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Conoscenza, conservazione e valorizzazione
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"Già chiamano in aiuto la chimica..." Il restauro da bottega a laboratorio scientifico e pratica di cantiere

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Restoration from *bottega* to scientific laboratory and site practice

a cura di

Susanna Caccia Gherardini
Emanuela Ferretti
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Mariacristina Giambruno
Marco Pretelli

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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)

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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. Petro in Valle, external view: main facade and side wall (photo R. Angeloni, 2023)

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

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

Fig. 4 Fano (Italy), Church of S. Petro 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 con 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 structures[3] 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).

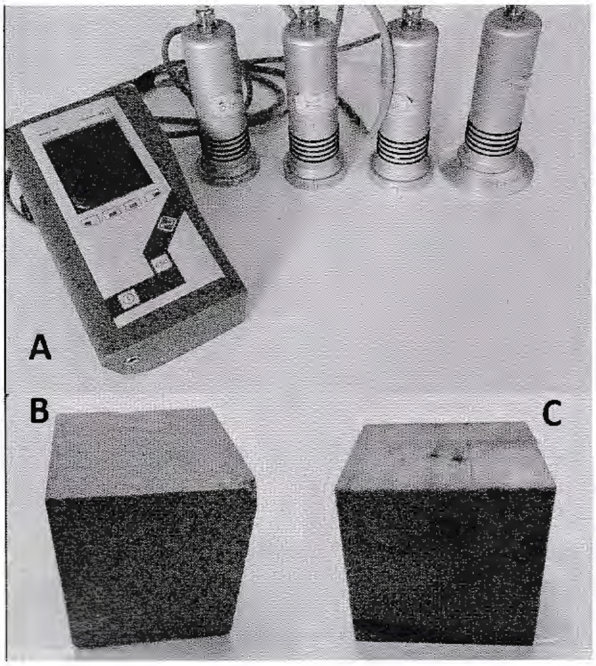

Fig. 5 The MOIST350B device and the sensor heads Fano (A), the sample for preliminary laboratory test: concrete (B) and wood (C).

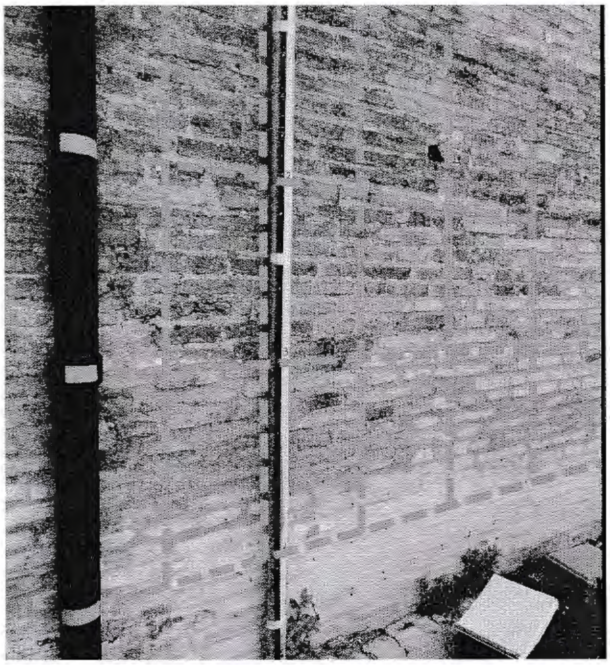

Fig. 6 Example of the grid used for the MOIST350B in-situ measurements on the side wall of the church of S. Pietro in Valle, Fano (Italy).

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.

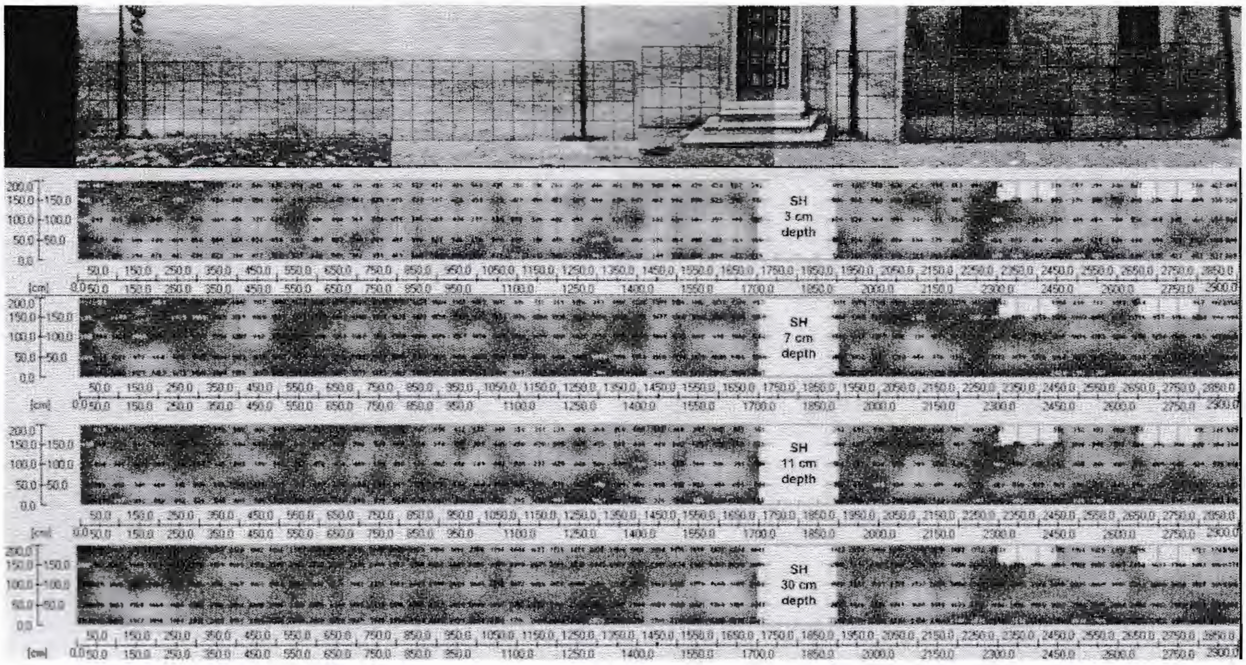

Fig. 7 Moisture maps related to the side wall of the church of S. Pietro in Valle, Fano (Italy), taken using the several sensor heads

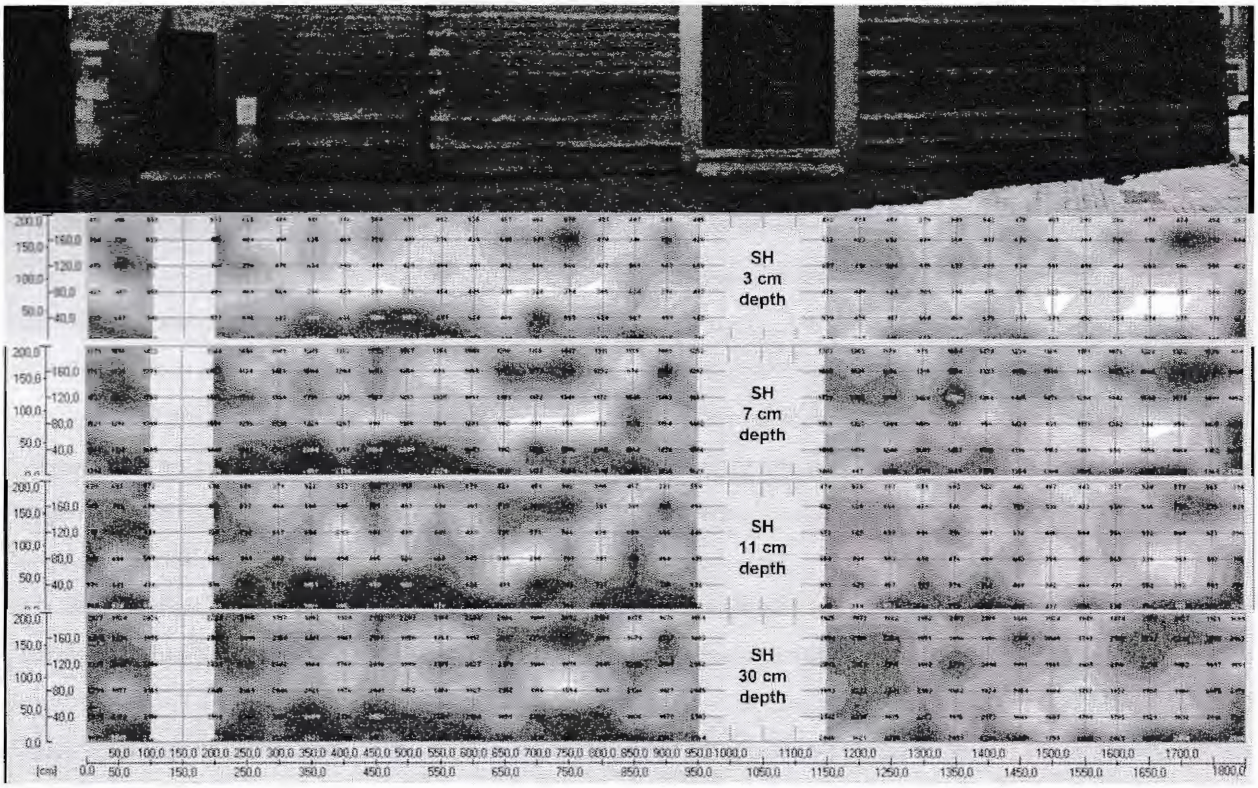

Fig. 8 Moisture maps related to the main facade of the church of S. Pietro in Valle, Fano (Italy), taken using the several sensor heads.

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.

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