003 to 2013, together with arch. Antonio Polimeni from 2003 to 2005 and arch. Sandra Cassone from 2006 to 2008;
- from 2011 to 2012 within the Center for Heritage Conservation at the Texas A&M University-USA;
-from 2013-2017 within the İstanbul Kemerburgaz University-Turkey (2013-2015) and for the Architectural Heritage Center of University of Technology, Lae-Papua New Guinea-Australasia (2016-17).

1. Masonry buildings with timber floors and roofs
1.a. Churches and monumental buildings

St. Domenico Maggiore Monastery, Naples-Italy

Abstract

St. Domenico Maggiore Monastery in Napoli-Italy is one of the largest monumental complex in Italy and its constructive history, with its articulated palimpsest and valuable artistic heritage, makes it one of most relevant monumental site in this great historical city. In occasion of a long a difficult intervention of conservative restoration, started ten years ago and yet in progress, the monument was subject to several kinds of activities, aimed to its knowledge, consisting above all in a historical and stratigraphic analysis, but also diagnostic tests. In some cases these two categories of investigations were integrated or superposed each other, especially to understand the most complicated issues. The St. Domenico Maggiore Monastery, constructed on a first little chapel built in the seventh century, had a first vast enlarging intervention in the eleventh century, but it is possible to recognize at least nine great transforming phases, realized both for functional needs and after severe earthquakes. In this context this contribution regards a specific experience, which can evidence how diagnostic investigation, in this specific case endoscopies, were able to represent an element of implementation of technical and constructive knowledge and how these data were useful to help stratigraphic and historical comprehension of one of the most complicated part of monastery, the St. Domenico cloister and its large staircase. In fact the capability to directly verify technological characteristics of every masonry pilaster of the cloister (tufa; bricks; tufa and bricks) with an easy, but micro-invasive, investigation, permitted to correlate the wings of the cloister to different constructive phases, giving elements useful in phase of numerical evaluation of seismic structural performance in comparison with other buildings in the monastery, placed around the St. Domenico cloister, with a consequent simplification of the restoration project. This case history, conventional in terms of content, but interesting in terms of strategy and approach, is inspired by a cultural orientation, which is based on interdisciplinary, permitting a holistic vision, born through interconnection of different points of views, able to reduce evaluation mistakes and consequently to improve and verify every project choice.

St. Domenico Monastery, aerial view, 2010 (top) and in 1653 (bottom)

The main constructive phases

Anamnesis

A.1. Introduction and history

The complex of San Domenico Maggiore is the largest monastery in Naples, which is an important city of Southern Italy and UNESCO World Heritage Site. The complex is very important not only for its architectural and artistic value, but also for a very interesting and complicated construction history, summarized below in order to highlight the difficulty of knowledge of its stratification and how the execution a dense endoscopic investigation contributed to clarify some of the unknown aspects:

- Phase I: original foundation, VIII-X century. The analysis of the historical documents shows that the original foundation, relating to a period between the VIII-X century, had to be very articulate and it was largely preserved in the deep transformations made in the XIII century, but today there are not more large parts attributable to this time.
- Phase II: the XIII century. The bibliographical sources have led to attribute to this second phase (1283-1320 approx.) the following parts of the current configuration of the Monastery: the Church of St.

Domenico Maggiore, the St. Thomas Dormitory (second floor), the Master Dormitory (second floor). These new buildings were connected to the wings pertaining to the first phase and not demolished; so, reading the complicated plan of the complex, emerges that it in this time large part of the available lot was already occupied, so as it was necessary occupy the South limits, bordering the roads and very close to some private buildings.

- Phase III: the XV-XVI century. The fact that already in the XIII century the available land of the lot was mostly occupied by the old monastic buildings meant that in the later phases it was not possible the construction of new buildings, but only three kinds of intervention: the first one was aimed to enlarge the monastery with a new novitiate; the second phase occupied some little free areas with a sort of duplication of volumes (for sample the porch beside the main building), optimizing the use of large part of the residual open spaces; the third one consisted in a reconfiguration of four existing volumes (like in the case of the St. Thomas cloister and its North-East wing, built on an old road inside the lot, building a new wing for the monastery, also demolishing many small private houses).

- Phase IV: the XVII century. The fourth phase is an important step in the history of the monastery, which assumes the architectural articulation and aesthetic configuration, which still today characterizes it, being this phase the last one during which a not sporadic and occasional reorganization was made, as it will happen later, but an extended and generalized reorganization. Like during the third phase, in this occasion the lack of available spaces in the lot put in the need for increasing the urban density of the lot, like in the third phase. In fact, even in this time, it was chosen to proceed with an occupation of some empty spaces (construction of the cloister for the St. Thomas dormitory) or with a duplication of volumes (realization of the upper level for the St. Domenico cloister) or with some new elevations (like the third floor for the main building, the St. Thomas cloister and the second floor of the novitiate) or finally with some little enlargements (like the new main entrances), located in two of the few not yet built areas.

- Phase V: the XVIII century. The interventions of the XVIII century was not realized inside the lot, because completely saturated, so they chose to build in an area located near the North limit, occupying little private houses, closing an old little road, which became a sort of covered gallery. In fact in this new part mainly warehouses and above all the great staircase for the St. Domenico cloister were hosted.

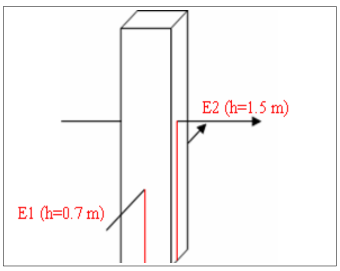
The St. Domenico cloister

The St. Domenico cloister is a key element for a better stratigraphic knowledge of Monastery, for this reason it was subject of a specific analysis, which led to concentrate in this area an intensive endoscopic investigation, referred to below.

The St. Domenico cloister was built during the fourth phase in the XVIII century, but probably in more steps. The sources suggests that during a first step, between 1669 and 1673, some intervention were carried out at the aim to define a new indoor reconfiguration of the existing rooms (adaptive reuse of the infirmary to refectory; reuse of Chapter, positioned over the St. Thomas room; reorganization of three rooms, pertaining the courtyard, as secondary entrance of the St. Domenico cloister; enlargement of the main dormitory and the St. Peter in Maiella back street; and the reconfiguration of the main façade of the church) and only later, between 1678 and 1682, new buildings were built (the third floor of the St. Thomas dormitory, the third floor of the St. Domenico dormitory, the second floor of the novitiate, the entrance hall with the library above).

The St. Domenico cloister

The St. Domenico cloister, diagnostic plan



One of the endoscopies

So during the first phase, the St. Domenico cloister could not be achieved on all four its wings, because there was not still the library building; probably between 1669 and 1673 only two wings at the East and North part were made, so to connect this area to the West lot (which housed two dormitories) and also some Eastern parts, previously reconfigured (which housed the chapter room and refectory room, refitted at this stage), followed by the West wing. That is why the pillars of these three wings show the same constructive characteristics. During the second step of this fourth phase, between 1678 and 1682, a new entrance was built with above a new library, ending the cloister and presumably adding an arcade at the South wing. Supporting this hypothesis, in addition to the use of different constructive techniques for the pillars, there are some data: the South wall of the new library was built thickening the wall of the St. Thomas cloister, pertaining to the third phase (XVI century); the north wall of the library is not connected with its orthogonal walls; in the library the north entrance is different in comparison to the other one, in fact the east entrance (which probably was the only access to be placed on the originating East wing of the cloister) has regular brick and tuff lintels; the other entrance instead is smaller and irregular, so it could be opened after the completion of the fourth wing of the cloister; lastly the North wall has some windows, subsequently closed and filled, which do not appear to be false windows, in fact their shapes are regular also in the wall, which overlooks the cloister.

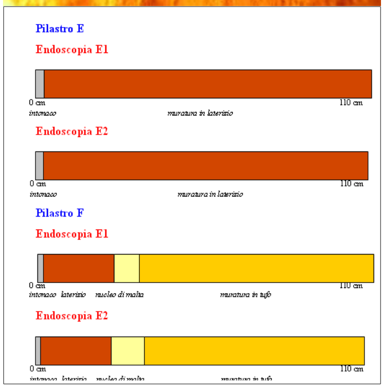
B. Diagnosis

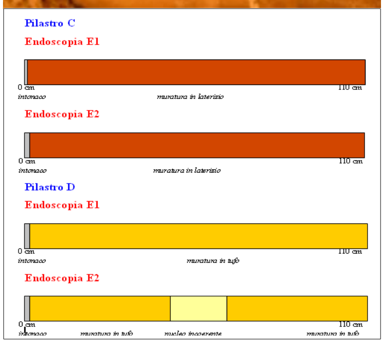
B.1. Diagnostic plan

Considering the importance of the St. Domenico cloister in determining the history of this monument, large part of the diagnostic investigations focused this zone. This activity is included in long and complicated conservative restoration of the whole St. Domenico Maggiore monastery, representing also an opportunity for a direct verification, though still partial, of the articulated stratification of this valuable architectural monument; this has been made possible above all through execution of a series of activities such as inspections and controlled demolition, always strictly kept to the less invasive approach, evidencing unknown data, able to clarify the reconstruction of the history of this building and joining the bibliography and documentation sources, which for this monument are extremely numerous, but at the same time partial, adversarial and sometimes misleading. These data, almost never accidental, are the result of an intense research, a systematic reading of the historic sources, including some of them unpublished, several inspections and an extensive on site and laboratory diagnostic tests. The St. Domenico Maggiore Monastery has been subject to a set of diagnostic instrumental investigations both in a first phase, aimed to optimize the conservation project, and in a second phase, during the restoration works, such as controlled demolitions, retrofitting, etc., highlighting situations and circumstances able to offer a better general and historic knowledge. In fact these investigations were carried out also in support of technical and structural evaluations, useful for structural retrofitting project, as well as for understanding its of constructive palimpsest. So the endoscopic investigations at the St. Domenico cloister are a part of this wide knowledge program.

B.1. Implementation of the diagnostic investigations

Endoscopic technique can allow to observe, inspect and document masonry walls in their section and generally hidden portions of structures. Endoscopy can be applied for a lot of different uses: inspection of structural elements (walls, floors, vaults, etc.) in order to





Some of the endoscopies

investigate their materials, techniques and construction phases; analysis of degradation and instability (moisture, cracks); evaluation of effectiveness of in progress works (for sample during the implementation of mortar injections it is possible to value paths of injected material and tom locate accumulations and deformations).
However, endoscopy requires execution of a small hole, so it is a micro-invasive investigation, but sometimes it provides detailed and reliable information, difficulty to obtain using other techniques, especially non-invasive ones. In this study case the diagnostic investigation plan was very extensive, in fact it provided for tests in each pillar of St. Domenico cloister at the ground and first floor (Fig. 3), with execution of a couple of endoscopies,, positioned in two orthogonal directions and at 70 cm and 150 cm height from the floor.

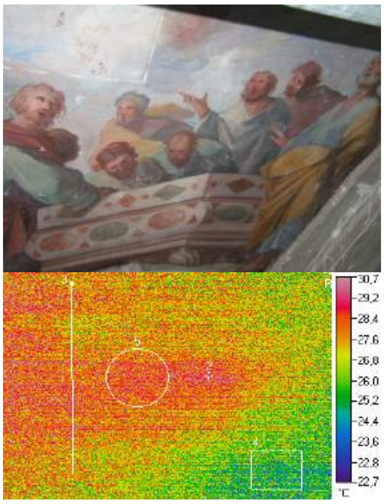
C. Prognosis: suggestions for the architectural conservation, retrofitting and restoration

The results of endoscopic investigations were carried out first of all using an inspection mirror and later, to observe the details, using a modular rigid endoscope, 14 mm in diameter, with variable prism and monocle zoom, highlighting the data listed below.
The pillars of the main staircase and cloister pertain to four different constructive typologies:
- the eastern pillar is made of large bricks (red);
- the second pillar is built with brick masonry and it is characterized by use of very flat bricks, also used to build the cover of the north wall of the staircase (yellow);
-the other pillars are realized only with tuff or tuff and bricks (blue).
It is possible that the different texture of these pillars is due to their different function, in fact, pillars, built with tuff (blue), must also support the load of the staircase ramp, unlike the first two pillars (yellow and red), which support only the upper wall. But it was not possible to understand why these two pillars were built with so different bricks in terms of size. It is clear, however, its stratigraphic correlation with a staircase, nowadays no longer existing and probably located on the back wall.
From this technological classification of the pillars and staircase of the cloister finally emerges that there is convergence between the typological characteristics of the staircase and these pillars, highlighting that they refer to the same phase (XVIII century), but were built in different constructive steps (1669 and 1678). The large number of investigations and the need to correlate the results each other led to propose a stratigraphic synthesis of the endoscopic results, which was very useful in interpreting the investigative qualitative and quantitative data.
This dense diagnostic plan shows that, if on one hand historical knowledge of particularly articulated monuments often cannot be solved only in terms of direct investigation and documentation, on the other hand the minimization of invasive diagnostic tests, however, can be obtained only through a deep preliminary historical analysis, where the instrumental diagnostics is not a support just for structural issues and is effective if it is seen as one of the many steps of the complicated process, which sees also in the restoration project an opportunity to better know the monument.

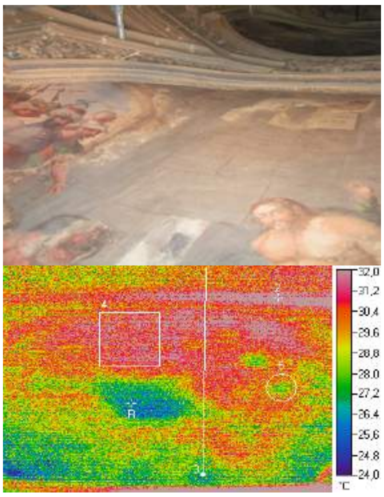
The Great Capitolo Hall

The Great Capitolo Hall of the St. Domenico Maggiore Monastery pertains to the expansion phase after the strong 1688 earthquake; in fact, this large and valuable hall was built starting from 1692 and its decorations, consisting of a rich figurative program, was concluded in1699.

The Great Capitolo Hall

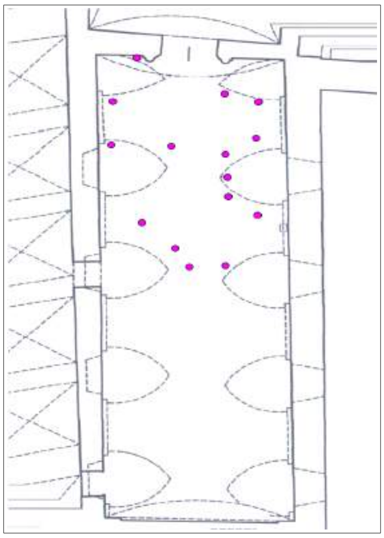


A thermographic test of a fresco



A thermographic test of a stucco

The Great Capitolo Hall consists of a wide rectangular hall, covered by a flattened barrel vault with lunettes and transverse arches.
The recent restoration of the entire complex allowed to have a direct access and to make an inspection about its conservative conditions.
The presence of a lot of ancient and recent interventions on the fresco and stucco decorations was highlighted especially in the central parts, which is almost flat and therefore most risky for the heavy stucco decorations in terms of detachments and downfall; in fact these parties had undergone a detachment from the substrate with the consequent fall of many parts of the painted fresco.
Relatively to the stucco decorations, it was observed the presence of extensive alterations of very large portions, evidently due to the excessive weight, producing detachments and downfalls, so, before the retrofitting and preservation project, it was therefore necessary to understand in detail which parts were detached.
Unfortunately, the lack of detailed and consistent documentation about their old restorations, made necessary an alternative cognitive approach, hence the choice of making an unconventional non-invasive diagnostic investigation.


Diagnostic plan about ultrasonic and magnetometric tests


Ultrasonic and magnetometric tests

B. Diagnosis

B.1. Diagnostic plan

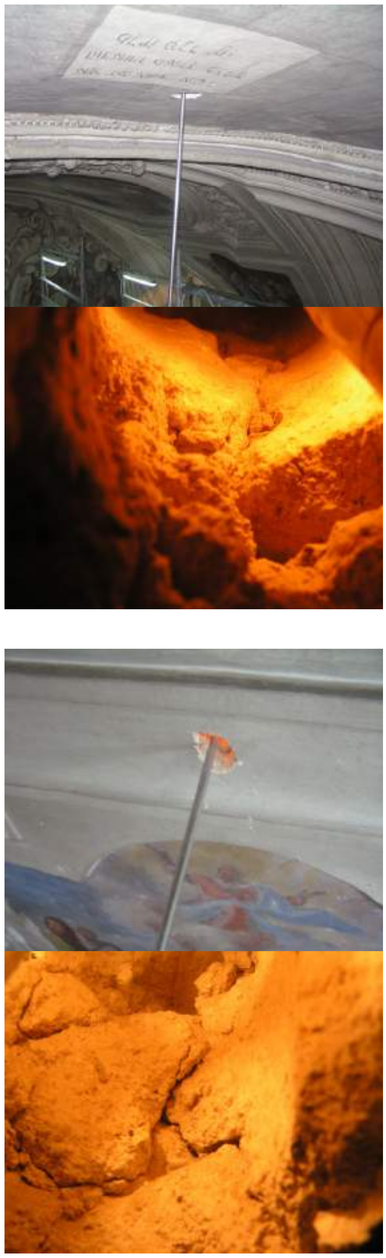
The diagnostic tests were performed following different levels of detail. First of all, a thermographic investigation was performed with the support of a hot air generator, artificially heating the surfaces, for exploiting the principle of different natural thermal emission of materials in the infrared spectral band, in the form of electromagnetic radiation, which is proportional to the surface temperature, with the aim to better note and compare the thermal inertia of the whole vault (fresco and stucco; restored and not restored parts; detached or not detached areas; etc.).
In this way it was obtained:
1) a mapping of the fresco portions, which were restored in the past and belonging above all to the nineteenth century restoration aimed to fill the missing parts, highlighting how this nineteenth-century was not a sort of complete restyling, as suggested by one of the few sources, but it consisted in local, although extended, integrations;
2) a mapping of the fresco parts, which were subject of some re-adhesion works of the detached areas with resin injections, relating to a '60s restoration, which was known but not documented by direct sources.

B.1. Implementation of the diagnostic investigations

In order to understand if the nineteenth century restorations solved the detachment troubles of the fresco parts, placed in the flat areas of the vault, an ultrasonic investigation was carried out; the ultrasonic tester is a specific tool for analysing concrete elements and structures, but in this case it was applied in an unconventional way, to highlight the propagation times and the vibration pulses transit between the fresco and their support, in order to detect the presence of cavities and air pockets, so as to understand the effectiveness of the nineteenth-century restoration.
The investigation revealed that even these portions were largely detached, thus highlighting that the nineteenth century retrofitting work did not have a decisive role in the solution of the question about the adhesion between the fresco and the intrados of the vault. This is evidenced by the fact that the resin injections are concentrated in the central portions of nineteenth-century restoration. But even the '60s intervention was proved inadequate, in fact the resins, being inelastic and vitrifying too quickly, did not show a right adhesive capability.

These investigative methods were not enough to clarify the main issues, concerning the detachment of the stucco parts; in fact, the very substantial thickness of the stucco made difficult the thermographic mapping of the interface between the stucco decoration and the vault. Furthermore, given the complicated geometries of the stucco decorations, it was operationally difficult to perform the ultrasonic tests, as in the case of the fresco.

For this reason a magnetometric pacometer was used, which is a specific tool for concrete diagnostics, because it, using the principle of eddy currents, allows to detect the presence and sizes of metal elements and structures. In this specific case, it allowed to detect the presence of sixteen metal brackets, used to connect the stucco decoration to the intrados of the vaulted structure, better localizing the portions where the stucco was more detached and therefore and at risk to collapse. These brackets should not regard the first phase of decorative apparatus (late seventeenth century); in fact there is a correspondence between the positions of the brackets and the presence of not original stucco; it is impossible to date this intervention, although it seems reasonable to hypothesize that it was made during the nineteenth-century restorations, taking into account the used materials. Finally two endoscopies were performed, the first one in a fresco decoration and the other one in a stucco decoration, in the same points previously by investigated by the ultrasonic and magnetometric tests. Although this kind of investigation is moderately invasive, it allowed to directly observe and inspect the structure, verifying the reliability of the results, obtained using the previous investigations, relating to the detachment between the decoration (stucco and fresco) and its support apparatus (intrados of the masonry vault).



Two of the endoscopies

C. Prognosis: suggestions for the architectural conservation, retrofitting and restoration

This experimental research show the unconventional potential of diagnostic tools, largely used for the knowledge of concrete (magnetometric and ultrasonic tests), in order to investigate some of the old and historical restorations of a so complicated and valuable structure, in order to highlight the weaknesses and inefficiencies of their technological solutions.

Its results can be useful also to highlight some of the old troubles of this decoration (for example detachment from the support, overweight, etc.), which were never solved by the previous restorations; they are not only a decision support for the choices that will guide the upcoming restoration, but they can also be repeated, during the restoration work, as quality control process.

Infodata

This investigation was carried out by the SIS Section-MA.R.E. Laboratory of PAU Department-Mediterranea University of Reggio Calabria-Italy for the Superintendence for Architectural Heritage of Naples and its Province in 2011.

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1. Masonry buildings with timber floors and roofs
1.a. Churches and monumental buildings

Abruzzo 2009 earthquake-Italy: St. Pietro Church, Alba Fucens; St. Bartolomeo Abbey, Carpineto della Nora; St. Onofrio Monastery, Campli; St. Francesco Monastery, Campli

St. Pietro Church, Alba Fucens

St. Bartolomeo Abbey, Carpineto della Nora

St. Onofrio Monastery, Campli

St. Francesco Monastery, Campli

Abstract

After the 2009 L'Aquila-Italy earthquake, the scientific and professional community has strongly focused its interest for understanding the genesis of a so vast damage and for proposing restoration methodologies for its historic architectural heritage. Less attention has been paid instead to defining strategies for mitigating the seismic risk, through preventive interventions. The research, described below, reports a case study about a preventive structural seismic project, outlining the contribution that on site diagnostic investigations can be able to provide, during the anamnesis and diagnosis steps.

Introduction

The work, outlined below, regards a research project aimed to evaluate the seismic risk, especially in terms of determining the seismic vulnerability of the monumental architectural heritage of the Abruzzo Region, specifically analysing four historical architectural sites, protected by the "Italian cultural heritage code", and placed in a little damaged areas by the 2009 earthquake: St. Pietro Church in Alba Fucens, St. Bartolomeo Abbey in Carpineto della Nora, St. Onofrio Monastery and St. Francesco Monastery both in Campli.

The research, in addition to a historical reconstruction of their historical palimpsest and an extensive and meticulous geometric and structural drawing documentation, includes a specific interest in the design, management and validation of non-destructive and non-invasive diagnostic tests, specifically carried out according to diagnostic protocols, which were planned considering the specificity and needs of all the monuments in question and developed in the preliminary stages at the same time of the historical analysis and stratigraphic-structural investigations.

This approach was preferred in order to pursue, case by case, two main aims:

- to provide information about the alterations and modifications of the buildings, taking into account that, with the exception of St. Pietro Church in Alba Fucens, the bibliographical and archival investigations was unable to give detailed data for defining the constructive phases of the investigated monuments;
- to suggest other elements concerning the material and structural conservation state, with particular reference mainly to the alterations belonging to the last century restorations.

CASE I: St. Pietro Church in Alba Fucens

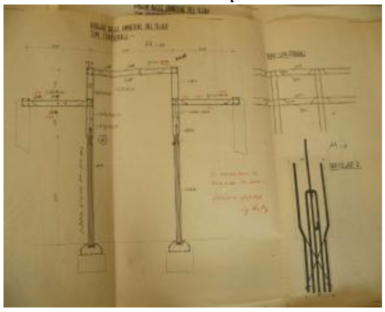
History

The St. Pietro Church is located on the site of an Italic temple of the third century BC, perhaps transformed in the second century BC in a temple dedicated to Apollo. It became a Christian church in the forth century and a Benedictine property in the seventh century. Between 1123 and 1126 it was deeply transformed, so that only the cell of the temple with two doors and the porch were preserved.

A series of severe earthquakes (first half of the thirteenth sec., second half of the fifteenth century, the beginning of the eighteenth century)

was the cause of repeated strong damages, followed by vast restorations, obtaining an interesting and complicated stratigraphic palimpsest.
With the strong 1915 earthquake the building was again heavy injured and the restoration project proposed an almost complete anastylosis of the building, with the introduction of one of the first structural reinforced concrete frames, concealed by the replacement and reuse of the original materials, with a particular attention to the numerous decorated artistic elements.

St. Pietro Church, apse in 1915



St. Pietro Church, technical drawing about its 1915 post-seismic restoration project

The diagnostic plan and its implementation

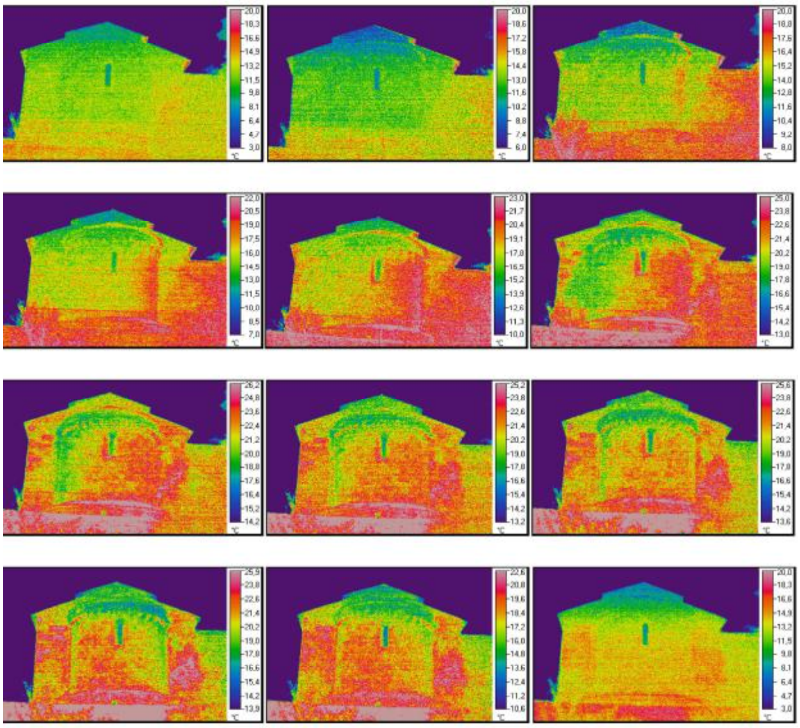
The diagnostics at the St. Pietro Church in Alba Fucens was conducted, given the complexity of its stratigraphic history and the lack of technical-constructive homogeneity, in order to understand the constructive phases of the building, with specific reference to two issues: the reconstruction/restoration works, performed after the 1915 earthquake; an evaluation of the structural properties of the materials (stones and reinforced concrete frame), especially in terms of degradation.
Firstly an intense thermographic monitoring (conducted every hour for twelve consecutive hours) was carried out, giving evidence to several thermal anomalies, used as support for the stratigraphic analysis of the constructive phases, showing its utility especially for the longitudinal façades, because the lack of a detailed historical pictures of the parts about the post 1915 restoration could not provide direct and clear data.
The main limitation, showed by the application of this methodology, is the scarcity of temperature differences, which needed a particularly laborious post processing phase to map the thermal anomalies.
These diagnostic investigations were not helpful in the study of the reinforced concrete frames, which is inside the columns; in fact, although a detailed documentation of the project drawings and a good photo catalogue of the restoration site were available, the thermography was no able to suggest useful data about its conservative conditions, considering also the 2009 earthquake.

St. Pietro Church, restoration and reconstruction after the 1915 earthquake

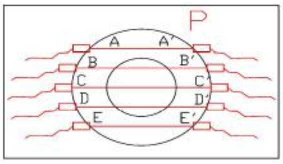
Therefore the diagnostic survey continued integrating two tools, which are widely used for reinforced concrete investigations, i.e. a magnetometric detector and an ultrasonic tester, used for investigating the presence of the metal reinforcement and ultrasonic velocity, through a very detailed scanning of every relevant section, for all the indoor columns. It is clear that this investigation, clearly unconventional, could only provide qualitative data about the size and the position of reinforcement inside the stone columns, however, it can be adapt to give an answer to some of the issues about the technical constructive characteristics of this retrofitting.

St. Pietro Church, apse in 2011

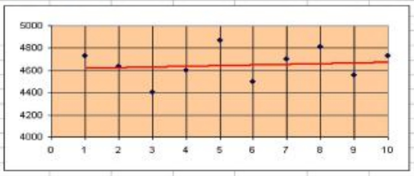
Another less important investigation methodology, but rather ordinary in diagnostic practice, is the SonReb test, used to investigate the reinforced concrete foundation plinths of the columns and for combining sclerometric and ultrasonic tests of the stone columns, performed in order to provide, albeit grossly, the fc (N/mm^2) and Rc (N/mm), useful for the successive phases of numerical verification of the structural behaviour of the building.
The diagnostic plan had also to take into account two dissonant aspects:
-on the one hand to provide quantitative detailed data;
-on the other hand to be less invasive and destructive as possible.
For this reason and obviously according to the general aims of this research, large part of the investigative tools were used, in this applicative case, using no-standard procedures and no-conventional methodologies, in order to better respond to the investigation needs.



St. Pietro Church, thermographic monitoring

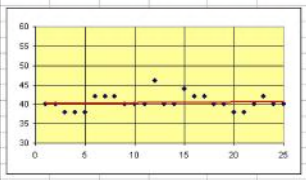


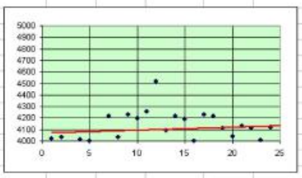
n.	UT (m/s)
AA'	4713
AA'	4711
BB'	4274
BB'	4277
CC'	3193
CC'	3193
DD'	4194
DD'	4188
EE'	4491
EE'	4478
V	4171,2



St. Pietro Church, ultrasonic tests

n.	IR	UT (m/s)			Rc (N/mmq)
1	40	4017			33,96
2	40	4031			34,05
3	38	3774	e	0,00004	29,16
4	38	4015	f	2,09747	30,49
5	38	4001	g	0,71981	30,41
6	42	3912			36,91
7	42	4215			38,95
8	42	4033			37,73
9	40	4228			35,24
10	40	4194			35,03
11	40	4255			35,40
12	46	4515			49,53
13	40	4091			34,41
14	40	4215			35,16
15	44	4191			42,76
16	42	4003			37,53
17	42	4228			39,03
18	40	4213			35,15
19	40	4113			34,34
20	38	4036			30,60
21	38	4128			31,10
22	40	4113			34,54
23	42	4008			37,36
24	40	4115			34,36
25	40	3854			32,96





$fc = e \times IR^f \times V^g$

St. Pietro Church, SonReb investigations

CASE II: St. Bartolomeo Abbey in Carpineto della Nora

History

The construction of the St. Bartolomeo Abbey started in the last years of the tenth century, probably as an extension of an earlier monastery, which, in all probability, is partially included in the tower of the main façade. The construction lasted almost a century, with a partial reconstruction, dated between 1180 and 1208, regarding especially the church, which in the middle of the same century was equipped with a front porch, due to distribution and functional changes of the monastery, according to the rule of a new monastic community, hosted in the Abbey, the Cistercians. Some other significant transformations of the monastery were made in the fifteenth century, after a serious injury, due to an overflowing of the adjacent river.

The abbey was the subject of an extensive number of renovations and restorations in the twenty century, to provide solutions to geotechnical problems and degradation, caused by poor maintenance.

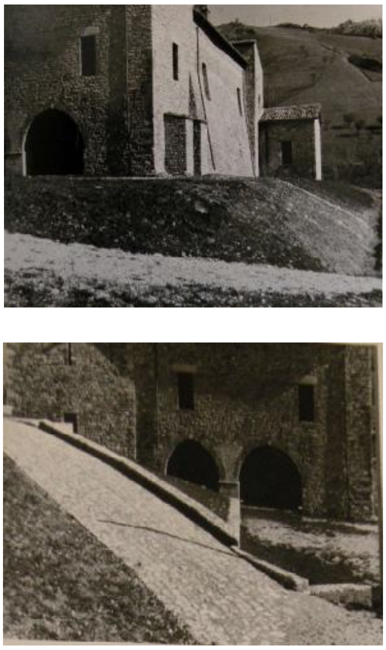
The diagnostic plan and its implementation

Most ordinary investigations were performed at the St. Bartolomeo Abbey in Carpineto della Nora, which, although it showed after a preliminary inspection no particular issues, in terms of seismic vulnerability, after a more detailed analysis instead manifested the presence of a set of structural troubles (such as long poorly constrained longitudinal walls, belfry and inconspicuous but complicated cracks and deformations).

In this context, the diagnostic tests have not been able to much, if not provide quantitative elements about the technical and constructive consistency and the conservative conditions of some reinforced concrete top beams (via pacometric mapping, ultrasonic investigations and sclerometric tests) and roofing timber trusses (pilodyn and ultrasonic tests). Even the thermographic mapping, performed on every indoor and outdoor walls of the church, was able to give just a modest contribution in the knowledge of the building, supporting only the stratigraphic analysis of the architectural palimpsest.

It must be said, for completeness, that the limitations of the available methods and the need to preserve the monument, giving way to micro-invasive investigations, had a significant impact on the design and implementation of this investigation plan.

This conclusion, far from debating about the potential and confidence in diagnosis as important step in the knowledge process of monuments, however, suggests a reflection about the possible risks of redundant diagnostic surveys.



St. Bartolomeo Abbey in 1959

St. Bartolomeo Abbey in 2011

CASE III: St. Onofrio Monastery in Campli

History

The St. Onofrio Monastery, placed on the ruins of a late fourteenth century hospital and church, was built in the two decades at the end of the fourteenth century and elected abbey about hundred years later. The building, certainly damaged by the severe 1703 earthquake, was repeatedly subject to changes and alterations, until the early years of the nineteenth century, when the abbey was closed.

In 1951, during the construction of the new route of the state road 262, a part of the building, including half of the cloister, was demolished, acquiring the current configuration. Only since 1985 it was subject of some first restoration works of the timber roof and the corner tower, followed in the late '90s by extensive conservation and preservation intervention of the precious frescoes of the refectory and some adaptive reuse works, currently still in progress, for creating a Diocesan Museum.

The diagnostic plan and its implementation

The diagnostic investigations, performed at the St. Onofrio Monastery, had, in the process about the evaluation of its structural and seismic vulnerability, a relevant role in the set of activities, such as historical research, drawing documentation and technical and constructive analysis. In fact, the lack of helpful historical sources, relating especially to the transformative changes and adaptive reuse interventions, which were evident, but little known under the technical point of view, made it necessary to design a diagnostic plan, aimed to investigate technical and constructive issue of some not original elements, such as reinforced concrete curbs and tie-rods), rather than the investigation about the historical issues, in fact the monastery did not show specific vulnerabilities, if we exclude some recently built elements.

Therefore, the diagnostic survey was planned in order primarily to the understanding of these alterations, starting with some tie-rods of the arches in the courtyard, which only partially showed the position of their tie-rod plates. A quick pacometric mapping led to evidence of the presence of many tie-rod plates under the plaster, but also the lack of two tie-rod plates, suggesting the need of their relocation, with a little and simple intervention, but crucial for improving the structural performance of the façade of the building, in case of earthquake.

The second step of the diagnostic plan concerned some ordinary investigations, such as SonReb tests for the top reinforced concrete beam and pilodyn-ultrasonic investigations of the timber trusses of the roof, but also less usual tests, as magnetometric mapping of the anchoring system between the timber trusses of the roof and the reinforced concrete beam, placed on the top of the walls, before the construction of the new roof.

Even if, for the S. Onofrio Monastery, the pacometric-magnetometric test, which in a specific investigative for concrete, was used in an unconventional way, was really helpful to investigate, even if only qualitatively, several technical issue (tie-rods; anchoring plates, etc.) which are relevant to evaluate in detail the seismic vulnerability of a such large and complicated monument.

St. Onofrio Monastery in 1942

St. Onofrio Monastery in 1942

St. Onofrio Monastery in 1942

St. Onofrio Monastery in 2011

CASE IV: St. Francesco Monastery in Campli

History

The construction of the St. Francesco Monastery in Campli and its church probability started in the early fourteenth century and was completed in the last decade of the same century. A radical transformation took place two centuries later, followed by an addition of the arcades of the façade facing the main square.

Surely the 1703 earthquake injured the monument, but there is are historical sources until the early years of the next century, when, monastery was transformed in district prison, with partial demolition of the arches, placed close to the road. A radical restoration was operated in the 60's of the twenty century, when it took the current configuration, only partially modified by an adaptive reuse interventions as museum, completed in 1997.

The diagnostic plan and its implementation

The on site diagnostic survey, performed at the St. Francesco Monastery in Campli is in many ways homologous to the investigation carried out at the St. Onofrio Monastery, although the troubles of the St. Francesco Monastery are more complicated, because not only connected to the seismic vulnerability (due to: the addition of new buildings; its location on a site characterized by frequent landslides; the presence of tick and high masonry walls), but also by indirect vulnerability, attributable to some of some surrounding buildings, for example the presence of the adjacent church bell tower, strongly affected by rotations, deformities and cracks. For these reasons the diagnostic investigation started with a routine thermographic mapping, confirming that the top of the tower was cut, most likely as a result of a partial collapse, subsequent to the 1915 earthquake. About the vulnerabilities of the monastery, the thermal camera tests were able tu suggest some info on the technical and constructive characteristics of the top reinforced cement concrete beam, which interests the whole building, as confirmed by the SonReb tests. The most interesting investigations are the tests carried out for the locating and sizing of the hidden plates of the tie-rods of the arches. This not only provided some data, useful for a better knowledge of the monastery, but it was a validation of the already encouraging results of the same kind of investigations, carried out at the St. Onofrio Monastery, suggesting a methodology that does not unlikely to be useful in future case studies, given the prevalence and structural importance of metal tie-rods.

Conclusions

The investigations, used for the four previously described diagnostic surveys, can be classified into two main categories: - extensive and indirect investigations, such as especially passive thermography, which was particularly useful to support the knowledge of complicated historical palimpsest; - detailed and direct tests, such as ultrasonic or SonReb tests, useful to investigate materials and structures, to understand historical and recent technological and constructive systems, above all related to the reinforced concrete technologies (pacometric mappings, rebound pilodyn testing).

Particular emphasis was given to the possibility, conditioned by the specific nature of the post earthquake situation, to achieve expeditious diagnostic surveys, which did not need particular logistical conditions (scaffolding, long-term monitoring, etc.). The qualitative and quantitative potential of these diagnostic tests, was partially limited by the need to exclusively propose non-destructive tests, excluding also micro-invasive technologies (eg. endoscopies and resistographic profiles), due to the artistic and architectural relevance of the investigated monuments; in any case the carried out tests were helpful for the subsequent phases, above all in terms of evaluation of the seismic vulnerability. We must also remember that the experiences, described above, supported the development of a scientific approach, which promotes the use of investigative protocols sometimes far from ordinary methodological standards, suggested by the norms and codes in the field of diagnostics. Considering, for example, the tests carried out on the reinforced concrete beams, although they can be cumbersome and may sometimes be a risk, in terms of expected targets, as well as reliability and validation of the results, however, an unconventional approach has great potential, especially in really complicated and unique circumstances such as the investigations of St. Pietro Church in Alba Fucens. In these cases, the inventiveness of the diagnostician, balanced by a rigorous methodology and the ability of critical evaluation, may constitute a crucial factor, especially for the purpose of giving results useful for the project decisions, aimed to be at the same time effective, in terms of mitigation of seismic vulnerability, and respectful to some decisive instance for architectural heritage, such as its conservation and preservation, with a positive reverberation also for reduction of the economic and logistic investment, related to the restoration.

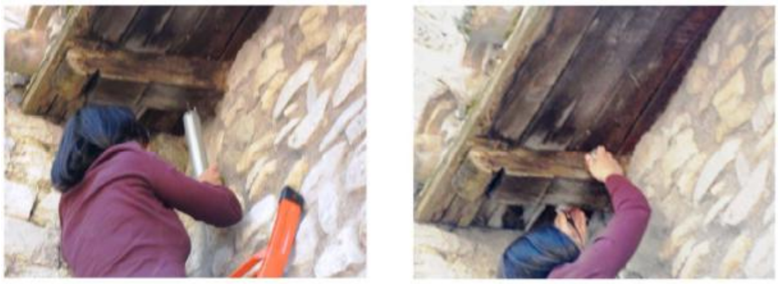
It is interesting to note that no one of these monuments was injured by the long and strong Richter M 6.5 seismic crisis, which happened in the Autumn 2016 and involved a large part of the Middle Italy.

St. Francesco Monastery in 1928

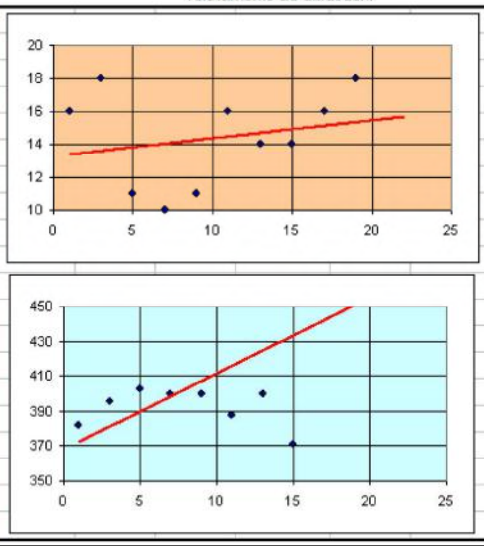
St. Francesco Monastery in 1931

St. Francesco Monastery in 1936

St. Francesco Monastery in 2011



Punto n.	PI	UT (m/s)
1	16	382
2	18	396
3	11	403
4	10	400
5	11	400
6	16	388
7	14	400
8	14	371
9	16	471
10	18	502



St. Onofrio Monastery, investigations of the timber roof

St. Francesco Monastery, magnetometric location of the tie-rod plates

Infodata

This investigation was carried out by the SIS Section-MA.R.E. Laboratory of PAU Department-Mediterranea University of Reggio Calabria-Italy, as experimental research "Seismic vulnerability of the monumental architectural heritage after the 2009 Abruzzo earthquake" for the Italian Ministry of Cultural Heritage in 2010-11.

Refecences

Bianco Alessia, "Patrimonio architettonico d'Abruzzo post sisma del 2009 e prevenzione. Indagini diagnostiche speditive non invasive per la valutazione della vulnerabilità sismica", in: *Archeomatica*, Rome-Italy, n. 9, 3 (2012), pp. 12-17.

1. Masonry buildings with timber floors and roofs
1.a. Churches and monumental buildings

St. Eusanio Church,
St. Eusanio Forconese-Italy

Abstract

The 2009 L'Aquila earthquake, which strongly injured the historic and artistic heritage of a particularly rich in monumental buildings area of Italy, also produced significant damages in the St. Eusanio Forconese village, situated in the epicentre of the earthquake and characterized not only by valuable historic palaces and houses, but also by a big church, founded in twelve century, damaged by three earthquakes, happened in the next five centuries and each time rebuilt. This research, consisted of realizing an experimental investigation plan (ultrasonic and thermographic tests), provided a set of data in support of historical research and constructive-technical analysis, that demonstrates how the 2009 earthquake produced damages, which can be considered homologous to the injuries, induced by the others three previous earthquakes (eg. the damage of the façade and apses), which were not solved by the ancient restorations, even if finalized to remove the general and local vulnerabilities. This research supported the retrofitting choices, which will therefore include not only the repair of damages (partial reconstructions, repair of the cracks), as done during the previous restorations, but also interventions aimed to reduce its vulnerability (metal tie-rods, double stone masonries, etc.).

St. Eusanio Forconese Church before (top) and after (bottom) the 2009 L'Aquila earthquake

A. Anamnesis

A.1. Introduction and history

The 2009 earthquake, while not significantly strong in terms of magnitude (M=5.9), produced in the small historic St. Eusanio Forconese village, L'Aquila-Italy, and in its main church extended, albeit differentiated, damage, continuing the construction history of this site and its church, several times injured by earthquakes and consequently rebuilt, restored, expanded and transformed.

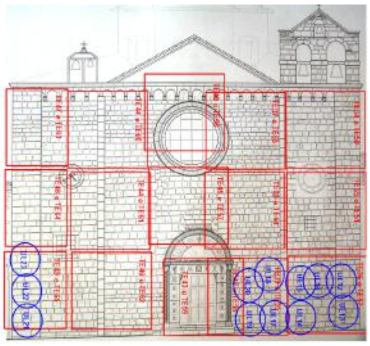
The seismic damage of the church is related to the configuration of the building, which is rather articulated, with the consequence of damaging severely a lot of parts of the church, such as the top of the main façade and the two of the three apses, leading to a significant impairment of its structural behavioural resources. This made necessary to implement a multidisciplinary understanding of the intrinsic and extrinsic structural sources of the church, preparatory to the definition of a retrofitting and restoration project, aimed to reduce its seismic vulnerability; this set of studies included non-destructive diagnostic tests, which pursued the intent to provide useful information about technical characteristics of the different typologies of masonry walls of the church.

The apses before (top) and after (bottom) the 2009 L'Aquila earthquake

B. Diagnosis

B.1. Diagnostic plan

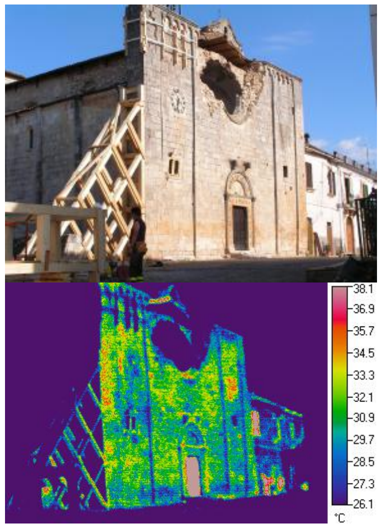
The experimental diagnostic survey provides for execution of non-invasive diagnostic tests, specifically planned to face an emergency situation trying to balance two contrasting instances. In fact on one hand the investigations were carried out expeditiously because they were necessary to implement a first shoring interventions, given the long and strong aftershock phase; on other hand the collapse risk of the church did not provide adequate safety conditions to implement an exhaustive testing program. This made necessary to perform, according to the diagnostic protocol, a preliminary at a distance thermographic mapping, aimed to localize the main collapsing parts and subsequently to plan where to perform the other investigations (ultrasonic tests), choosing areas which were at the same time interesting for the research and where the risk of collapse was lower, including some zones where the infrared results showed thermal anomalies, on which to recognize detailed ultrasonic tests, focused on the investigation of constructive characteristics of masonry walls, built or restored in different historical phases. Another significant constraint, also induced by the state of post earthquake emergency and contingency, was the impossibility to reach the top parts of the church (tympanum, roof, etc.), with the consequence to perform the ultrasonic tests only in an area contained within 2.5m in height.



Diagnostic plan of the façade (rectangles= thermographies; circles= ultrasonic test)

B.2. Implementation of the diagnostic investigations and diagnosis

The thermographic investigations allow us a visualization of thermal images of the materials of the masonry walls, using the principle of their different natural thermal emission in the infrared spectral band, thanks to the use of thermal camera, a tool which is capable of measuring at a distance temperature of bodies, without physical contact between the measuring equipment and the investigated surface. It is based on the fact that any material continuously emits energy in form of electromagnetic radiation proportionally to its surface temperature, that is related to its thermal conductivity and specific heat energy. Different materials can be mapped and localized due to their different correspondences of thermal inertia, above all if they are exposed to a good thermal stress, induced naturally from sunlight or artificial heating by lamps. So, in architecture thermographic tests can be used to show the morphology of hidden structures (pre-existing parts, structural changes, structural abnormalities, presence of cavities), to detect injuries and degradation (cracks, deformations, detachments, dampness), and as quality controls (retrofitting works, mortar injections).



A preliminary thermography

The thermographic investigation for the St. Eusanio Forconese Church was performed to provide useful data for detection of of thermal anomalies:

- thermal anomalies able to map on the walls the partially or completely detachment of the stone facing;
- thermal anomalies showing portions of walls subject in the past to repair or partial reconstruction, given that the buildings was repeatedly damaged by severe earthquakes, to which over time localized and extended reconstructions and restorations followed.

Over than fifty thermographies were performed within a strict testing program, according the following instances:

1) the impossibility to stay for a long time inside the building, given its risk of collapse, did not allow us an indoor thermographic mapping. For this reason only outdoor thermographies were performed, choosing the most appropriate hours of natural radiation, being impossible to induce a controlled artificial heat stress, generally preferred, but not feasible in these specific working conditions and in this particular emergency situation, where any investigation would necessarily be quickly. For this reason only the external walls were investigated.

Thermographic mosaics of the detached masonry of the façade

2) the orientation to natural sun radiation, taking account of the presence of many surrounding buildings and the orographic placement of the church, which is located in a valley; for these reasons the two side façades are never sufficiently irradiated to allow an adequate thermal stress to determine the minimum temperature differential in order to obtain an appropriate thermographic detection. Furthermore, these two façades do not have historical elements, peculiar technical and constructive characteristics as well as

damage, so they were less relevant in the diagnostic plan; these circumstances instead are particularly evident for the other two façades, the main façade and the apses, severely damaged and characterized by evident differentiations in terms of construction techniques, that are interesting for a thermographic investigation. For this reason only these two short façades were investigated.

3) the thermographic mapping was carried out in two different phases: the apse were investigated during the morning, the main façade in the afternoon; so the investigation was performed in the best direct sunlight conditions and therefore heat stress. In fact the thermographic investigations were carried out on the apses between 8.30 and 11.30 am and on the main façade between 2.30 and 6.30 pm of the same days, allowing a closer comparison of their thermic performance.

4) the complexity of this diagnostic survey, due to presence of very heterogeneous walls, complicated stratigraphic palimpsest, emergency conditions and shadows, projected by other buildings or by some big trees made necessary to plan a double thermographic mapping: the first phase was performed in the initial stage of irradiation (between 8.30 and 10.00 am for the apses and between 2.30 and 4.30 pm for the main façade) and the second phase during the heat release(between 10.00 am and 11.30 am for the apses and between 4:30 and 6:30 pm for the main façade). Thus, for each thermal image, carried out during direct irradiation, there is an equivalent thermal image of the same area, performed during heat release.

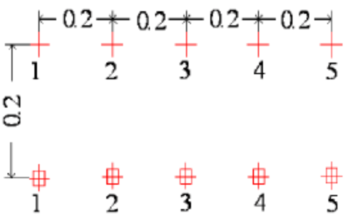
5) both of the façades needed to be investigated with a thermographic mapping of their entire extension. For this reason the thermograms of each façade were collected on a sort of thermographic sequence, proposing a mosaic configuration, understood as a typesetting of the main macroareas, where the thermographic investigation showed the presence of cracks and deformations, but also technical-constructive anomalies to attribute to historic post seismic reconstructions and restorations. This thermographic mosaic is helpful only in qualitative but not quantitative terms, because each thermographic image has been filtered according to its chromatic range, in relation to its thermal emission and hygrothermal conditions.

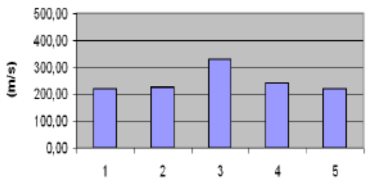
To overcome this discrepancy some mappings of areas with undifferentiated thermal emission on laser scanner drawing were made, highlighting two types of anomalies, induced by severe material degradation (result of seismic damage), or due to different construction phases.

These elaborations of thermograms allowed us to identify and localize several thermal anomalies, but it was necessary to ensure a correspondence between these anomalies and the possible presence of conservative troubles, like detachments of the stone facing, deformations and cracks, cavities, etc.

For this reason some ultrasonic investigations were carried out, at the aim to knowledge propagation times of vibration pulses in the masonry walls. Thanks to this tests it is possible to measure propagation velocity of ultrasonic pulses, understood as relation the distance between the tow investigated points and time spent in transit.

The use of ultrasonic pluses provides information about the thickness of the walls, crossed by the pulses, and their inner elements. In fact this survey may be used to evaluate homogeneity of investigated material, in order to detect presence of cavities or cracks. Requiring a direct contact with the wall surfaces, this kind of investigation was not performed on the apses, because their damage was so vast that it was impossible to ensure adequate safety conditions.





Results of an ultrasonic test of the main façade

Moreover, the lack of adequate equipments, to access to the top parts of the main façade, limited the ultrasonic investigations to a zone of the main façade, which is no higher than 2.50m from the ground. Finally, the investigation could only be realized using the indirect transmission method, due to impossibility to spend long time inside the building in safe conditions.
Given these constraints, twelve ultrasonic investigations were performed, involving only the lower area of the main façade, but providing a detailed and effective verification of the constructive anomalies, suggested by the thermographic investigations, showing the good combination of these two methods and the potential of this diagnostic protocol.

C. Prognosis: suggestions for the architectural conservation, retrofitting and restoration

These diagnostic tests, although limited by operating and logistic after earthquake emergency conditions, evidenced to be a useful support in the definition of technical characteristics and troubles of historical buildings, above all if they are characterized by particular stratigraphic palimpsest.
This assumption opens up an additional scenario to the possibility of using diagnostic tests as quality control of the technical solutions, suggested in the restoration project, in order to evaluate their effectiveness to reduce seismic vulnerability.

Infodata

The investigation was carried out by the SIS Section-MA.R.E. Laboratory of PAU Department-Mediterranea University of Reggio Calabria-Italy, as part of the research program: "Studies and Preliminary project for the restoration of St. Eusanio Forconese historic village, damaged by the earthquake of April 6th, 2009", coordinated by prof. arch. Vittorio Ceradini.

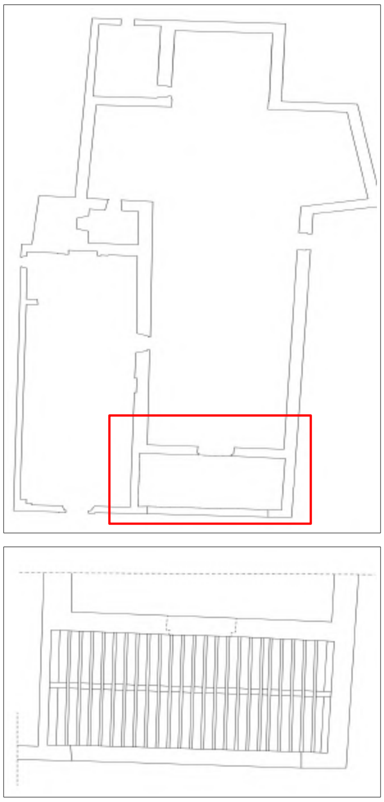
Refecences

Bianco Alessia, Ceradini Vittorio, "The church of S. Eusanio, damaged by the April 6th 2009 l'Aquila earthquake: in situ diagnostic investigations as confirmation of historical research and aimed at restoration plan", in: **Varia**, *Proceedings of the European Conference on earthquake engineering,* 1-4 September 2010, Ohrid-Albania, pp. 531-536.
Bianco Alessia, "Post-earthquake Restoration Strategies: a Pilot Project in Casentino, Sant'Eusanio Forconese-L'Aquila, Italy", in: *Restoration of Buildings and Monuments*, Freiburg-Germany, n. 2, 2 (2012), pp. 93-104.

1. Masonry buildings with timber floors and roofs
1.a. Churches and monumental buildings

St. Lorenzo Church, Signa-Italy


St. Lorenzo Church, façade


St. Lorenzo Church, general plan and detail of the investigated timber roof

Abstract
This diagnostic survey pertains the eighteenth-century timber roof of the St. Lorenzo Church in Signa, a medieval building site in Tuscany-Italy. This experience was an opportunity to debate about the technical regulations in the area of diagnostics for historical architecture. In fact, the rules in force at the carrying out time of this diagnostic investigation in 2003, indicated a discrepancy between the law framework and the technical potential that the diagnosis expresses in those years, with the result of several attempts to propose diagnostic procedures and experimental protocols, designed to bridge the gap between the normative and operational reality both in scientific and professional field. The tests about the timber roof of the St. Lorenzo Church is indeed an effort to propose a diagnostic protocol, responding to two of the main issues in this field: to use of no-invasive tools and to provide useful quantitative and qualitative data in the numerical verification process and subsequent retrofitting and conservation project.

A. Anamnesis
A.1. Introduction
The overall framework of technical legislation in the field of on site diagnostics for historic buildings is characterized both at the Italian and European level by a particular complexity and fragmented nature, derived from the decision, made in the 80s of the twentieth century, to regulate this issue according two different approaches: norms about surveys aimed to investigate materials (requirements, features, performance); norms concerning methods and instruments (tests, measurements, monitoring), whit the result to appear sometimes divergent, if not conflicting, especially in particularly applicative areas, such as diagnostics for timber elements, characterized by historical or artistic value.
For example it is useful to compare the not only operational differences between the UNIEN 380_1994 "Timber structures: test methods, general principles for load tests" and the UNI 10478-2_1997 "Non-destructive testing: electronic controls", at the same time producing a deep gaps in the regulation of methods and techniques, when compared with the potential offered by technologies. In this context technicians, pertaining both to the scientific community and the professional system, not infrequently respond evading the application of these standards, developing and implementing protocols and operating procedures, which propose to overcome this gap. Therefore, it can happen that interesting experiences and good solutions become very popular and common, sometimes thanks to their rapidity and economy, and subsequently they can be transformed in a sort of applicative rule, but ignoring the regulation framework in which they should be included. This phenomenon encourages experimentation and technological advancement, but offers few objective references and therefore poor guarantees in terms of quality and transparency. For example, in the case of diagnostics for timber structures, for several years a standard method, commonly known as "classification according to Giordano" (purpose: timber species, degradation, residual section; method: visual direct inspection, tests), is generally accepted by the scientific community, but never transposed into a formal norm.

Even the detailed Italian"Guidelines for diagnostics, restoration, and reconstruction of damaged buildings-2012", issued after the 2009 L'Aquila earthquake, while regard detailed procedures and protocols for diagnostic investigations for a wide variety of structures (reinforced concrete buildings, brick buildings, mixed technologies), they completely overlooks diagnostics for timber structures.

A.2. History

The diagnostic testing of the timber roof of St. Lorenzo in Signa arises within the framework, described above, and, compared to it, is an interesting experience, because it was carried out according to an expeditious diagnostic protocol, especially designed to minimize the invasiveness of investigations.

The St. Lorenzo Church in Signa is an ancient church, which already existed before the eleventh century, transformed, gradually expanded and currently consisting of a single nave and porch, rectangular transept, enlarged in the Late Medieval Age building on the West side a vast hall, overlooking the bell tower. The building is entirely covered with a pitched roof, with visible timber structure, double frame of beams and tiles mantle.

B. Diagnosis

B.1. Diagnostic plan

Given the high artistic value of the trusses in the nave, diagnostic investigation focused on the timber porch trusses. The investigation began with a set of preliminary analysis, such as historical research, drawing documentation and photographic mapping, useful to determine the type of timber (chestnut), the material characteristics (defects, degradation, faults) and the technological solutions (connection between trusses and walls; connection between the components of the truss elements: chain, struts, etc.) concluding with a map of the macroscopic alteration and degradation, so as to define in detail the project for the on site diagnostic investigations.

It was therefore given particular emphasis to the visual inspection potential, which is also a diagnostic method, but often underestimated in favour of instrumental investigations.

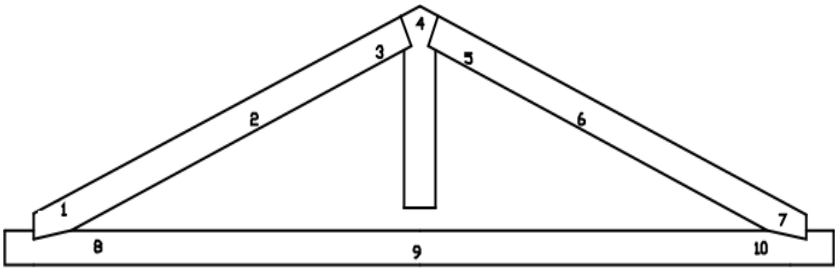
This phase partly incorporated the data suggested by the UNI EN 13018_2002 "Non-destructive testing: visual examination, general principles", which however does not distinguish visual inspections in relation to their purpose (mechanical properties? degradation?) and above all does not consider the visual inspection as a diagnostic method, which can be integrated by other diagnostic tools, but considers visual inspection as an autonomous and exhaustive survey.

B.2. Implementation of the diagnostic investigations

The diagnostic survey was articulated in two levels of detail: in a first stage several ultrasonic tests were carried out (accompanied by hygrothermal detection of relative humidity and indoor temperature), on all the trusses, by selecting ten areas for each truss.

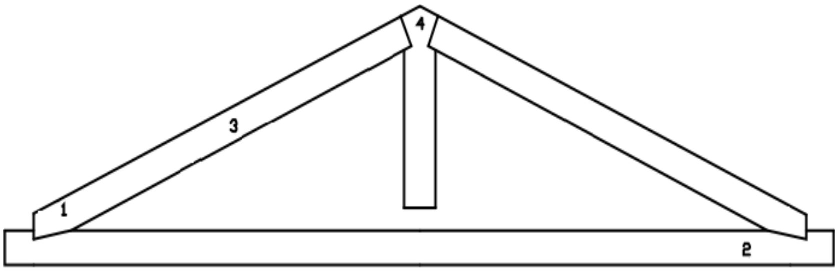
This was possible because the ultrasonic investigation is particularly quick, expeditious and above all completely non-invasive. In this way a complete set, even if only indicative, was obtained about the conservative conditions of these trusses and it was possible to understand the average performance of this roof, by identifying a little amount of cases where the instrumental results were particularly discordant without an evident reason. This phase led to highlight some inconsistencies with the norms, in fact, in the specific case of the temperature and humidity monitoring, the UNI 9010-1-1987 "Tests for timber: moisture determination: Electrical method" proposes the electrical method as the only way for detaching on site moisture in

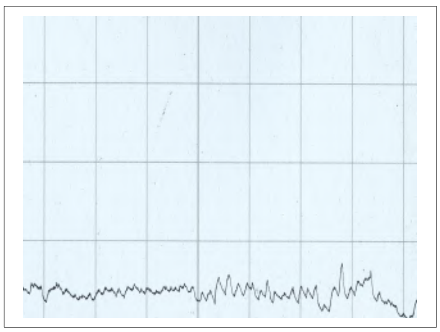
One of the ultrasonic tests



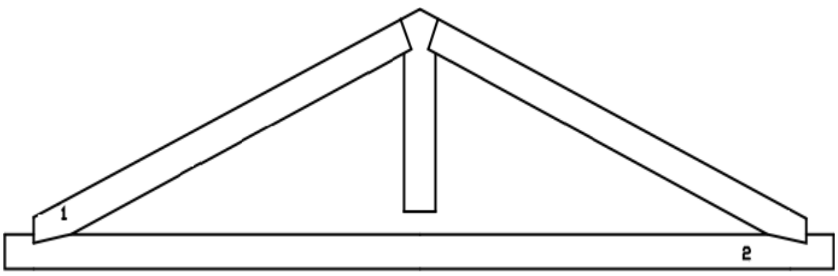
	Point	KHz
ULTRASONIC TESTS	1	813
	2	1011
	3	907
	4	923
	5	915
	6	922
	7	798
	8	756
	9	808
	10	801

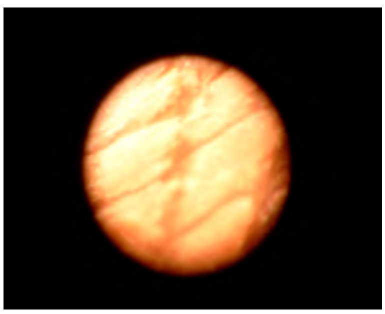
One of the resistographic investigations





One of the endoscopic inspections





timber; but this method is less applicable to ancient degraded timber and further it suggests measurement ranges which have a too wide tolerances for the type of measurements useful in diagnostics of historic buildings.
In this case in fact the degradation factors for the preservation of timber is greater for relative humidity levels between 12% and 15%, and then a 2% increase can significantly change the exposure conditions to risks of biotic attack.
This is not even contemplated in the UNI EN 1311-1999 "Round timber: biological degradation and measuring method" and the UNI EN 844-4_1999 "Terminology: terms relating to moisture", which don't contemplate substantial particularization for ancient timber, making it difficult and not very meaningful their application to cases such as the roof of the St. Lorenzo Church.
On the contrary, some norms, regarding ultrasonic investigations (including the UNI EN 583-5:2000 "Non-destructive testing: ultrasonic examination, characterization of discontinuities" or the UNI 8555_1984 "Non-destructive testing: use of ultrasonic control, terms and definitions", as well as the UNI 9040_1987 "Non-destructive testing: determination of the ultrasonic propagation velocity in solids materials") provided useful indications for the application of this technology to ancient timber, but only in terms of their implementation and not as a support to the interpretative evaluation of the results, which is generally the most complicated phase of diagnostic surveys.
However, the first phase of the diagnostic investigations allowed us to classify trusses, according the results of the diagnostic tests, and three trusses, that provided the worst results, were subject of more detailed, but invasive, investigations, i.e. resistographic tests and endoscopic inspections.
Specifically, for both of the selected trusses four resistographic tests and two endoscopic inspections were performed, choosing two zone among the ten areas previously subjected to ultrasonic investigation.
In the case of the resistographic tests, it was possible to take account of the UNI ISO 3351_1985 "On the timber tests: determination of the dynamic penetration resistance", but only for interpreting the quantitative results of resistographic profiles and not about the procedural aspects.
With regard to the endoscopies, the normative reference, considered in the execution of the investigation, is the norm EN 384_1985 "Timber structures: test methods, determination of characteristic, mechanical properties and density" only were partially helpful in the phase of qualitative interpretation and quantitative evaluation of the results.

C. Prognosis: suggestions for the architectural conservation, retrofitting and restoration

The diagnostic tests, performed at the timber roof of the St. Lorenzo Church in Signa, provided a fairly detailed knowledge of the conservative conditions of the timber trusses, suggesting to preserve the existing roof, replacing only small damaged parts (typically the ends of the trusses, because in contact with the masonry) and integrating the metallic connections of several timber elements of the make trusses, with a significant advantage in terms of cost-effectiveness of the intervention, simplification of the logistics and especially preservation of the structure.
This experience also helped to develop a diagnostic protocol, which, starting from the current regulatory framework, can implement it in relation to the purposes for which the diagnostic testing is performed case by case.

Infodata
The investigation was carried out by the SIS Section-MA.R.E. Laboratory of PAU Department-Mediterranea University of Reggio Calabria-Italy for the Superintendence for Architectural Heritage of Florence and its Province in 2003.

Refecences

Bianco Alessia, “Normativa tecnica e protocolli attuativi per la diagnostica sugli elementi lignei dell'edilizia storica: il caso della chiesa di San Lorenzo a Signa (FI)”, in: **Varia**, *Proceedings of the ARCo Italian Conference,* 4-5 June 2004, Naples-Italy, pp. 195-202.