Diagnostics archive data for the analysis of the Architectural Heritage’s conservation state

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Abstract

Placed as a hinge between analysis and decision making, the diagnosis implies interpretations on whose correctness may depend the effectiveness of restorations and the building’s future life.
In the diagnosis’ context, an important role is played by the knowledge of the restoration interventions’ history and investigations in order to orient new diagnostic investigations and to compare data acquired at different times with the aim to integrating them and discovering constructive and structural variations occurred.
This integrated methodology aspires to multiple objectives including the design of a new investigation plan made reliable and effective through ‘archival diagnostics’.
In this sense, archival research stands as a means of adding information on the conservation history and degradation, representing a useful diagnostic tool.
Hence the intention to begin a reasoning on the added value that the anamnesis and diagnosis based on archive data can provide from a cognitive and design point of view.

Keywords

Troia Cathedral, Diagnostic methods and tools, Archive diagnostics, Big Data, Architectural conservation

Introduction

During the 20th century, the concept of conservation of cultural heritage has undergone a deep evolution, from the idea to preserve the aesthetic function to preserve the role as historical evidence with the aim of keeping the integrity of the artefact and the identity content through coherent, coordinated, and programmed study, prevention, maintenance, and restoration activities (D. Lgs 22 January n. 42, 2004; Carbonara, 1976; Baldini, 1981; Torsello, 2005; Dezzi Bardeschi, 1991).
The documentary role of a cultural heritage, including architectural heritage, re-proposes the theme of conservation in a modern way: in order to take advantage of effective conservation strategies, an accurate analysis of the materials and their mechanical, physical and chemical properties is necessary.
The means that enables this in-depth analysis is the use of diagnostic methodologies.

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An in-depth knowledge of architectural characteristics and their state of conservation in relation to materials and construction events, is essential for the correct management of restoration work.
Together with modern conservation strategies, the concept of decay has been reviewed, understood not only as a macroscopic variation, but also as molecular or microstructural alteration of materials. Assessing degradation means analysing material integrity and quantitatively describe the evolution of physical and chemical properties (Fitzner et al., 1996, 2001; Amoroso, 1983).
In the field of knowledge and conservation of built heritage, investigation techniques, including non-invasive and non-destructive analysis, represent a fundamental means for physical, chemical, constructive, and mechanical characterisation.
In fact, the knowledge of buildings can benefit from a significant advancement by means of instrumental investigations through which it is possible to retrace techniques and measuring instruments used throughout the various epochs, analysing their complementarity, interpretations, limitations and progress over time (Masini, Soldovieri, 2017).
Furthermore, all sources of information, as well as the historical and archival data, needs to be considered in a full-ranging approach aimed at improving the historical-constructive knowledge of the monument, critically and consciously. The interpretation of archive documents represents a concrete tool for planning restoration interventions, reading between the pages about the events on the building, the construction techniques, the interventions carried out and the materials used.
This continuous exchange with the field of restoration and, in general, with the entire field of conservation of cultural heritage, makes diagnostics a cognitive path with strong multidisciplinary connotations. Multidisciplinary is intrinsic in the project approach and in the methodology of investigation, given the vast set of diagnostic techniques borrowed from several scientific sectors. The diagnostic cognitive project is therefore a complex procedure that defines, depending on the characteristics of the property under examination, the set of scientific investigations preliminary to restoration and related to monitoring during and after interventions.
Making diagnostics an operational protocol and method to support restoration projects means playing an active role in generating knowledge about the different components of the building, with the possibility of facing different methods of investigation to suggest and verify various hypotheses.
Thinking of a methodological and multidisciplinary standard for analysing and integrating a large amount of heterogeneous data coming from the different in-depth diagnostic campaigns, means having a system of big data that qualifies the role of preventive analyses. That is useful to orient the most suitable technical contributions or to suggest solutions for an effective conservation action.
This integrated methodology aspires to multiple objectives including the support and design of a new investigation plan, made reliable and effective through 'archive diagnostics' (Guida, Porcari, 2018; Diara, Rinaudo, 2018; Yang et al., 2020; Fanini et al., 2021; Pepe et al., 2021; Moyano et al., 2022).
Such diagnostics opens infinite opportunities: validating or refuting operational hypotheses of previous investigations, filling knowledge gaps, integrating and expanding the available datasets by intervening on the technological gaps of previous diagnostic investigations, that may not have allowed data to be acquired at the appropriate resolution, etc.
Several examples can be traced in which the reading of the monumental text has availed itself of the aid of diagnostic investigations, instrumental detection and comparison of the

data obtained in various investigations, achieving a commendable scientific and cultural advancement.
An admirable example was the unveiling of the 'secrets' of Brunelleschi's florentine dome; for centuries the subject of studies and research aimed at investigating its construction techniques with numerous theoretical elaborations from the time of its construction to the present day (Corazzi, Conti, 2011).
Between 2002 and 2008, specific instrumental tests were carried out to document the presence of metal elements and to specify the wall apparatus of the various members (Corazzi, Conti, 2011; Giorgi, Matracchi, 2008).
First investigations were georadar surveys on the extrados of the inner segment of the dome in order to identify the possible presence of cavities or consolidation elements in the wall thickness (Giorgi, Matracchi, 2008).
Data processing revealed that the section of the dome is made up of two brick faces, inside of which is a filling of incoherent material (Corazzi, Conti, 2011).
The diagnostic and cognitive process continued with a tomographic investigations aimed at understanding the composition of the masonry.
The results put in evidence showed the presence of different resistivity values, in agreement with the dome's structure made up of three different layers.
More precisely, the material of the extra-dossal face certainly consists of a brick texture with a thickness of no more than 70 cm; for the opposite curtain, the same texture characteristics and dimensions are assumed. For the intermediate part, the infill, it's possible to assume a real infill with incoherent material (Corazzi, Conti, 2011).
In order to confirm and compare the results obtained, a further investigation was carried out to qualify the wall structure: endoscopy, performed by means of cracks and splits existing on the segments of the dome.
During the course of the investigation, four cores were found, drilled in 1986 by S. Di Pasquale (2002), which provide important indications on the type and characteristics of the wall structure.
Although the cores subsequently used in laboratory tests no longer exist, the availability of images and photos of the internal surface of each core drill obtained through endoscopy, allowed the results of the georadar and tomographic surveys to be confirmed.
As part of the tomographic and georadar surveys, metal detector surveys were carried out.
Two areas were identified on the part of the dome's segment where was detected the presence of ferrous material.
The tomographic and georadar sections carried out at these points, however, did not reveal any particular anomalies that could suggest the presence of ferrous elements connecting the parts. For this reason, it is assumed that the detector simply detected nails or metal fragments, probably remnants of workmanship.
Confirming the absence of continuously placed metal hoops and brackets was an event of great importance as it put an end to a question long debated over the centuries as to their possible presence and function.
The careful and choral work of interdisciplinary contributions put in place for the dome of the Duomo of Florence only confirms the thesis that archive diagnostics is a fundamental phase in the restoration project, because it can provide information on execution techniques and previous interventions carried out on the artefact. Thus helping to reconstruct its history and guiding the restorers in the definition of new investigation campaigns and design choices, adhering to all available knowledge and thus managing the available economic resources in a well-considered and effective manner.

Florentine is also the research understood to provide a methodological guide that, starting from the diagnostic investigations, it leads to the definition of the restoration project and a plan for the periodic monitoring of critical issues about the typical Pietraforte. Investigating one of the most important florentine monuments, Medici Riccardi Palace, a multidisciplinary methodology was implemented starting from the historical analysis and architectural survey, arriving at the complete characterisation of the facades through mechanical, physical, mineralogical, and petrographic investigations.
It was therefore possible to combine the information acquired within a diagnostic programme based on measurements using experimental and traditional techniques, and on the collection, analysis and interpretation of the results associated with these measurements (Centauro et al., 2022).
The methodological procedure that is going to be proposed would allow to carry out a diagnosis of the state of preservation using non-instrumental diagnostics by replacing laboratories with archive rooms, reading and interpreting folders full of documents, reports. In this sense, archival research is a means of adding information on the conservation and degradation's history, representing, to all intents and purposes, a useful diagnostic tool.
This is the case of the research conducted on the amphitheater of Catania where, through archive documents, it was possible to trace a true 'history of decay', ascertaining that the amphitheater's state of conservation had remained unchanged for centuries because no one had taken care of the conservation issues. But, rather, a series of uncontrolled and damaging interventions had been carried out, such as the water diversion through the construction of new canals or sewers (Longhitano et al., 2021).
Whether in addition to the diagnostic data, anamnestic data are also available, and therefore the history of the restorations carried out over time and traced through archival study, the value of the data is even greater, as is the multiplying effect of the process of integration and interrelation of them that will be cataloged, classified, processed, and normalized.
It will thus be possible to obtain an ordered and standardized database capable of managing, containing, comparing, analysing, and interpreting the corpus of information collected, which becomes a valid implementation of pre-existing computer platforms dedicated to architectural heritage (Morero et al., 2021).
Hence, the intention to begin a critical and methodological reasoning on the added value that anamnesis and diagnosis based on archive data can provide from a cognitive and design point of view.
A case study that significantly validates the proposed methodology is the Cathedral of Troia (province of Foggia); one of the most valuable examples of Romanesque architecture in southern Italy (De Santis, 1986; Belli d'Elia, 2003).
The archival anamnesis of the Cathedral has allowed to explore how knowledge has grown over time through the study of restorations conducted over a time range that has no equal: from the mid-19th century to the entire 20th century, up to the early 2000s (Morero et al., 2022).
In this perspective, the Cathedral of Troia, as a palimpsest of practices and techniques, represents a useful tool for planning further studies and research on the architectural structure.
The paper retraces the history of the diagnostic investigations and monitoring carried out on the Cathedral between 1992 and 2004 from the analysis of published sources and unpublished archival funds.
The present work aims to discuss the potential, limits and opportunities provided by the integration of data obtained from laboratory analyses, in situ investigations and the study of constructive aspects, as a methodology suitable for a multiscale assessment and a complete

vision of the monument's state of conservation, which is fundamental for the realization of conservative and preventive interventions (also to optimize maintenance costs).

The case study of the Cathedral of Troia: history of the diagnostic investigations and monitoring

The Cathedral of Troia is undoubtedly the most complex of the religious buildings of the Apulian Romanesque style in terms of the compositional language expressed by the external facades, enriched using materials of different lithological nature.

The main facade is divided into three distinct elements that characterize the architectural proportions: the staircase, with the eight steps that allow access to the entrance portal, a first level with six blind arches and the marble portal enriched by the bronze door made by Oderisio da Benevento in 1119, and the fastigium dominated by the monumental rose window set within an arch resting on column-bearing lions[1].

A great polychromy characterizes the Cathedral: the chromatic effect is due to the alternation of white limestone, calcarenite, green calcarenite and marbles of various origin.

It is difficult to define whether the use of such a wide variety of lithotypes was due to a precise design intention or, instead, to the vicissitudes of the monument's construction (restorations carried out at different times) and to the use of reused materials of different origins. All hypotheses are probable, resulting in a highly suggestive expressiveness.

Diagnostic and conservation activities, marked by a strong multidisciplinary connotation, have a prerequisite in the knowledge of the characteristics of the constituent materials of an artefact, the state of conservation and the context in which it stands. Thus, between the end of the 20th century and the early 2000s, diagnostic investigations, cleaning and consolidation tests, structural interventions, have been carried out, in addition with several monitoring campaigns of the state of conservation of the Cathedral[2,3,4].

The mineralogical, petrographic, and chemical study of the lithotypes of the external east facade dates to June 1992 by Dott. Prof. Patrizia Tucci[2]. The facade analysed is mainly made of sedimentary rock blocks, which can be classified into four distinct lithotypes (T1-4), identified and studied through:

- minero-petrographic characterization;
- X-ray powder diffraction;
- chemical analysis for the definition of oxides and trace elements.

Microscopic observation of thin sections obtained from rock fragments, as well as the results of X-ray diffractometric analysis carried out on powder allowed to recognise:

T1- Green-grey calcarenite, stratified, not cohesive with clasts, both lithoclasts and bioclasts, between 1 and 5 mm in size. The rare calcitic cement is associated with chlorites and small amounts of clay minerals.

T2- Organogenic limestone of medium grain size, well cemented.

T3- Whitish limestone with clasts around 1 mm in size, completely recrystallised. Neither matrix nor cement is observable.

T4- Beige-pink calcarenite with muscovite clasts, rare chlorites. No bioclasts detectable. Stratified but more compact than T1.

Due to the state of conservation, the study of the physical-mechanical parameters by Dott. Giancarlo De Casa2 has been extremely difficult and limited to samples T1 and T3.

From summer 1992 to autumn 1995, given the complexity of the conservation problems posed by the monument, an intervention plan that included laboratory and in-situ analysis and two test areas on the upper part of the Cathedral's east facade was required[2,5]. The tests, focused on solving the degradation mechanisms of the Cathedral, under the direction of Arch. Nunzio Tomaiuoli and Dr. Rosa Gnisci, involved the Iconos consortium for the development of a methodology aimed at the recovery of the green calcarenite elements which showed serious degradation phenomena.

The work plan was divided into three phases. The phases followed one another, allowing at least one complete seasonal cycle to verify, control and monitor the reactions of the material over time following the treatments and tests performed.

The first phase of intervention, started in May 1992, was characterized by cleaning and consolidation tests carried out in-situ on an area of 1 m2 and on green calcarenite fragments. One of the alterations was caused by lichens which have colonised the East elevation and parts of the main facade, causing physical and chemical alterations. Various tests have been carried out on site with a biocide product, Preventol RI80 (Lanxess Deutschland GmbH, Germany) at different concentrations.

The results have demonstrated the effectiveness of the product, even at low concentrations (ratio 1:10), given on the surface by brush and spray and left to act for at least a week.

The product was then washed with water and the lichens were removed mechanically using scalpels and brushes.

Consolidation tests have been carried out on small samples to identify the most suitable product to mitigate the problems of calcarenite decay. Tests conducted in the lab on spontaneously detached facade fragments relied on the application of hydrated lime in the form of lime milk and lime water, as well as the utilization of ethyl silicate.

The result of the consolidation was negative: the area collapsed under the slightest mechanical stress, as if the lime had no cohesive force but seemed to have turned into calcium sulphate, dusty and fragile.

On the building site, where the same action was taken, the ineffectiveness of hydrated lime as a consolidator was demonstrated, due to its low penetration capacity and the harmful chemical-physical reaction that was triggered.

The second test was carried out by treating a sample with ethyl silicate applied by brush and infiltration until rejection.

The test carried out in situ gave positive results, demonstrating that the ethyl silicate performs its consolidating action by penetrating into the material. The archive records do not specify the extent of penetration facilitated. This is influenced by the degraded surface's morphology (micro-fractures, flaking, partial detachment) and its compatibility with the mineralogical structure of the substrate.

Despite the high cost of the product and the large quantity absorbed by the material (2 litres per m2), given the satisfactory results it was decided to adopt this consolidation method2,5.

In the summer of 1993, the second phase began. The aim was to implement the previously established intervention methodology and observe its long-term effects on a substantial section of the facade.

With the objective of ensuring the adhesion of the detached calcarenite fragments, an experimental phase was carried out. This involved injecting a mixture of hydraulic mortar composed of Lafarge lime and ventilated pumice in a 1:1 ratio through small, pre-drilled holes (following the pre-consolidation of the stone material with ethyl silicate).

Since it was also necessary to ensure continuity and bonding between the layers of calcarenite and the layers of injected hydraulic mortar, a further application of ethyl silicate was applied to consolidate the entire system.

To improve the mechanical characteristics of the stone facade and to make it more compact and less accessible to the damaging action of atmospheric agents, a fluid mortar (based on

Lafarge lime, alpine green and local yellow sand) was applied, almost a whitewashing plaster, to create a 'sacrificial' layer. From an aesthetic point of view, this intervention modified the chromatic effect of the calcarenite.
Finally, in 1995, the second lot of work, the third and final phase, was carried out, on the upper part of the East facade, starting from the transept for an extension of 40 m2.
The work was divided into two phases: the static consolidation, carried out by Eng. Antonio Resta and the facade treatment of the stone carried out by the Iconos consortium.
The relevance of this last phase is that the two treatments were carried out almost simultaneously on the same large portion of masonry.
Before intervening again on the surface, the restoration carried out in 1993 has been examined: the 12 m^2 sample appeared to be in a good state of conservation, thus, the methodology of the intervention did not deviate from the previous one but followed the fundamental stages, perfecting the use of materials and application techniques. Because of the whitening effect due to the application of the lime mortar on the surface, a mortar composed of 1 part green calcarenite, ½ part green alpine, 1 part grey or yellow sand as aggregate and as binder Wacker® OH ethyl silicate was proposed[3].
The restoration work carried out is therefore an example of good practice. In fact, in view of its effectiveness over time and its good results, it was decided ten years later to use the procedures used in the third phase.
However, the intervention under consideration opens up a delicate reflection on the priorities and sensitivities that underlie all the choices, and in some cases the renunciations, of a project.
A conflict between values, as Riegl said. In the execution phase, in fact, while the conservation of the material was certainly guaranteed, from an aesthetic point of view, the mortar whitened the surface and modified the chromatic effect of the polygenic green calcarenite (probably extracted from the quarry in Roseto Valfortore), characterised by its typical dark green colour[2,3].
In June 1999, the Iconos Consortium and Giovanni Quarta of CNR-ICCOM carried out an inspection to monitor and verify the results of the conservation treatments previously carried out. The visual inspection showed that the restored stone was in a good state of conservation, considering the serious initial situation of the green calcarenite.
Geol. Quarta carried out sampling of stone material by a core drilling system on the two areas subject to the intervention, on which other samples had already been taken in 1993 and 1995.
The previous samples and the new 1999 core (taken next to the previous ones) were subjected to laboratory tests in order to outline their mineralogical-petrographic and physical-chemical characterisation and, where possible, to obtain information on the effectiveness of the products used for the restoration.
More specifically, X-ray diffractometric analyses, stratigraphic thin section analyses in transmitted light, porosimetric analyses and imbibition tests were carried out[2].
In 2004, minero-petrographic studies, based on optical microscopy observations of thin sections in polarized light, and X-rays diffractometry analyse have been performed for the identification of the building materials used for the realisation of various architectural elements on the Cathedral's rose window.
To keep the destructive impact of the sampling to a minimum and considering the high number of constituent elements, samples were taken from elements representative of the various typologies recognised.
The mineralogical and petrographic analyses added further elements on the characteristics

Sample	Sampling point - Architectural element	Macroscopic characteristics	XRD Analysis	Petrographic classification
TR1	Column 11	Marble	Calcite, quartz traces	Pentelic marbe
TR2	Interlacing arches in correspondence of column 11	Beige calcarenite, very well cemented		Grainstone
TR4	Central oculus	Avana-beige, fine-grained compact limestone	Magnesian calcite	Wackestone
TR5	Capitals, column 1	Avana calcarenite, well cemented	Magnesian calcite, gypsum and opal traces	Packstone
TR6	Carved triangular panels between columns 1-11	Reddish, medium-fine grained calcarenite	Magnesian calcite, quartz traces	Packstone-Grainstone
TR7	Carved triangular panels between columns 10-11	White-greyish, medium-fine grained calcarenite		Packstone
TR8	Carved triangular panels between columns 1-2	Reddish calcarenite coarse-grained, well cemented		Grainstone
TR10	Capital, column 1	Calcareous stone, compact	Magnesian calcite	Grainstone
TR11	Capital, column 10	Calcareous stone, compact	Magnesian calcite, opal traces	Wackstone
TR12	Capital, column 2	Coarse-grained calcarenite, well cemented		Grainstone
TR13	Column 3	Green-grey calcarenite		Calcarenite
TR14	Carved triangular panels between columns 3-4	White fine-grained compact calcarenite	Calcite, gypsum	Packstone-Grainstone
TR15	Carved triangular panels between columns 4-5	White-greyish, medium-fine grained calcarenite		Packstone
TR16	Carved triangular panels between columns 9-10	Reddish fine-grained calcarenite		Packstone-Grainstone
TR17	Interlacing arches in correspondence of column 4	Coarse-grained, well cemented calcarenite, abundant bivalves		Grainstone
TR18	Capitals, column 6	Greyish, medium-fine grained calcarenite		Packstone

Table 1
Sampling points, macroscopic characteristics, XRD analysis, petrographic classification for each samples (© Calia, 2003)

of the materials used. Different materials have been used for the realisation of various architectural elements: the table below summarises the essential data relating to each sample (sampling points, macroscopic characteristics, XRD analysis, petrographic classification)[4, 6] [Table 1].
The rose window presented a set of damages and deformations of seismic origin which could be ascribed to a rotation of the facade around a horizontal hinge. This condition caused cracks and detachments in the architectural elements, as well as the noticeable out-of-plane strains at some ashlars in the circular curb, and the loss of perfect verticality of the plane of the rose window. Disconnection and rotation of the capitals and compression failures of the columns could be seen.
Giving the situation of fragility and the resolution of the required information on the state of degradation and on the state of decay and construction techniques, in order to make a diagnosis for a structural restoration, the damages and the deformations described above have been subjected to in-situ investigations.

The campaign was carried out in collaboration between the University of Lecce, the University of Basilicata and the Institute of Analysis Methodologies for the Environment (IMAA-CNR)[4, 6].

The investigation campaign was based on the use of non-invasive techniques, such as Ground-penetrating radar (GPR), ultrasonic test and thermography.

The GPR investigation took place along the 11 external columns (approximately 1 m long and 10-12 cm wide), the 11 crossed arches (half circumference with a linear length of 3.75 m and a thickness of approximately 25 cm), the entire external curb (circumference with a diameter of approximately 6 m and a linear length of approximately 20 m). The inner part of the rose window was also investigated (some small columns and the upper part of the curb).

The GPR survey provided fundamental information on the internal structure and state of preservation of the rose window, detecting cracks in the columns and calcarenite elements with intersecting arches, as well as the boundaries between original and restored parts. Moreover, metal elements between columns and capitals, and between columns and central oculus have been localized, giving useful information about the original construction techniques, essential to planning restoration strategy.

The thermographic investigation was carried out on the entire rose window on the external side, which has a W-NW exposure.

Cracks that were not easily detected by visible light, the presence of metal connecting elements between the columns and the capitals (which were also highlighted by the georadar survey), and mortar integration carried out in previous restorations have been identified.

Ultrasonic tests were conducted on six measuring points per column, internal and external, at 20 cm intervals with frequencies between 40 and 200 kHz. For most of the columns, the lithotype, the main problems of deterioration (scaling, erosion) and instability (cracks from crushing, joint dislocations) and the existence of critical points from a constructional point of view were already known. The aim of the ultrasonic tests was a) to assess the pathologies already known; b) to discover anomalies in those points in which measured velocities were very low. The tests have shown a good average propagation speed, generally between 4000 and 5000 m/s, with some 'drops', corresponding to damage condition.

To complete the diagnostic survey described, for the purposes of a more correct possible restoration and consolidation intervention, it was agreed to also proceed with a structural diagnosis.

The diagnosis established that the deformation/deflection framework of the facade is essentially attributable to rotational motion with sub-horizontal hinge at approximately 9.05 m on the external surface and at approximately 10.55 m on the internal surface[4,7-9] (Nuzzo et al., 2010; Masini et al., 2007, 2016).

In December 2021, the Superintendency of Archaeology, Fine Arts and Landscape of Bari commissioned the CNR of Potenza to carry out a campaign of diagnostic surveys to assess the Cathedral's state of conservation and to draw up a seismic vulnerability assessment. These investigations and studies are still ongoing.

Discussion

Diagnostics and conservation activities involve skills and technologies from different disciplinary fields. The contribution of new technologies increases knowledge and investigation potential on cultural heritage, involving material aspects and contributing to provide answers both in terms of historical and cultural instances, both in terms of research into best technical-operational practices.

The review of the various data acquired through the analysis of the diagnostic campaigns carried out on the Cathedral of Troia highlighted the importance of integrating laboratory analyses, in-situ investigations, and the study of the constructive aspects to point out problems associated with the maintenance, conservation, and restoration of the monument (D'Andria et al., 2010).

The decay of stone is a complex phenomenon, controlled by intrinsic factors, such as minero-petrographic and physical characteristics of the lithotype, relating especially to pore-volume and pore-size distributions, as well as by influences by external ones, e.g., the chemical composition of the atmosphere, influenced by human activities, and the meteorological and climatologic factors that control the state of water in the pores of the stone.

Starting from the analysis of the conservation state, serious and widespread decay affected the Cathedral's facades. The most represented and evident forms of decay were scaling, erosion, biological colonization (UNI-11182, 2006).

The lithotype with the most severe forms of alteration was green calcarenite, poorly cemented and characterised by almost parallel lithostratigraphic planes. The use of vertical sedimentation planes has caused problems on the outer surfaces: axial compressive stress can lead to crushing phenomena with the consequent expulsion of scales.

Ground-penetrating radar (GPR), ultrasonic test and thermography investigations have added information about structural instability to make a diagnosis for a structural restoration, revealing critical points from a constructional point of view, previous restoration interventions, metallic connection between architectonic elements.

The presence of water into the voids between the surface scales and the undamaged material probably have accelerated the detachment process. The action of wind, thermal shocks and earthquakes led to the definitive detachment of material. In addition to the macroscopic decay, the action of atmospheric agents led to a microscopic degradation of the stone surface, which is highly incohesive due to the leaching of the carbonate matrix of the rock (Lazzarini, Laurenzi Tabasso, 2010; Doehne, Clifford, 2010).

The consolidation of the stone elements also raised several scientific questions. Stone consolidants have been extensively used for the preservation of historical structures since the 19th century.

For example, the first major restoration of critical acclaim was conducted by Arch.Federico Travaglini in the years 1857-1860.

It was a project of embellishment in which the naves were freed from 17th-century altars and chapels by means of partitions and gates. The project also included the consolidation of the apsidal rose window with a new element of circular and square shapes linked by curvilinear elements.

A characteristic feature of the intervention was a polished stucco imitating marble with a blue background and golden stars in the naves, transept and vaults (Picone, 2000).

With the passage of time and the evolution of artistic taste, the stucco and polished marble of the Baroque began to be despised. It was therefore decided to carry out a de-restoration, which was carried out in the middle of the 20th century.

In addition to the removal of all the stuccoes and Baroque elements, consolidation work was also carried out with the construction of a concrete slab with reinforced concrete kerb[10].

The documents also tell us that towards the end of the 19th century, Arch. Adolfo Avena, then Superintendent, submitted a new project divided into five main interventions, including the restoration and consolidation of the N-O corner11. Although we do not have detailed information on the work carried out, we know that the 1903 inspection of works showed that the works were carried out in a professional manner but that the use of cement was not sparing[12].

However, the true effectiveness of stone consolidants is often a source of debate. Consolida-

Archive sources

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[2] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 3 (2001-2002), *«Progetto esecutivo per i lavori di completamento del restauro della Basilica Cattedrale di Troia (FG)»*, Prot. n. 010521, 12.04.2002.

[3] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), *«Relazione preliminare all'intervento di restauro della facciata della Cattedrale di Troia»*, Prot. n. 6667, 18.07.2003.

[4] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), *«Progetto esecutivo per i lavori di completamento del restauro e consolidamento delle facciate della Basilica Cattedrale di Troia (FG)»*, Prot. n. 8985, 30.09.2005.

tion treatments encompass a wide range of issues: the use of consolidating products modifies the porous network of the treated substrates, changing physical and aesthetic properties (Praticò et al., 2020; Doehne, Clifford, 2010; Becerra et al., 2021).
Given the nature and state of conservation of the green calcarenite, intervention methods compatible with the nature of the stone have been tested. The tests aimed to stop the pathologies in progress by following two possible methods:
integrating the carbonate matrix with natural products like those present in the stone material (lime water for consolidation and hydraulic mortar for grouting and filling the joints);
using a consolidant such as ethyl silicate, widely experimented but unrelated to the nature of the material. In this specific case, experimentation with lime water did not produce any appreciable improvement effects.
Despite archival research reveals the constant lack of maintenance and the consequent phenomena of severe water infiltration that have been damaging the Cathedral since 1892 and finally resolved only in 2004[13-15], passing through numerous, incomplete interventions. The interdisciplinary approach to the study of the material and constructive aspects of the Cathedral could be defined as a good practice in which the conservation state has been evaluated, risk condition and factor have been identified and best intervention strategies have been planned.
This approach, in a view to future developments, can be made more immediate and effective from an operational point of view through the structuring of communicating and correlated cards that would contain all the information recorded or deduced in the various survey campaigns. The cards so will be generating a data system of great interest for the historical-critical process of knowledge.
The card designed for diagnostic surveys (Fig. 1) would, in fact, make it possible to relate a considerable amount of heterogeneous data by means of key elements such as the type of investigation conducted, the architectural element investigated, the construction material, etc. Each card would talk about the individual experimental test, indicating its type, the methodology of execution, the staff involved and the results obtained.
By structuring a standard digital layout using existing or new open source platforms (Morero et al., 2021, 2023), it would be possible to correlate and compare research and experimental data from different construction sites, but associated by the system through keywords that recognize their complementarity and affinities.
The system, therefore, would be configured as a sort of expeditious cataloguing that collects a dataset of information common to several folders, from which it will then be possible to extrapolate information of a specific nature in a critical and comparative manner.
The advantages that one could then immediately benefit from concern technical and technological evaluations, compared with architectural specificities and with data that can be deduced in situ or in the laboratory.
These advantages take on even greater relevance in the field of interest given the heterogeneity of architectural heritage diagnostics (ranging, for example, from georadar to SEM), the multi-scalarity of the investigations (from satellite radar interferometry to microscope observations), as well as the extreme richness and variety of the skills required.
This generates a fluid process of information exchange and sharing, all aimed at integrating the conservation project and the maintenance plan.

Conclusions

The reader will easily have grasped between the lines the exceptionality of the case taken as

[5] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), *«Analisi delle forme di alterazione dei paramenti lapidei della facciata esterna Est della Cattedrale di Troia (FG)»*, Prot. n. 001178, 15.01.2003.

[6] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), Fasc. *«Lavori di completamento del restauro delle facciate della Cattedrale di Troia. Relazione descrittiva dei lavori eseguiti»*, 26.07.2007.

[7] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), *«P.I.T. n. 10 dei Monti Dauni - Misura 2.1. Lavori di completamento del restauro e consolidamento delle facciate della Basilica Cattedrale di Troia»*, Prot. n. 0011387, 27.11.2007.

[8] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), *«Relazione preliminare all'intervento di restauro della facciata della Cattedrale di Troia»*, Prot. n. 6667, 14.03.2003.

[9] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 4 (2003-2008), «*Lavori di completamento del restauro della Basilica Cattedrale di Troia (FG)*», Prot. n. 027446, 27.01.2003.

[10] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n.1 (1892-1950), «*Perizia di spesa e relazione per i lavori di restauro alla Cattedrale*», Report n. 33, 14.05.1958.

[11] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n.1 (1892-1950), «*Stato estimativo per il restauro dei tetti, della cornice, dell'angolo N-O e per la sostituzione della scala di accesso principale*», Annex n. 4, 09.03.1902.

[12] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n.1 (1892-1950), «*Verbale di collaudo*», Annex n. 2, 17.11.1910.

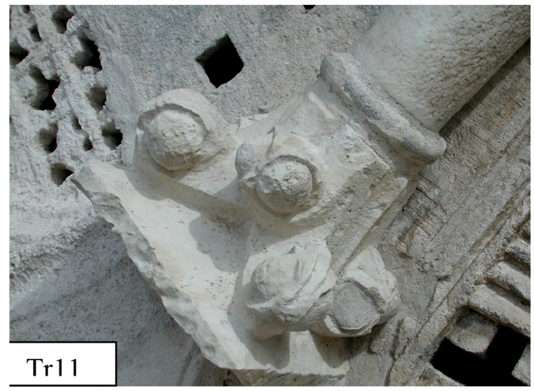
[13] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 1 (1892-1950), *«Lettera. Troia - Duomo»*, Prot. n. 598, 06.04.1929.

[14] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 2 (1950-2000), Telegramma, Prot. n. 12570, 23.08.1991.

[15] Archivio SABAP, *Cattedrale di Troia*, position: FG LVIII, Folder n. 2 (1950-2000), Lettera, Prot. n. 12664, 27.08.1991.

Diagnostic Survey Card

Folder: Cathedral of Troia — Card n. 1



Tr 11 I Points on the rose window and photo

Type of investigation

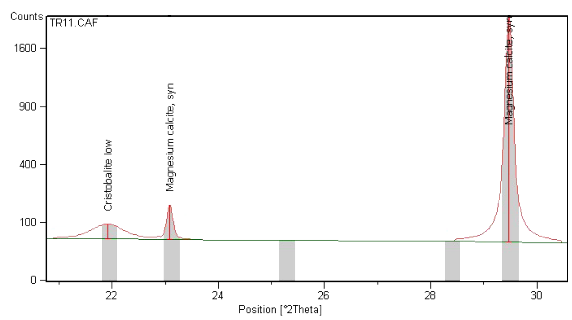
☐ in situ ☒ laboratory

Analysis

X-rays diffractometry analyses, has been performed for the identification of the buil - ding materials.To keep the destructive impact of the sampling to a minimum and con- sidering the high number of constituent elements, samples were taken from elements representative of the various typologies recognised from macroscopic observation.

Results

Sample	Sampling point - Architectural element	XRD Analysis
TR1	Column 11	Calcite, quartz traces
TR4	Central oculus	Magnesium calcite
TR5	Capitals, column 1	Magnesium calcite gypsum and opal traces
TR6	Carved triangular panels between columns 1-11	Magnesium calcite quartz traces
TR10	Capital, column 1	Magnesium calcite
TR11	Capital, column 10	Magnesium calcite opal traces
TR14	Carved triangular panels between columns 3-4	Calcite, gypsum



Sampling Points and XRD analysis

Keywords: Rose window, column, capital, XRD, calcite

Linked cards: n.2 Macroscopic characteristics I n.3 Petrographic classification

Date: 2003 | **User:** Dr. A. Calia (IBAM-CNR) | **Pag.** 1/14

Fig. 1
Example of diagnostic survey card
(© Morero, 2022)

an example. The Cathedral of Troia is not only one of the finest examples of Romanesque architecture, but an unique palimpsest of practices, techniques and theories developed and conducted over a period of time that has no equals; from the mid-19th century to the entire 20th century, up to the early 2000s.
An emblematic case study in which the historical-constructive events and a dense history of cognitive and diagnostic investigations allow us to read the theoretical and methodological evolution of the restoration discipline (Morero et al., 2022).
The multi-scale integrated investigation proved to be a successful diagnostic strategy to deal with the problem of detecting features at different scales, ranging from microscopical size up to the sub-metre scale of the masonry structure of the circular ashlar curb linking the rose window to the facade.
The experience on the Cathedral of Troia was aimed at improving knowledge through non-destructive and non-invasive techniques, which provided a great deal of complementary information on the internal and surface characteristics, materials, state of conservation and construction techniques. All of this information are essential to address restoration issues and design an effective strategy. Continuous research and experimentations on materials and methods are the essential elements for identifying a suitable method of intervention, constantly verifying results and treatments from a multidisciplinary point of view.
According to a logic of modern restoration as a dynamic science, that changes and evolves over time, but always aiming at knowledge preservation, thinking of a user-friendly database can be a fundamental aid both for research and for the definition of restoration and maintenance interventions.
The creation of a digital data synthesis tool can be a fundamental aid for the definition of restoration interventions, as it would guarantee the easy retrieval of general and specific information. Systematisation, digitization and the possibility of making all information available online represents a fundamental means of disseminating knowledge, as well as an executive guarantee of correct interventions on monuments. Bringing together different types of data in a single reference tool can allow for a complete anamnesis and diagnosis of the heritage, avoiding incorrect design choices due to the lack of an adequate cognitive substratum. The structuring of digital index cards, that can be implemented with continuously updated data, represents an extraordinary tool for the restoration work, taking the form of a decision-supporting instrument that inhibits the dispersion of data to be interpreted and compared. The proposed filing would allow data to be analytically interpreted and processed by means of a database that, qualitatively and quantitatively, integrates different types of investigation methods, creating links between results obtained with different instruments.
A reference in this sense is the digital application developed within the research project “HeMaIn - Product and process innovation for a sustainable and planned maintenance, conservation and restoration of cultural heritage (SNC_00520)” (Guida, Porcari, 2018), with respect to which, such a filing can be a valuable implementation. A digital platform conceived in this way constitutes a support to the knowledge, analysis and planning of interventions according to a new approach based on the interoperability building’s anamnesis and diagnosis.
Guaranteeing the design of an integrated system that allows all known information to be managed and made usable, and the possibility of implementing the dataset in real time with new data obtained from experimental investigations, monitoring and interventions in progress.

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