

RA

restauro archeologico

Conoscenza, conservazione e valorizzazione
del patrimonio architettonico
Rivista del Dipartimento di Architettura
dell'Università degli Studi di Firenze

Knowledge, preservation and enhancement
of architectural heritage
Journal of the Department of Architecture
University of Florence

1 | 2023

**“Già chiamano
in aiuto la chimica...”**
Il restauro da bottega
a laboratorio scientifico e
pratica di cantiere

special issue

UNI
FIRENZE
UNIVERSITY
PRESS

"GIÀ CHIAMANO IN AIUTO LA CHIMICA..."

Il restauro da bottega
a laboratorio scientifico e
pratica di cantiere

Restoration from *bottega*
to scientific laboratory
and site practice

a cura di

Susanna Caccia Gherardini

Emanuela Ferretti

Cecilia Frosinini

Mariacristina Giambruno

Marco Pretelli



UNIVERSITÀ
DEGLI STUDI
FIRENZE

DIDA
DIPARTIMENTO DI
ARCHITETTURA

RA | restauro archeologico

Conoscenza, conservazione e valorizzazione
del patrimonio architettonico
Rivista del Dipartimento di Architettura
dell'Università degli Studi di Firenze

Knowledge, preservation and enhancement
of architectural heritage
Journal of the Department of Architecture
University of Florence

Anno XXXI special issue numero 1/2023
Registrazione Tribunale di Firenze
n. 5313 del 15.12.2003

ISSN 1724-9686 (print)
ISSN 2465-2377 (online)

Director

Giuseppe De Luca
Università degli Studi di Firenze

Editors in Chief

Susanna Caccia Gherardini,
Maurizio De Vita
Università degli Studi di Firenze

Guest Editors

Susanna Caccia Gherardini
Università degli Studi di Firenze

Emanuela Ferretti
Università degli Studi di Firenze

Cecilia Frosinini
Opificio delle Pietre Dure

Mariacristina Giambruno
Politecnico di Milano

Marco Pretelli
Alma Mater Studiorum Università di Bologna

INTERNATIONAL SCIENTIFIC BOARD

Hélène Dessales, Benjamin Mouton, Carlo Olmo,
Zhang Peng, Andrea Pessina, Guido Vannini

EDITORIAL BOARD

Andrea Arrighetti, Sara Di Resta, Junmei Du,
Annamaria Ducci, Maria Grazia Ercolino, Rita
Fabbri, Gioia Marino, Pietro Matracchi, Emanuele
Morezzi, Federica Ottoni, Andrea Pane, Rosario
Scaduto, Raffaella Simonelli, Andrea Ugolini, Maria
Vitiello

EDITORIAL STAFF

Paola Bordini, Giorgio Ghelfi, Francesca Giusti,
Pierpaolo Lagani, Francesco Pisani, Adele Rossi

"GIÀ CHIAMANO IN AIUTO LA CHIMICA..."

Il restauro da bottega
a laboratorio scientifico e
pratica di cantiere

Restoration from *bottega*
to scientific laboratory
and site practice

15 - 16.12.2023, FIRENZE

COMITATO SCIENTIFICO INTERNAZIONALE International Scientific Committee

Gianluca Belli
Università degli Studi di Firenze

Debora Berti
Università degli Studi di Firenze

Francesca Bewer
Harvard Art Museums

Marco Biffi
Università degli Studi di Firenze

Susanna Caccia Gherardini
Università degli Studi di Firenze

Emanuela Daffra
Opificio delle Pietre Dure

Emanuela Ferretti
Università degli Studi di Firenze

Cecilia Frosinini
Opificio delle Pietre Dure

Mariacristina Giambruno
Politecnico di Milano

Alessandra Marino
Istituto Centrale per il Restauro

Annunziata Maria Oteri
Politecnico di Milano

Federica Ottoni
Università degli Studi di Parma

Irma Passeri
Yale University Art Gallery

Emanuele Pellegrini
IMT Alti Studi di Lucca

Marco Pretelli
Alma Mater Studiorum - Università di Bologna

Renata Picone
Università degli Studi di Napoli - Federico II

Emanuele Romeo
Politecnico di Torino

Eike Schmidt
Gallerie degli Uffizi

Arianna Spinosa
Parco Archeologico di Pompei

Emanuele Zamperini
Università degli Studi di Firenze

COMITATO ORGANIZZATIVO Organising Committee

Università degli Studi di Firenze

Paola Bordini
Maddalena Branchi
Giorgio Ghelfi
Francesca Giusti
Pierpaolo Lagani
Francesco Pisani
Adele Rossi

INTERNATIONAL
CONFERENCE

Gli autori sono a disposizione di quanti, non rintracciati, avessero legalmente diritto alla
corresponsione di eventuali diritti di pubblicazione, facendo salvo il carattere unicamente
scientifico di questo studio e la sua destinazione non a fine di lucro.

Copyright: © The Author(s) 2023

This is an open access journal distributed under the Creative Commons
Attribution-ShareAlike 4.0 International License
(CC BY-SA 4.0: <https://creativecommons.org/licenses/by-sa/4.0/legalcode>).

cover design

●●● didacommunicationlab

DIDA Dipartimento di Architettura
Università degli Studi di Firenze
via della Mattonaia, 8
50121 Firenze, Italy

published by

Firenze University Press

Università degli Studi di Firenze
Firenze University Press
Via Cittadella, 7 - 50144 Firenze, Italy
www.fupress.com

Cover photo

Louis Jules Duboscq-Soleil, *Naturalista al lavoro con alambicchi, una candela,
un piccolo scheletro all'interno di una campana di vetro e un teschio* (1854 ca.),
dagherrotipia / fotografia stereoscopica.

© Archivi Alinari, Firenze



Stampato su carta di pura cellulosa Fedrigoni

ELEMENTAL
CHLORINE
FREE
GUARANTEED



Indice | Summary

I PRODROMI

PRELUDES

«*Une coopération intellectuelle s'impose*». The beginnings of scientific methods applied to monument restoration 8
Susanna Caccia Gherardini

Restauro e chimica: un significativo rapporto inter e intradisciplinare nell'evoluzione storica della cultura della conservazione 14
Serena Pesenti

Il ruolo di Piero Sanpaolesi nel processo di rinnovamento della disciplina del restauro durante gli anni Trenta del Novecento 22
Arianna Spinosa

La formazione dei settori di restauro dei Tessili e degli Arazzi presso l'Opificio delle Pietre Dure 30
Marta Cimò, Claudia Cirrincione, Riccardo Gennaioli, Guia Rossignoli, Licia Triolo

Scienza e autarchia nelle prime attività del Regio Istituto Centrale del Restauro (1939-43) 38
Stefania Di Marcello

Ai primordi del restauro scientifico in Germania e in Italia fra la fine del XIX e gli inizi del XX secolo: Alois Hauser, Otto Vermehren e Augusto Vermehren 46
Anna Mieli, Lucia Borghese Bruschi

GABINETTI SCIENTIFICI, GLI STRUMENTI TECNICI E LA DIAGNOSTICA

SCIENTIFIC LABORATORIES, TECHNICAL INSTRUMENTS AND ANALYSES

Il San Giovannino di Úbeda restituito 56
Maria Cristina Improta

Per una scienza della conservazione. L'esperienza di Antonietta Gallone nel panorama scientifico e museale milanese dell'ultimo quarto del XX secolo 64
Serena Benelli

Le sperimentazioni dell'ICR sui prodotti per la conservazione dei materiali lapidei tra gli anni Quaranta e Sessanta del Novecento 72
Giorgio Ghelfi

UNA PROSPETTIVA STORICA: LE REALTÀ REGIONALI E I PROTAGONISTI

FROM THE HISTORICAL PERSPECTIVE: THE REGIONAL LABORATORIES AND THE PROTAGONISTS

Toward the scientific laboratory: Massimiliano Ongaro 82
Marco Pretelli

Umberto Chierici e la Soprintendenza ai Monumenti del Piemonte, 1953-1976. Il contributo alla cultura della tutela e la pratica di cantiere 88
Francesca Lupo, Monica Naretto

"I restauri bisognerebbe farli con un soffio". L'intervento di Pietro Lojacono per la conservazione del pavimento della chiesa di San Filippo Neri a Siracusa 96
Rosario Scaduto

Luigi Angelini e il restauro architettonico nella Bergamo del Novecento 104
Antonella Versaci

La scoperta, i trattamenti protettivi e i restauri del teatro greco di Eraclea Minoa in Sicilia 112
Gaspere Massimo Ventimiglia

Tra scienza, tecnica e storia. Hermes Balducci restauratore 120
Emanuele Zamperini

Piero Sanpaolesi e il laboratorio scientifico di Firenze 128
Francesco Pisani

Cementi nascosti. Pensiero, tecnica e sperimentazione nel cantiere-laboratorio di San Marco a Venezia 136
Giorgio Danesi

Vittorio Granchi (1908-1992) e la nascita del Gabinetto Restauri della Soprintendenza alle Gallerie di Firenze. Dai "restauri di rivelazione" agli interventi ai tempi della guerra 1940-45 e dell'alluvione del 1966 144
Andrea Granchi, Giacomo Granchi

La malta Minéros di Max Krusemark: un unguento amarillo per il restauro dei materiali lapidei nel Secondo Dopoguerra in Spagna <i>Luigi Cappelli</i>	152
Un approccio interdisciplinare ante-litteram: l'Accademia di Francia e Michele Ruggiero nella Pompei dell'Ottocento <i>Ersilia Fiore</i>	160
Per una storia dell'Opificio delle Pietre Dure nel primo cinquantennio del Novecento <i>Maria Vittoria Thau</i>	168
Lo spoglio dell'archivio privato di Ugo Procacci. Il caso della <i>Trinità</i> di Masaccio: vicende storiche e conservative <i>Valentina Monai</i>	176
Assisi 1926. La costruzione dello "stile" francescano <i>Antonio Festa</i>	182
LA NASCITA DELLE ISTITUZIONI PREPOSTE ALLA TUTELA E LA LEGISLAZIONE PER LA PROTEZIONE DEL PATRIMONIO STORICO ARTISTICO THE BIRTH OF THE BODIES RESPONSIBLE FOR THE SAFEGUARD AND LEGISLATION OF HISTORICAL AND ARTISTIC HERITAGE	
L'istituzione della Commissione conservatrice provinciale di Terra di Lavoro e la nascita del Museo Campano di Capua <i>Emanuele Romeo, Riccardo Rudiero</i>	192
«Le vere amicizie sono forse più intense sul loro nascere». Frammenti da un 'dialogo' tra Cesare Brandi e Giulio Carlo Argan (1933-1940) <i>Valentina Russo</i>	200
Giappone: nascita del sistema legislativo per la protezione del patrimonio culturale <i>Barbara Galli</i>	208
La tutela, i monumenti, la proprietà: interessi e valori a confronto. Frammenti da un dibattito <i>Lorenzo de Stefani</i>	216
Tutela e riqualificazione dei quartieri del Moderno: un confronto tra i protocolli di sostenibilità ambientale GBC e ITACA <i>Alessandra Cernaro, Giuseppina Currò</i>	220
Alle origini della protezione del patrimonio. Giuseppe Castellucci e l'Ufficio Regionale per la Conservazione dei Monumenti in Toscana <i>Pierpaolo Lagani</i>	228
IL LESSICO, LA MANUALISTICA E I GLOSSARI SCIENTIFICI LEXICON, HANDBOOKS AND SCIENTIFIC GLOSSARIES	
Trattamenti e patinature delle terrecotte architettoniche ferraresi: ricette e sperimentazioni tra metà Ottocento e inizio Novecento <i>Rita Fabbri</i>	238
Dalla fonderia artistica al laboratorio. Il lessico del restauro dei bronzi a Firenze: voci tra scienza, arte e tecnica <i>Maria Baruffetti</i>	246
«Monumenti vivi» e «monumenti morti»: Giovanni e il restauro tra lessico e categorie operanti <i>Sara Bova</i>	254
Il lessico del cantiere tradizionale a Napoli tra XVIII e XIX secolo: dalle fonti alle norme per la classificazione e definizione dei materiali e delle tecniche costruttive <i>Damiana Treccozi</i>	262
Appunti per un panorama sul ruolo e l'attività della Commissione NorMaL nella definizione di un lessico comune per il restauro, a partire dagli anni Settanta del Novecento <i>Adele Rossi</i>	270
MUSEOLOGIA E CONSERVAZIONE DEL PATRIMONIO. IL RUOLO DEGLI STORICI DELL'ARTE E DEI CURATORI DEI MUSEI MUSEOLOGY AND HERITAGE CONSERVATION. THE ROLE OF ART HISTORIANS AND MUSEUM CURATORS	
Restoration and Museography: the value of "open sites" as a promotion of conservation activities <i>Aldo R. D. Accardi</i>	280
Connoisseurship at Trial: Hahn vs Duveen (1921-1929) <i>Matilde Cartolari</i>	288
Lo spazio delle collezioni e delle competenze: il caso della Galleria Sabauda a Torino nel progetto di Piero Sanpaolesi <i>Francesca Giusti</i>	296
«La grande dame des musées»: Françoise Cachin et la muséologie en France de la seconde moitié du XXe siècle <i>Matilde Martellini</i>	304

LA PUBBLICISTICA DI SETTORE, I PERIODICI E I CONVEGNI

PUBLICATIONS, JOURNALS AND CONFERENCE PROCEEDINGS

La valorizzazione delle fonti dirette e indirette: i contributi del giovane Giovanni Poggi per "Rivista d'Arte" e "L'Arte", fra storia dell'architettura e teoria del restauro (1902-1910) 312

Emanuela Ferretti

L'esperienza di "Fede a Arte": la cultura del restauro in una rivista vaticana 320

Saverio Carillo

Il Research Laboratory del British Museum e l'attività di divulgazione nella pubblicistica inglese (1919-1938) 328

Daniele Dabbene

LA COLLABORAZIONE FRA SCIENZA, STORIA DELL'ARTE E RESTAURO

COLLABORATION BETWEEN SCIENCE, ART HISTORY AND RESTORATION

Storici dell'arte e restauratori tra tradizione e spinta al cambiamento. Riflessioni e pungoli di Roberto Papini nel secondo Novecento 338

Annunziata Maria Oteri

"et auro occultatus": Silvio Ferri e la cultura del restauro 346

Maria Carolina Campane

Mineralization and preservation. From the 19th-century petrification of corpses to the green conservation of cultural heritage 354

Davide Del Curto, Anna Turrina

Prime considerazioni sul progetto di ricerca Co.R.A.Ve.: applicazioni di prodotti sperimentali per la conservazione del patrimonio archeologico 360

Leonardo Borgioli, Emanuele Morezzi, Tommaso Vagnarelli

L'archivio scientifico dell'Opificio delle Pietre Dure come patrimonio di conoscenza e risorsa di ricerca 368

Andrea Cagnini, Monica Galeotti, Simone Porcinai

Collaboration between science and art history: wood for carving, a database on statuary in Italy 376

Nicola Macchiioni, Giovan Battista Fidanza, Lorena Sozzi

«Il restauro non è una scienza arcana che pei gonzi». Giuseppe Mongeri e i prodromi del rapporto tra scienza, storia dell'arte e restauro 384

Michela Marisa Grisoni

INFN-CHNet and the Opificio delle Pietre Dure: a long-lasting fruitful collaboration 392

Anna Mazzinghi, Lisa Castelli, Chiara Ruberto, Lorenzo Giuntini, Francesco Taccetti

La seconda fase della storia della diagnostica applicata ai beni artistici: dalla fondazione dei laboratori storici di stato, alla nascita di laboratori privati al servizio del pubblico 400

Cinzia Pasquali

Le nanotecnologie per il restauro: scenari di applicazione per la conservazione delle superfici architettoniche musive del XX secolo 408

Sara Iaccarino

Dal laboratorio alla realtà del cantiere: il progresso delle soluzioni nel trattamento dell'umidità di risalita capillare 416

Manlio Montuori

Study of ready-mixed plasters applied to the conservation of architectural heritage: comparison between different types of binders and aggregates 424

Maria Cecilia Carangi, Francesca Baratta

IL RUOLO DELLE UNIVERSITÀ E DEL SISTEMA DI ISTRUZIONE E FORMAZIONE

THE ROLE OF THE UNIVERSITIES; THE EDUCATION AND THE TRAINING SYSTEM

L'architetto restauratore e l'esperto dei materiali. Esperienze didattiche come occasione di riflessione su interazioni, competenze e ruoli 434

Sara Goidanich, Lucia Toniolo

Per una innovazione della disciplina Restauro 440

Renata Prescia

Dalla bottega al laboratorio e viceversa. Verso una logica dell'attenuazione 446

Angela Squassina

Il rapporto tra pratica e approccio tecnico-scientifico nei laboratori di restauro dell'Università di Urbino: le nuove tecnologie a supporto dell'intervento 452

Laura Baratin, Alessandra Cattaneo, Francesca Gasparetto, Veronica Tronconi

Se non "chiamano in aiuto la chimica". Rifazione vs "approccio scientifico" nei cantieri dei Paesi emergenti	462
<i>Mariacristina Giambruno, Sonia Pistidda</i>	
Commissioni ministeriali e prime indagini strumentali sulla Cupola del Brunelleschi: l'inizio di un processo	470
<i>Federica Ottoni</i>	
La chiesa di Santa Maria delle Grazie al Calcinaio di Cortona. I restauri dei paramenti lapidei tra gli anni '60 e '90 del XX secolo	478
<i>Pietro Matracchi, Carlo Alberto Garzonio, Gabriele Nannetti, Isabella Seghi, Teresa Salvatici, Federico Salvini</i>	
Dal rilievo digitale al progetto di restauro, linee guida per la conservazione di un tratto di cinta magistrale a Verona	486
<i>Sandro Parrinello, Giovanni Minutoli, Anna Dell'Amico</i>	
Le pietre storiche fiorentine: caratterizzazione e conservazione	494
<i>Massimo Coli, Mauro Matteini</i>	
Il restauro della Cattedrale di San Lorenzo a Genova. La ricerca di un fondamento scientifico	502
<i>Lucina Napoleone, Rita Vecchiattini</i>	
Il rilievo per la conservazione dei monumenti: il cantiere di restauro del Tabernacolo di Lupo di Francesco nel Camposanto Pisano	510
<i>Giovanni Pancani, Matteo Bigongiari, Roberto Cela, Sara Chirico</i>	
Un palinsesto di architettura e natura. La protezione delle superfici dell'abbazia di San Pietro a Crapolla (Massa Lubrense) tra conoscenza e ricerca applicata	518
<i>Stefania Pollone, Mariarosaria Villani, Claudia Di Benedetto, Fabio S. Graziano</i>	
Monumento ai Caduti e alla Vittoria: esperienze di cantiere nel restauro di un'opera del Novecento forlivese	526
<i>Giulia Favaretto, Giancarlo Gatta, Alessia Zampini</i>	
Il Restauro e l'apporto della Chimica: alcune esperienze nel contesto napoletano	534
<i>Claudia Aveta</i>	
Il restauro della facciata della chiesa degli Scalzi a Venezia: dallo studio del monumento all'intervento, tra immagine e materia	542
<i>Silvia Degan, Marco Comunian</i>	
I restauri delle architetture ecclesiastiche nei primi decenni del Novecento a Venezia. Casi, protagonisti e metodi nel confronto tra teoria e prassi	550
<i>Luca Scappin</i>	
Microwave reflection method for moisture assessment for architectural heritage conservation: first results on the case study of church of S. Pietro in Valle (Fano, Italy)	558
<i>Francesco Monni, Andrea Gianangeli, Enrico Quagliarini, Marco D'Orazio</i>	
La diagnostica in imaging sul campo: i cantieri di restauro delle pitture murali	566
<i>Ashley Vidler</i>	
La storia dei restauri come metodo scientifico a supporto dell'intervento. Una lettura regressiva su nuclei significativi del Castello di Aghè (TO)	574
<i>Giulia Beltramo</i>	
Cantieri del dopoguerra milanese: Ferdinando Reggiori e il restauro di Casa Silvestri	582
<i>Caterina Valiante</i>	
L'INTERDISCIPLINARITÀ DEI PROCESSI: LA RELAZIONE TRA RESTAURO E LABORATORIO SCIENTIFICO	
THE INTERDISCIPLINARITY OF PROCESSES: THE RELATIONSHIP BETWEEN RESTORATION AND THE SCIENTIFIC LABORATORY	
Moenia urbis. L'interdisciplinarietà dei processi per le scelte di restauro. Le mura greche nella sede centrale della Federico II	592
<i>Renata Picone</i>	
Dalla conservazione dei materiali alla conoscenza del costruito, tra «scienze della natura» e «scienze storiche»	600
<i>Alberto Grimoldi, Angelo Giuseppe Landi</i>	
Reintegrazione e analisi degli elementi ornamentali nell'architettura modernista	608
<i>Graziella Bernardo, Fabio Minutoli, Luis Manuel Palmero Iglesias</i>	
Beyond the limestone. Indagini sulle dinamiche degenerative per la rigenerazione del patrimonio costiero fortificato pugliese	616
<i>Michele Coppola, Federica Mele, Claudio Natali, Cristina Tedeschi, Samuele Ansalone</i>	
Analisi speditive per la conoscenza dell'edilizia storica: alcune applicazioni nei cantieri marchigiani post sisma 2016	624
<i>Enrica Petrucci, Graziella Roselli</i>	
Il restauro delle opere in cemento armato: interdisciplinarietà della ricerca scientifica e della pratica progettuale	632
<i>Stefania Landi</i>	

Microwave reflection method for moisture assessment for architectural heritage conservation: first results on the case study of church of S. Pietro in Valle (Fano, Italy)

Francesco Monni | f.monni@staff.univpm.it

Department of Construction, Civil Engineering and Architecture (DICEA), Polytechnic University of Marche, Italy

Andrea Gianangeli | a.gianangeli@staff.univpm.it

Department of Construction, Civil Engineering and Architecture (DICEA), Polytechnic University of Marche, Italy

Enrico Quagliarini | e.quagliarini@staff.univpm.it

Department of Construction, Civil Engineering and Architecture (DICEA), Polytechnic University of Marche, Italy

Marco D'Orazio | m.dorazio@staff.univpm.it

Department of Construction, Civil Engineering and Architecture (DICEA), Polytechnic University of Marche, Italy

Abstract

Moisture is one of the most important causes of deterioration of building materials, because water is involved in a lot of decay mechanisms. The problem results to be particularly relevant in the field of historic buildings, due to the fact that water presence could destroy great value elements and surfaces. To conserve this heritage is very important assess the features of water presence in masonry structures. Among the several non-destructive techniques that could be used on historic architectural heritage for moisture measurement, there is the microwave reflection method. In this paper are presented the first results of an in-situ campaign of moisture evaluation using microwave method on the church of S. Pietro in Valle (Fano, Marche Region, Italy), executed after a preliminary calibration of the test device. In this context results very important understand sources, penetration paths and spatial distribution of moisture to set up an effective conservation strategy of the monument.

Keywords

Moisture mapping, Microwave reflection, Architectural heritage

Introduction

As well known, moisture is one of the dominant factors of degradation of building materials, because water is involved in a lot of decay mechanisms (e.g., biological growth, salt crystallization, freeze-thaw cycles, expanding clays presence, etc.) and the complete removal of water is not possible.

In the field of historic buildings and cultural heritage conservation the problems results to be particularly relevant, due to the fact that mentioned processes related to water presence could destroy great value elements and surfaces (in particular painted plaster, frescoes and stuccos).

Moisture content (MC) of building materials is determined by the hydrophilic nature of the material and there are many parameters that regulate MC: (I) ambient relative humidity (RH); (II) condensation when the surface temperature decreases below the dew point; (III) hygroscopic salts adsorbing water, especially when the ambient RH exceeds the salt deliquescence level; (IV) presence of rising damp; (V) presence of wetting from falling

RH exceeds the salt deliquescence level; (IV) presence of rising damp; (V) presence of wetting from falling raindrops due to a building envelope not completely waterproof.

Hence, moisture in historic buildings represents a big issue, and most relevant activities of technicians working on built heritage conservation concern monitoring and measure it.

Nowadays several methods are available for measurement of moisture in building structures.

Some of these has to be considered as "destructive methods" because involve taking samples to be tested in laboratory (e.g., gravimetric method) but, in restoration field this kind of methods must as much as possible be avoided on behalf of non-destructive testing (NDT) methods.

Among the most used NDT methods it is worth mentioning thermal-based methods (e.g., infrared thermography) that utilize the change in temperature of materials caused by the change in moisture conditions (a wet material has a lower temperature than when it is dry), and methods that utilize the electrical properties of materials (resistance/capacitance methods) among which we can also include microwave-based methods^{1, 2}.

In this paper are presented the first results of an in-situ survey campaign of moisture evaluation using microwave method on the church of San Pietro in Valle (Fano, Marche Region, Italy), executed after a preliminary phase of calibration of the test device.

The church of San Pietro in Valle (Fig. 1) is located in the historical center of Fano, a city of Roman origin of Marche Region (Italy) and was built at the beginning of the 17th century (probably erected on the remains of an earlier building).

It shows a Latin cross-shaped plant with a single nave (covered by a vault), a large transept and a deep presbytery. The central zone of the transept is covered by a dome (Fig. 2, 3, 4).

On the sides of the nave there are six lateral richly ornamented chapels where were located by notable authors of 17th century (e.g., Reni, Guercino, Cantarini, Garbieri, Guerrieri).

This, together with the features of its interior - richly decorated with decorative marble and molded plasterworks - makes the Church of S. Pietro in Valle one of the most important examples of Baroque art in the Marche region. The building is currently closed due to the lack of safety condition caused by the loss of integrity of the heavier decorations.

In this context, an analysis and the correct identification the potential sources, the penetration paths and the spatial distribution of water results very important, in order to set up an effective conservation strategy of the monument and, therefore, conservation intervention works.



Fig. 1 Fano (Italy), Church of S. Pietro in Valle, external view: main facade and side wall (photo R. Angeloni, 2023)



Fig. 2 Fano (Italy), Church of S. Pietro in Valle, view of the nave and presbytery from the main entrance, (photo A. Gianangeli, 2023)



Fig. 3 Fano (Italy), Church of S. Pietro in Valle, view of the nave and main entrance from the presbytery, (photo R. Angeloni, 2023)



Fig. 4 Fano (Italy), Church of S. Pietro in Valle, view of the dome, (photo R. Angeloni, 2023)

Measurement method and testing device

Microwave moisture measurement methods utilizes the well-known fact that the dielectric permittivity of water is much higher than the permittivity of most building materials and microwave reflection coefficient depends directly from dielectric permittivity of material. It means that amplitude of reflected microwave signal value contains information about water content of material. The advantages of this method can be summarized as follow:

- it is a non-destructive testing (NDT) method;
- it allows high measurement speed;
- it allows the acquisition of large numbers of moisture values;
- it allows a 3D measurement (it can be applied to different depth layers by choice of different microwave sensors);
- it is independent from salinity.

The method also has limitations, in fact it cannot be used in presence of metallic conducting areas (on the surface or within the depth interested by the microwave bundle) or in presence of voids (air gaps cause additional reflections superimposing the measuring signal and impairing the clarity of measuring results).

Other problems are connected to the non-homogeneity of the medium, in terms of density and porosity variations or layered structures³ Cases that can be very frequent in building materials, especially in historic construction. In this work was used a commercial device, a handheld microwave moisture meter designed for non-destructive moisture measurements in various building materials, the "MOIST 350B" by hf sensor GmbH (Leipzig, Germany). It consists of a microcontroller based handheld and interchangeable measuring heads (that can easily and quickly be changed) to achieve different measuring ranges (Fig. 5A). The device produces microwave fields of varying geometry sensitive to different depths^{4,5}. The recorded reflection values are based on average properties within the measurement area, but with decreasing sensitivity to moisture further away from the sensor. We have availability of four measuring heads having measuring ranges (according to manufacturer's specifications) of up to 3 cm (MOIST-R1M V2), up to 7 cm (MOIST-R2M V2), up to 11 cm (MOIST-DM V2) and up to 30 cm (MOIST-PM V2).

The instrument, for the potential offered and declared by manufacturer and also for its versatility (lightweight and not dependent on electrical power), is particularly suitable for 3D in situ investigations, such as those we needed to analyse the conditions of the church.

Experimental: preliminary laboratory test and in-situ measurements.

Before using the device in situ, we tried to calibrate it in the laboratory on samples for which we did know the content and spatial distribution of water. The calibration procedure is addressed to obtain the maximum expected measurement range, from dry to wet (saturation) on different material types. For preliminary calibration test, we used a concrete sample and a wood sample, both on cubes 15x15x15cm, in saturated condition (Fig. 5B, 5C).

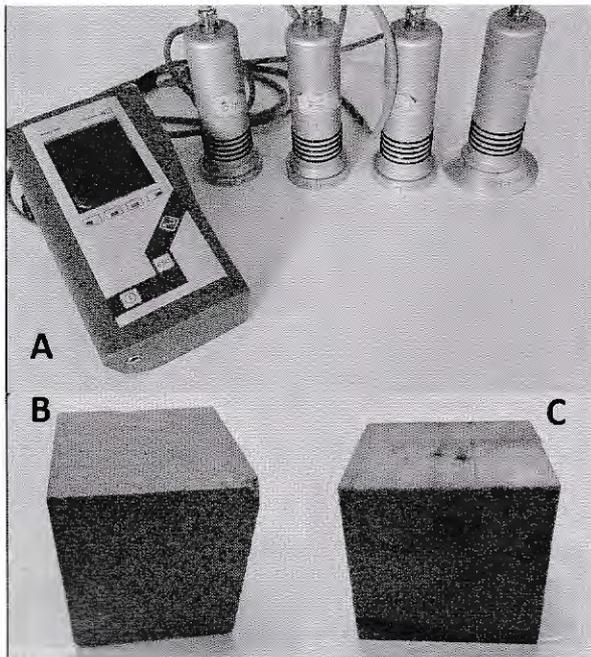


Fig. 5 The MOIST350B device and the sensor heads Fano (A), the sample for preliminary laboratory test: concrete (B) and wood (C).

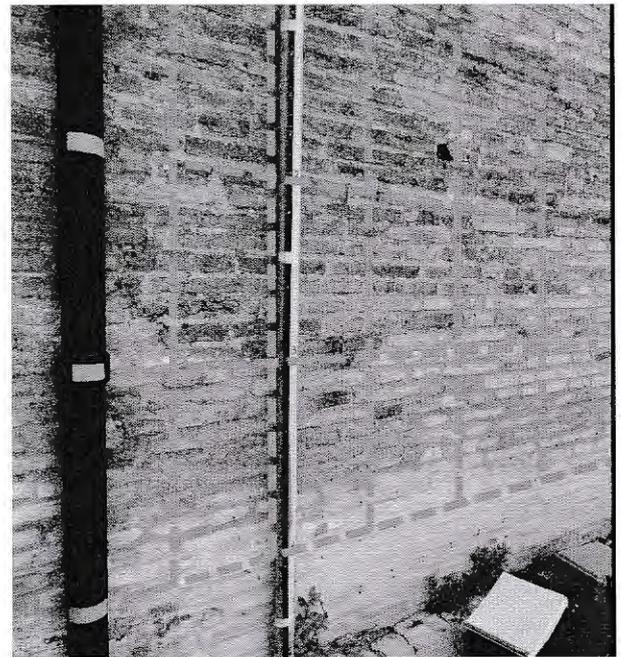


Fig. 6 Example of the grid used for the MOIST350B in-situ measurements on the side wall of the church of S. Pietro in Valle, Fano (Italy).

According to the MOIST350B operation manual the measure has to be executed at a distance far enough from the lateral bounds of the measurement zone and with a thickness material greater than the penetration depth of the sensor head. For these reasons, the sample dimensions allow the use of only 3 sensor head: MOIST-R1M V2 (penetration depth of 3 cm), MOIST-R2M V2 (7 cm) and MOIST-DM V2 (11 cm).

The in-situ measurements were executed on the main façade and on the side wall of the church (Fig. 1), that result affected to moisture problems and is supposed (but not confirmed) that is due to rising damp (capillary rise of water from the ground to the walls of the building), a phenomenon recurrent in ancient constructions, due to the fact that the old buildings have often masonry foundations and lack of a layer hindering the water transport from the ground to the upper structure.

For in-situ measurements have been used all the available sensor heads: in fact, the wall has a thickness compatible with use of MOIST-PM V2 sensor head (penetration depth of 30 cm).

The device allows to perform single measurements or map the surface to be investigated: for preliminary test was used the procedure "single measurement", while for the in-situ test the measurements was performed following a grid with mesh 50 x 50 cm (Fig. 6).

For laboratory test the measurement was recorded using the device setting that returns the average value of a series of fifteen measures, while for in-situ campaign the device was set to return the average value of five measures for each measure point.

Each sensor head includes a set of calibrations for typical building materials where the reflection coefficient is transformed into a percent water content. While these are named for broad categories of materials, they were developed for one particular type of that material. In addition to these calibrations, a unitless moisture index

(MI) can be used, which is a set of arbitrary units related more directly to the reflection coefficient. This is the basic output signal of the microwave probes. It is a dimensionless number, an expression of the microwave reflection coefficient measured, multiplied by a factor of 4000, that is supposed to increase with the water content. The MI has different ranges for different probes due to different microwave applicators used for different penetration depths. Following previous experiences in this field^{6,7}, the use of MI was preferred.

Results

In the Table 1 are reported the MI values recorded in the preliminary laboratory test.

PRELIMINARY LABORATORY TEST MI value recorded		Sensor heads		
		MOIST-R1M V2 (3 cm)	MOIST-R2M V2 (7 cm)	MOIST-DM V2 (11 cm)
Materials	Concrete	1166	2421	811
	Wood	940	2010	781

Table 1 Results of the preliminary laboratory test on cubic wood and concrete water saturated samples

Has to be said that each sensor heads works on different measurement scales and were declared from producer following typical spans (from "dry" to "wet"):

- Sensor head MOIST-R1M V2 (3 cm): 600 - 700 MI
- Sensor head MOIST-R2M V2 (7 cm): 1500 - 1700 MI
- Sensor head MOIST-DM V2 (11 cm): 500 - 600 MI
- Sensor head MOIST-PM V2 (30 cm): 800 - 1000 MI

It is evident as the recorded values are higher than typical spans indicated by the producer, but this fact can be justified by the completely saturation of the samples. Moreover, is evident as the nature of the medium investigated influences the measure, so that underline the need of a calibration for a use on materials which are different from the ones for that the producer provides the calibration curves.

Fig. 7 and Fig. 8 show moisture maps in the four different depths taken, respectively on side wall and on main façade (the x-axis and y-axis show the dimensions of the measuring field). As regards the color scale, due to the fact that, as said before, each sensor heads works on different measurement scales, it's not correct to apply the same color scale in all the layer, but seems to be more reliable using a color scale calibrated on the range of measures recorded in each layer. As can be seen from these images, the method is able to return a picture of moisture presence, useful to understand the bidimensional distribution of water and to hypothesize the causes at the origin of the phenomenon. In the moisture maps can be seen, especially in the case of main façade, that the moisture distribution presents an inhomogeneity higher at the surface than the one recorded in the inner layers. It could be a first indication toward the confirmation of a rising damp phenomenon.

An aspect that needs to be highlighted concerns the repeatability of the measurements: when the contact surface between the probe and the masonry wall is not completely smooth, it is common to record different values, albeit slightly, by repeating the measurement in the same measure point.

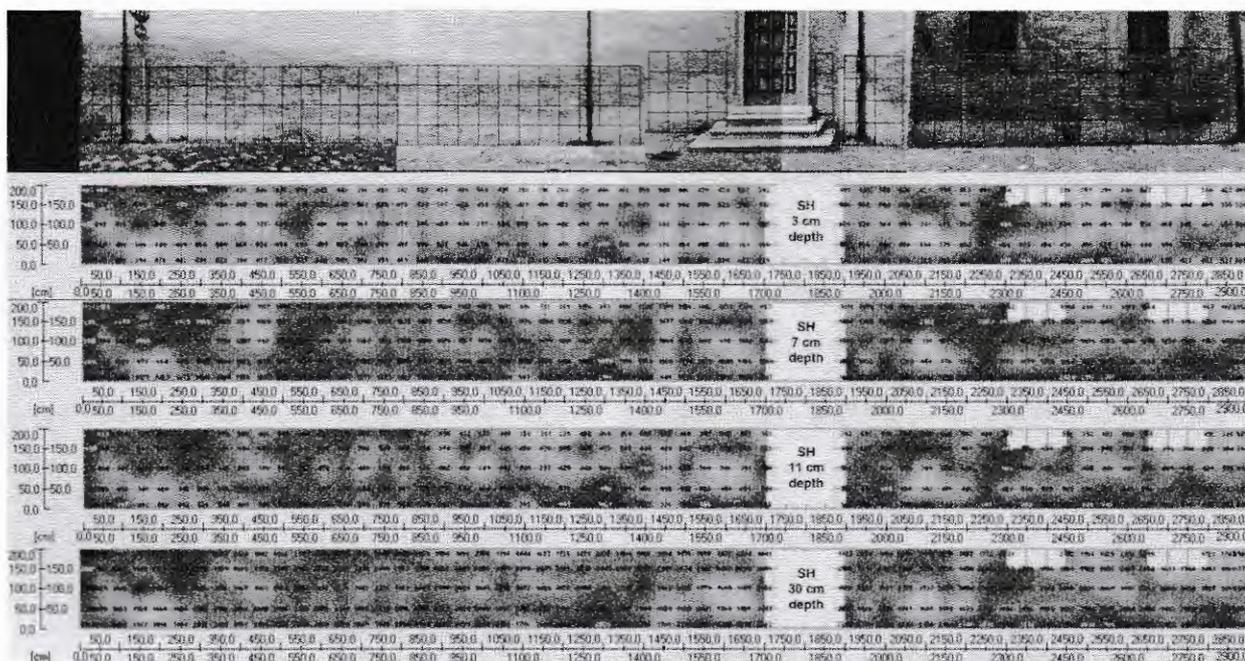


Fig. 7 Moisture maps related to the side wall of the church of S. Pietro in Valle, Fano (Italy), taken using the several sensor heads

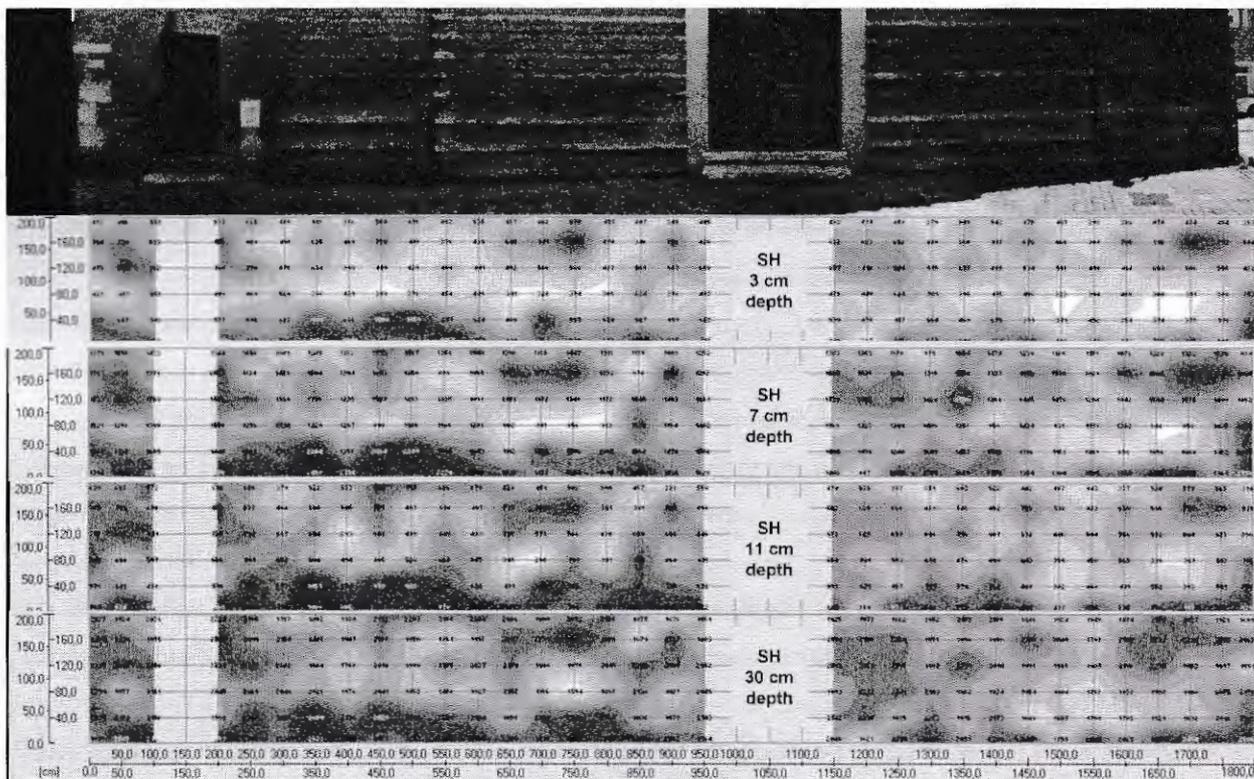


Fig. 8 Moisture maps related to the main facade of the church of S. Pietro in Valle, Fano (Italy), taken using the several sensor heads.

Conclusion

This paper focuses on moisture evaluation for cultural heritage restoration using microwave method and presents the first results obtained by application of this technique on the case of the church of San Pietro in Valle (Fano, Marche Region, Italy).

The method results well-suited for application on historic buildings moisture assessment because is a non-destructive technique, and so respectful of the historic building heritage conservation principles. Moreover, the test device is light and easily transportable, the sensor heads can be easily and quickly changed, the results (moisture maps) are easily readable.

However, the method has also several limitations. If on one hand it could be useful for obtain maps that could be enough for understanding nature and sources of moisture phenomenon, on the other it not allows to have absolute values of moisture content when the material is not homogenous (e.g., layered, presence of cavities, etc.) or it is not included among those for which a calibration curve is provided by manufacturer. For these reasons, in these particular cases, microwave technique should be supported by other traditional methods (e.g., gravimetric measurements). Another influencing factor could be represented by the effect of a non-smooth interface between probe and medium, a problem non to be underrated in existing buildings field, for the frequency to find facing-masonry walls.

Further developments of the research activities could be aimed to extend the database of available calibration curves, repeat measurements cyclically in long period (in order to analyse seasonal changes) and to perform the survey campaign also on the internal side of the investigated walls to support and validate the results already obtained.

Acknowledgements

We would like to thank Dr. Renato Angeloni for providing us some photos used in this contribution.

¹ D. CAMUFFO, C. BERTOLIN, *Towards standardisation of moisture content measurement in cultural heritage materials*, "e-Preservation Science", 9, 2012, pp. 23-35.

² M. NADY, A. SAÏD, *Measurement Methods of Moisture in Building Envelopes – A Literature Review*, "International Journal of Architectural Heritage", 1:3, 2007, pp.293-310, DOI: 10.1080/15583050701476754

³ JF LATASTE, A. GÖLLER, *Microwave Reflection*. In: Nilsson, LO. (eds) *Methods of Measuring Moisture in Building Materials and Structures*. RILEM State-of-the-Art Reports, vol 26. Springer, 2018.

⁴ A. GÖLLER, *Microwave scanning technology for material testing*, "Proceedings of the 9th European Conference on NDT", (Berlin, 25-29 September 2006), 2006.

⁵ A. GÖLLER, *Moist scan – multilayer microwave moisture scans at buildings masonry and civil structures*, "Proceedings of the 14th International Conference and Exhibition on Structural Faults and Repair", (Edinburgh, 3-5 July 2012), 2012.

⁶ L. KURIK, T. KALAMEES, U. KALLAVUS, V. SINIVEE, *Influencing factors of moisture measurement when using microwave reflection method*, "Energy Procedia", 132, 2017, pp. 159-164. doi: 10.1016/j.egypro.2017.09.675.

⁷ C. BLÄUER, B. ROUSSET, *Attempt to use microwave moisture mapping system (MOIST200B) to control and monitor the water uptake of stones in frame of cultural heritage conservation*, "Proceedings of the 12th International Conference on Microwave and High Frequency Heating (AMPERE 2009)", (Karlsruhe, 7-10 September 2009), 2009, pp. 29-32.