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INTEGRATED SURVEYS FOR THE ANALYSIS OF THE DETERIORATION IN THE CRYPT OF THE ABBEY OF MONTECORONA – ITALY

Rosella Cataldo[1], Stefano Siviero[1] , Giovanni Leucci[1],
Rita Pagiotti[2] , Paola Angelini[2]
[1]Department of Science of Materials, University of Salento, Via Arnesano, 73100 Lecce, Italy
[2]Department of Vegetal Biology and agro-environmental and zoo technical biotechnologies, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy

ABSTRACT

A study of the problem of deterioration in the crypt of the Abbey of Montecorona (Perugia, Northen Umbria-Italy) is proposed, with the aim to achieve a knowledge of the indoor and subsoil conditions. First of all we studied the microbial biodiversity of the crypt, analyzing the presence of microorganisms by microscopic and cultivation methods. Then we investigated the influence of the environment upon colonisation and growth of those micro-organisms, monitoring the microclimate, especially the thermo-hygrometric conditions. Various Ground Penetrating Radar (GPR) System surveys were carried out in order to localise archaeological remains and wet buried structures involved in the deterioration process and, by means a velocity analysis, we evaluated the underground water content. Microclimatic, biological and geophysical results were compared, in order to eliminate the ambiguity inherent each method. The results permits us to identify properly the causes of the deterioration in the crypt.

INTRODUCTION

The crypt of the Abbey of Montecorona (Perugia, Northen Umbria-Italy) is located at Latitude 43°18'23"40 N and Longitude 12°20'15"00 E, on 222-926 m above the sea level in the High Tiber Basin.

The abbey is a nice historical monument that contains 13th-century frescos of Umbrian school and an important wooden choir, the crypt is a beautiful 11th-century building with early Romanesque capitals and naïve 18c painted ceilings. The principal construction element of the whole complex is the compact limestone, while the pavement presents bricks in “cotto”; there are also elements of travertine and “pietra serena”, probably mined from local quarries.

The crypt has a rectangular plant of 16.5x18.9m^2, with an high of about 3m (Fig.1). It communicates with the outside trough the door P1, window W4 on the south side is opened every day, windows W1, W2 and W3 on the north side are rarely opened and the solar rays never penetrate.

Despite its small size, it is of great cultural value and attracts many visitors and pilgrims.

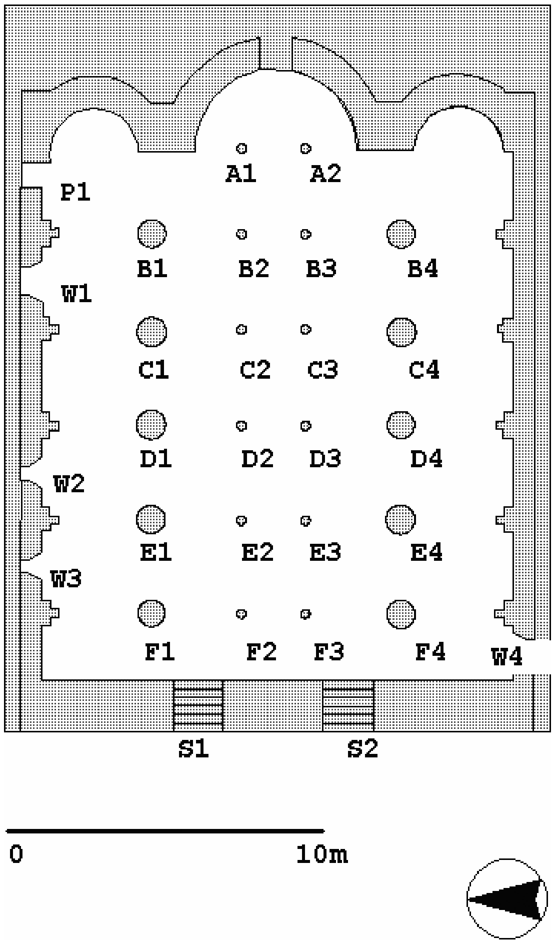
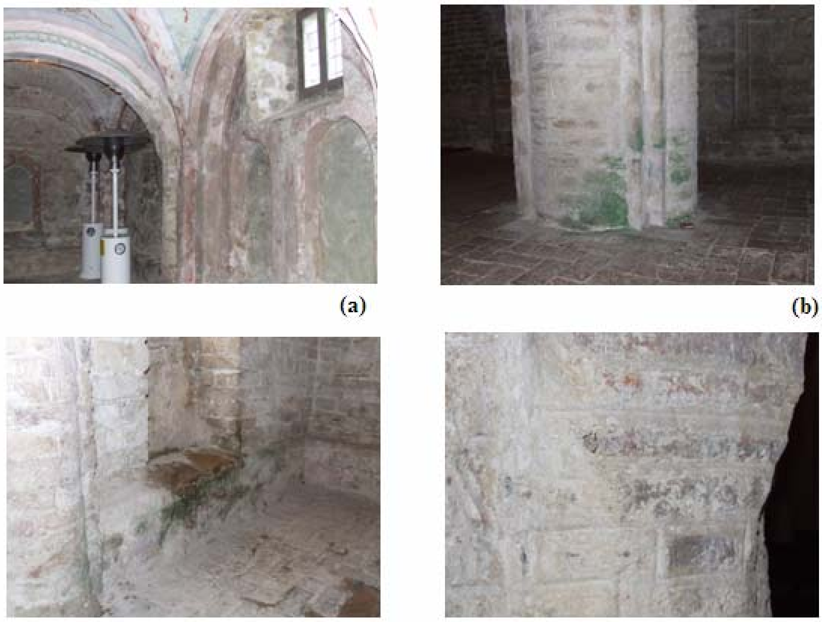


Fig. 1: Map of the crypt of the Abbey of Montecorona

As many historical buildings, churches and hypogea, the crypt exhibits deterioration problems (Fig. 2), the marble columns show variable degree of mould coating, both at the base of the shaft and on the capitals. Other biological and physical damages are present in particular on the wall of the north side, which never receives the direct sun irradiation, and on the pavement in front of the window W4 (south side in Fig. 1), that exhibits a wide stain of dampness with the presence of moulds.

It is very well known that the presence of particular microclimatic conditions inside monumental buildings can favour the development of bio-deterioration, moreover also particular conditions of the foundation subsoil can be involved in the degradation process of the stone [1,3].

So we achieved a knowledge of the indoor and subsoil conditions integrating biological, microclimatic and geophysical results, as described in the next sections.



(a) (b) (c) (d)

Fig. 2: Examples of deterioration: (a) on the northwest wall, (b) algae patina growing on the ground of the columns F1, (c) algae and moulds on the southwest wall, (d) blackish powdery patinas on a column

EXPERIMENTAL SECTION

Biological Investigation

Sampling was performed in the Crypt of the Abbey of Montecorona, in April 2007, on each column, on the walls and on the ceiling, where biological patinas were most evident. A sterile lancet was used and the fragments were stored in sterile tubes at room temperature.

All microorganisms were enumerated by plate counts following one week of incubation. The following media were used: plate count agar (PCA) Difco, for aerobic heterotrophic bacteria, YEPGA [13], for yeasts and fungi, and Detmeter liquid medium for *Chlorophyta* [4].

The microbial count ranged from 10^4 to 10^7 CFU/g of marble for the heterotrophic bacteria, between 10^2 and 10^3 CFU/g of marble for yeasts and between 10^3 and 10^5 CFU/g of marble for fungi.

A list of the most frequently occurring bacteria, yeasts and fungi is given in Table 1. The examined bacterial strains belong to the genera *Arthrobacter*, *Bacillus* and *Bacillus*-related genera that are, frequently isolated from mural paintings [7,9]. The predominance of bacilli in the samples can be explained by their ability to survive for a long time in the spore form. While the population of bacilli on the mural painting may be small at a given time, there may be very high numbers of spores, awaiting favourable conditions.

The presence of the identified yeasts in the crypt could either be natural or due to being transported by vectors such as insects, bats or wind currents.

The total amount of isolated fungal strains was 132, most of which were from the sample taken on the north wall. Several dark pigmented strains (in particular those manifesting meristematic and sometimes yeast-like growth with budding cells) were isolated.

The damage is not caused by acid formation and the dissolution of the mineral compounds, but it is the results of intercrystalline growth that physically disrupts the weakest structural components of the crystals that leads to biopitting and the formation of cracks and fissures [14,12]. The species diversity of this fungi is masked by a unique in-situ morphology. However, a broad biodiversity with numerous new species in various genera and orders only becomes apparent by DNA analysis [4].

The consistent detection of some fungi in the samples taken on the northwest wall, such as *Aspergillus, Paecilomyces*, or various species of *Penicillium*, could indicate water damage with subsequent fungal amplification.

The composition of the algal population in samples taken from the columns and southwest wall showed a predominance of *Clorella, Pseodococcomyxa*, and *Pseudopleurococcus* species (Table 1).

Table 1 – List of the most frequent microorganisms in the crypt of the Abbey of Montecorona

Bacteria
Arthrobacter spp.*, Bacillus*spp.*, Paenibacillus* spp.*, Staphylococcus* spp.*, Nocardioides* spp

Yeasts
Aureobasidium pullulans (de Bary) G. Arnaud, *Cryptococcus laurentii, Rhodotorula glutinis, Rhodotorula mucillaginosa,* Black yeast-like undeterminated

Moulds
Absidia corymbifera (Cohn) Sacc.and Trotter, *Acremonium* spp., *Alternaria* spp., *Aspergillus flavus* Link, *Aspergillus fumigatus, Apergillus nidulans* (Eidam) G. Winter, *Aspergillus niger* Fresen, *Aspergillus oryzae* (Ahlb.) E. Cohn, *Aspergillus pullulans* (de Bary) G. Arnaud, *Aspergillus terreus* Thom, *Aspergillus versicolor* (Vuill.) Tirab., *Aspergillus* spp., *Beauveria bassiana* (Bals.-Criv.) Vuill., *Chrysosporium* spp., *Cladosporium cladosporioides* G.A. de Vries, *Cunninghamella elegans, Paecilimyces variotii* Bainier, *Penicillium aurantiogriseum* Dierckx, *Penicillium citrinum* Sopp, *Penicillium glabrum* (Wehmer) Westling, *Penicillium purpurogenum* Stoll, *Penicillium thomii* Maire, *Penicillium* spp., *Scopulariopsis brumpti* Salvanet-Duvalin, *Trichoderma viride* Pers.

Algae
Clorella spp., *Pseudococcomyxa* spp., *Pseudopleurococcus* spp.

The main consequence of their growth leads to disfigurement and water retention. Colonisation by fungi and macroorganisms is favoured and, in some cases, corrosion is caused by organic acid.

Different microorganisms such as fungi, algae and bacteria may have a negative effect on the preservation of artistic-historical heritage, especially when microclimatic conditions favour their development. Materials which are found to be contaminated should be removed or decontaminated with some type of antimicrobic, even if it does not have a long lasting effect.

Microclimatic Surveys

Our microclimatic surveys cover the period from November 2006 to November 2007, using the climatic analyser/data logger BABUC/A by LSI (*Laboratori di Strumentazione Industriale*). The measurements of various microclimatic parameters, such as air temperature, surface temperature, relative humidity (RH), specific humidity, dew point, air velocity were performed in strategic places of the crypt on a grid of 48 points, as a function of the time [3].

Besides the measurements on the grid, some probes were also positioned on the outside of the crypt and in the abbey, near the left-staircase (S1 in Fig.1), on the north and south walls.

From the thermodynamic point of view we have a complex system made by two subject: the abbey, having a volume about three times as much the crypt, and the crypt itself. However, the crypt is influenced by the thermodynamics parameters of the abbey especially during the winter/spring seasonal change. In general there are no meaningful differences inside from one day to the other on short periods. The main source of variation for thermo-hygrometric parameters is the opening of the window W4 and of the P1 door towards the outside, but this happens only occasionally.

From the analysis, we observed that RH values are high trough the whole year. In fact RH is around 77% in the autumn-winter period and over 80% in late spring-summer. A typical spatial distribution is shown in Fig.3, related to February 2007.

We evidenced also that, despite here there is a minimum of solar irradiance, the south side has RH values until 5% higher than the north side.

We observed that the dew point in full winter is at least 5°C, while already in May, with external temperature of the order of the 22-23^{o} C, such value goes down to less than 2.5°C. So we presumed that on the north wall, in full summer, phenomenon of condensation can be happen.

Average air temperatures were about 13^{o} C in autumn/winter and about 17^{o} C in spring/summer.

In general those RH and air temperatures values, with a poor air flow through the environment, favour the moulds proliferation and degradation of the stone.

To give a more complete information about the microclimatic conditions, we observed that in October 2007, before the autumn rainfalls, and after a particularly dry and hot summer season, RH values were equal to 55% against about 80% of 5 months ago.

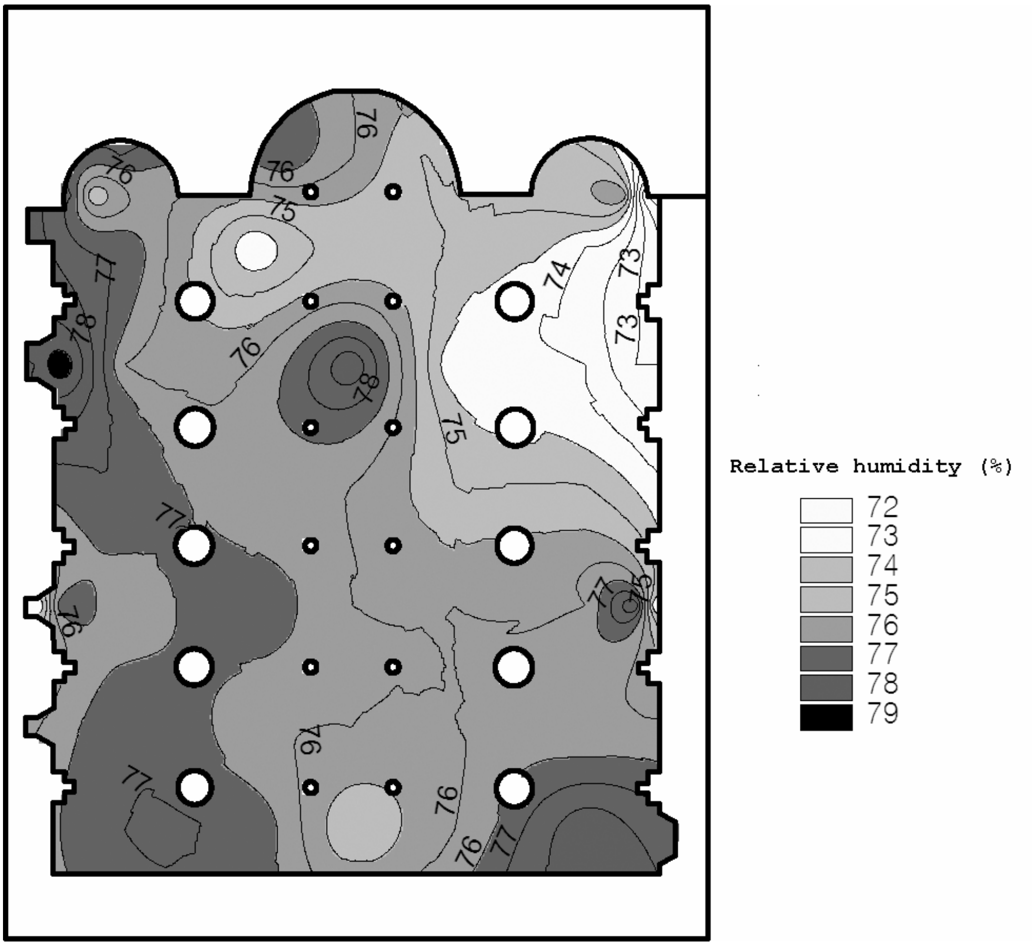


Fig. 3: Relative humidity at 09:00 am of 2/12/2007

Therefore we taught that in the process of the deterioration of the stone in the crypt not only the rainy infiltrations and those of the outflow of irrigated waters, of the subterranean tributaries of Tiber river basin, must be taken into account. This would cause large RH values and an important evaporation of the water with the summer heat.

So we argued to improve the possibility of the existence of buried cavities containing water (or wet materials) and a consequent important rising of water from the pavement, which significantly contributes to the large values of RH inside the crypt, as we experienced in another multidisciplinary study in the crypt of Otranto [5,10,11].

Geophysical Investigation
GPR surveys were carried out with a georadar model P/2000 by Era Tecnology (UK), equipped with 250 MHz antenna, by SGM Srl- Ingegneria Sperimentale – Perugia (Italy).

GPR data were processed using the linear Born Approximation [6]. In particular, we make use of a 2D scalar inverse scattering algorithm in frequency domain, based on the truncated singular value decomposition (TSVD) of the scattering operator [2]. Here, we avoid any mathematical description of the method, because it is quite well known and focus on the results.

In Fig. 4 a subset of the processed data is shown.

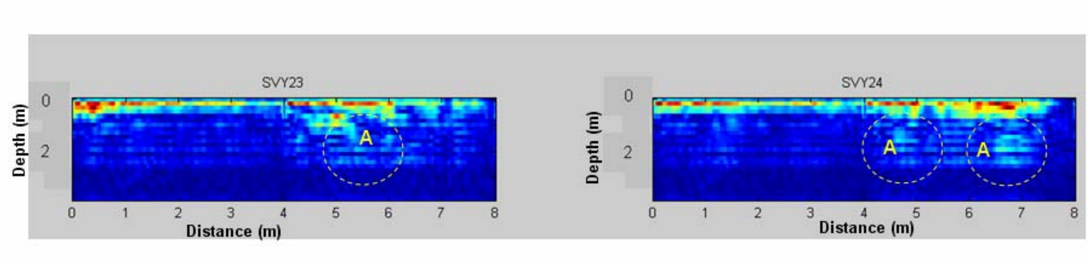


Fig. 4: A subset of the processed data in the Abbey of Montecorona

The denser subsoil (relative dielectric permittivity equal to 10) and some stronger losses make poorer the images. The processing enhances some of the targets (labelled A), and provides a substantially deeper insight with respect to the raw data.

A way to obtain visually useful maps for understanding the plan distribution of reflection amplitudes within specific time intervals is the creation of horizontal time slices [8]. This data representation plays an important role in GPR investigations as it allows an easier correlation of the most important anomalies found in the area at the same depth, thus facilitating the interpretation [5,10].

Time slice maps are built averaging the amplitude (or the square amplitude) of the radar signal within consecutive time windows. In the present work the time slice technique has been used to display the amplitude variations within consecutive time windows of width dt = 10 ns. The selected two-way time interval corresponds to a soil layer, approximately 0.50 m thick.

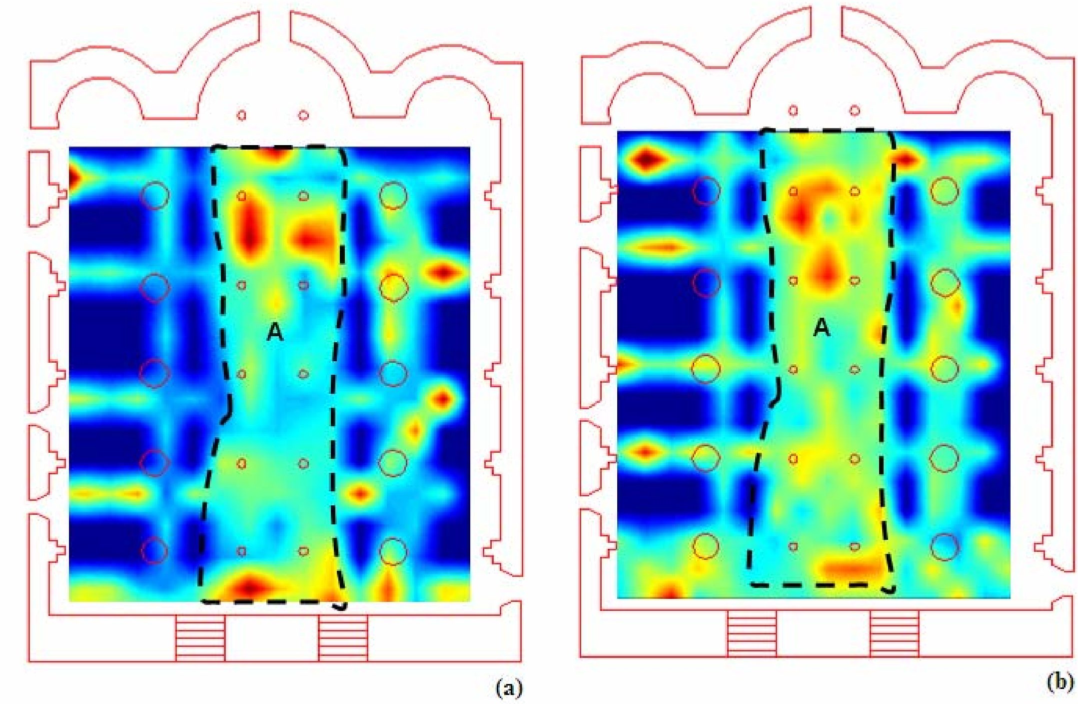


Fig. 5: Time slices at 2m (a) and 3m (b) of depth

The slices shown in Fig.5 were obtained using the processed data. Several events are visible as high amplitude anomalies (labelled A) that could be interpreted as archaeological interest features.

The EM-wave velocity plays an important role in defining shallow subsurface water-content [10]. The EM-wave velocity was determined from the point-source reflections.

Figure 6 shows the plan distribution of the volumetric water content. The yellow area, which represents higher velocities, probably corresponds to a lower soil water-content (about 0-10%). The intense red region corresponds to lower velocities, and thus to a higher water-content (about 30-40%). Area labelled W is evidenced, in that zone the underground water content is particularly high, so we assess a close correspondence of this evidence with the RH results (Fig.3).

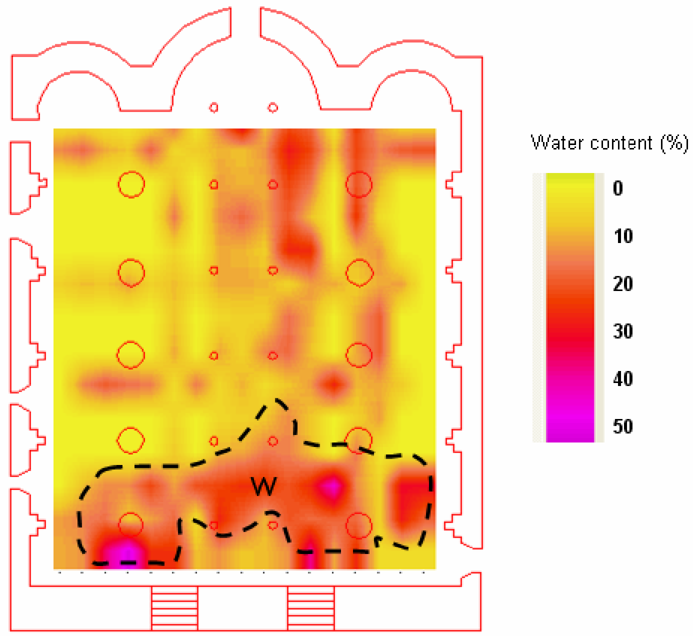


Fig. 6: Volumetric water content distribution in the subsoil of the crypt

CONCLUSIONS

Biological and physical analyses were conducted in the crypt of the Abbey of Montecorona in order to achieve a detailed knowledge of the indoor and subsoil conditions. The integration of the results of those surveys permits us to justify the deterioration evidences in the masonry. So we could identify the main interventions to protect the crypt, besides a decontamination by microorganisms, in a rebuilt of the drainage system of the rainy waters, both regarding the bell tower and the embankment around the abbey, to prevent the flooding of the area.

Those integrated methodologies seems to be very promising when it is necessary to depict the scenario more completely as possible to address properly interventions of protection and conservation.

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Back to Top