Geographic multidimensional approach for decay analysis of Gymnasium frescoes in Pompeii. Preliminary results

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Abstract – **The monitoring of the state of conservation of frescoes is still nowadays a crucial problem in the field of cultural heritage protection.**
With this aim, in the last years non-invasive diagnostics techniques have been introduced. However, even if they are widely considered an essential tool for knowledge, diagnostics for conservation is still struggling to establish itself in the operational practice. This is due to several reasons, including the still high costs, the difficulty of processing and interpretation of the acquired data, the lack of recognized operating protocols. In particular, from the point of view of processing, the integration of different techniques returns a very large dataset, where it is not easy to extract multi-temporal and spatial patterns that could tell us valuable information about the state of conservation of the analyzed fresco. Visual analytics methodology is an useful help for pattern extraction in large datasets [1].
In this work a wall of the Gymnasium of the Sarno Baths (located in Regio VIII) have been studied with the following non-invasive techniques:
- Structure-from-motion photogrammetry (SfM)
- GPR survey
- Multitemporal Infrared Thermography (MIRT)
Preliminary results of the integration of SfM, GPR and MIRT enabled to provide information on the decay pathologies of frescoes [2].
In this paper in particular, preliminary results of the GPR analysis with the geovisual analytics approach are showed, with the aim to facilitate the identification and interpretation of decay patterns of the Gymnasium's fresco.

I. INTRODUCTION

The preservation and restoration of monuments of high cultural interest requires a complete understanding of their state of conservation at present, the characteristics of the artifact, the history and vicissitudes over time, the damage and of the causes that have caused the decay, the typology and the extension of the same decay features. In order to preserve precious objects, invasive or destructive analysis technologies can not be used, so in recent years there is a growing interest in non-invasive geophysical methods as a tool for spatially correlating information obtained and optimizing their position in order to minimize their impact on the monument. In addition, the integration of classical geophysical techniques, such as geodarar (GPR), with surface detection techniques such as infrared thermography, provides a suitable methodology for multi-faceted assessment of the state of conservation.

GPR is a technique usually used in the field of environmental monitoring of the subsoil or archaeological prospecting [3].

Recently it had a great diffusion in the field of cultural heritage [2], [4], [5], [6].

One of the most innovative way to use GPR is in the monitoring of the state of conservation of frescoes [2]. Usually data coming from GPR are interpreted by an expert in the field, who looks for anomalies in the depth slices representing intensity distribution.

Between the different analytical methods that could be used there is the geovisual analytics approach, because of the structure of GPR data: the presence of spatial patterns and the n-dimensionality of the data. In this paper a first attempt to use geovisual analytic for the study of wall painting is showed and discussed.s The case study is the frescoe of the Gymnaium frescoes in Pompeii. The approach is thought to be a Support Decision System, based on Digital Relief Model (DRM) coming from Structure-from-motion photogrammetry (SfM) and a Multitemporal Infrared Thermography (MIRT). This experiment creates new perspectives) even if leaving open questions in the interpretation of the GPR data .

II. II. METHODS

A. *GPR*

Ground-penetrating radar (GPR) is a non invasive method for retrieving information on the internal structure of masonry or for plaster thickness (fresco detachment) and decay pathologies for the localization of voids and defects. Therefore this method is very used in the field of Heritage diagnostics , restoration and conservation.

The GPR equipment consists of a pair of antennasone emits EM pulses into the subsoil or masonry, the second one collects the refracted radar echoes. The antenna frequency used on masonry is typically in the range of 800-2000 MHz to investigate media ranging from a thickness of 1 m to the thickness typical of a plaster layer around 5-10 cm.

A key aspect it is to estimate the speed of the electromagnetic waves within the medium to be investigated [3]. This allows to identify internal reflections at interfaces separating the supports with different electromagnetic properties (dielectric permittivity, electrical conductivity, and magnetic permeability), and to detect the characteristics of the support being investigated such as the thickness of the masonry or the plaster, the presence of local reflector referable to decay pathologies such as voids, cracks and fractures [3]. The estimation of the EM wave velocity enables the conversion of time in depth along the radar profile.

GPR data processing can identify interfaces between different building layers, for example the constructive layers in the ancient Roman walls in opus coementicium or the local reflectors referring to voids, fractures and inhomogeneities. In the presence of moisture in the investigated medium, the increase in conductivity is determined and this appearance causes a high absorption of the EM waves. The interpretation of the obtained images can be best evaluated through the use of microwave tomography to obtain high resolution images useful for detecting anomalies for both archaeological exploration [7] and surveys of historical monuments[8]. The various 3D reconstruction models of GPR results enable a more effective visualization and can help in the interpretation of anomalies that refer to strong spotlights as large inhomogeneities and empty, but at the same time it is not possible to identify smaller cracks attributable to weak reflections , whose nature is more easily understood by looking at the radargrams.

B. *GEOVISUAL ANALYTICS FOR FRESCOES*

Geovisual analytics comes from the research field of geovisualization, that is visual data mining of geospatial data. It pursues the three main tasks of data mining (prediction, data exploration and data reduction) [9] with the main aim of improving the human visual ability to find patterns [10] and by integrating different disciplines, such as geographic information science, image analysis and exploratory data analysis [11].

In this paper a wall painting was considered as a geographic space. Even if this is not a classic or properly geographic space it has a strong spatial component that affects the properties of the wall, such as the state of conservation of materials, or thermical properties. Moreover it is a big dataset because we have to treat 5(number of row)x26(number of columns)x26(number of field associated to each pixel) for a total of 3380 informations.

With Geovisual Analytics it is possible to analyze at the same time the geographic component, together with other multidimensional and heterogeneous information, complex to analyze and manage for human mind also for the numerousness of data to treat. With this methodology it is possible to do a substantial reduction in size and complexity [12] in order: 1) to have pattern extraction, 2) and to understand which dimensions are more or less significant in this application field. This could bring a deeper study of each component, deeper than a study done and interpretated with human eyes.

To study the GPR data the V-analytics software was used [13], [14]. In particular parallel bars and the Self-Organizing Maps [15] were used.

Parallel bars are simple histograms constructed by considering intensity variation at the different depth.

The Self-Organizing Maps is an instrument for dimensionality reduction and pattern extraction. It is a neural network architecture that reduces the n-dimensionality of the input data in a two-dimensional lattice by maintaining topological relationships, without supervision in an iterative way thanks to a learning algorithm. The colors of SOM shows similarity between events, while the black to white color shows distances between clusters.

III. THE CASE STUDY

The ancient city of Pompeii is divided into nine quarters or *Regiones* [16], each in turn contains blocks (*insulae*) that are made up of numerous buildings (*domus*) bordered by roads. The *Regio VIII* occupies the southwestern area of urban area of Pompeii and is limited (to the south) from an irregular stretch of city walls between the two ports Porta Stabia and Porta Marina and is subdivided into seven *insulae* (see Figure 1). Among the prestigious buildings the *Regio VIII* includes palaces and public spaces such as the Triangular Forum, the Basilica, the Theater, the Odeon, the Sanctuaries of Athena, Hercules and Venus, important private homes such as the Domus of Championnet, the Domus of Geometric Mosaics, the Cornelii houses. These are also the Sarno Baths, within which the gymnasium is located. Gymnasium is one of the most significant rooms decorated by frescoes

depicting athletes and fight scenes dated to 50 AD (17) within the Sarno bath which occupies most of the complex of the second *insula* of Regio VIII of Pompeii (for more explications see [2]). The Sarno baths consist of a block of four levels built in the II century BCE. Severely damaged by the earthquake of 62 AD, the thermal rooms were still being renovated at the time of the eruption. The most significant rooms are the Frigidarium, decorated by paintings representing Sarno river (from which the name of Sarno bath) and Nilotic landscapes, and the gymnasium (Fig. 1, bottom),
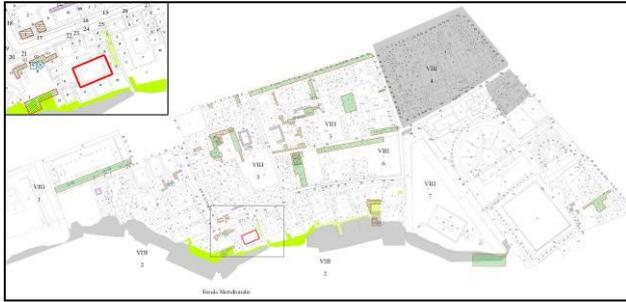

Figure 1.Plan of Regio VII, Pompei with indication of the investigated area: wall painting in Gymnasium in Sarno Baths (red box).

The dataset concerning the wall painting of the Gymnasium includes:
-   The RGB images of the fresco.
-   The DRM derived with SfM, having a spatial resolution of 1.7mm.
-   A MIRT dataset, with three thermograms taken with a time resolution of 8 minutes, while the spatial resolution is of 1.5cm. Consequently we have a thermogram taken at the time 0 (t0), a thermogram taken after 8 minutes (t8') and a thermogram taken after other 8 minutes (t16'). With map algebra the change over time of the infrared channel was calculated, by subtracting t0-t8', t8'-t16', t0-t16'.
-   The GPR data carried out using a 2GHz frequency antenna of the GPR Hi-Mod Hi-Mod equipment of the IDS. The data acquisition procedure was performed by moving the GPR outline onto a plastic panel placed on the surface of the frescoed wall. GPR data was acquired with a scan of 512 samples for a 30 ns recording window and using a manual gain function. The surveyed area was subdivided horizontally with 20 cm vertical spacing (Fig. 2) for a total area of 5m per 1 meter high starting at one meter above the floor. The estimated speed of the electromagnetic wave is 0.10 m / ns.
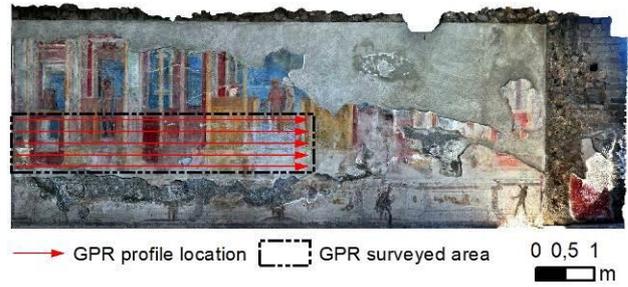

Fig. 2. Location of GPR profiles on the frescoes.

According to the distances between the profiles, we choose to study the depth slices with a spatial resolution of 0.2m, while the depth between slices is 0f 2mm. We considered time slices till a depth of 5cm. In fact, as is it possible to see from fig. 3 anomalies decreases and at this distance they are not meaningful. Instead the part of the sample more altered is probably at a depth from 0.4 to 1.6cm.
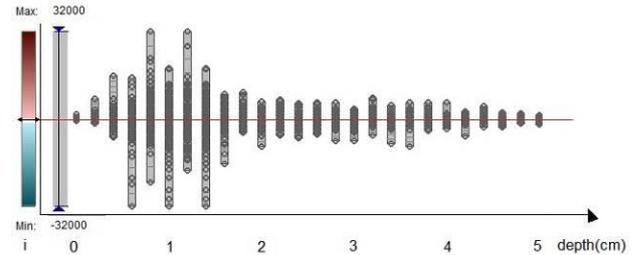

Figure 3. Variation of intensity for each depth slice considered.

Over the 26 GPR time slices the parallel bars and the SOM were calculated, while the RGB, the DRM and the MIRT were used only as comparison with patterns found with SOM.
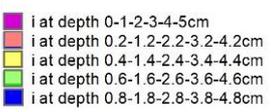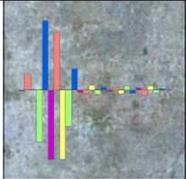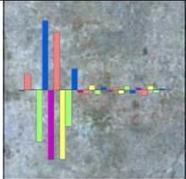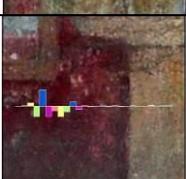
For what concerns the SOM. a lattice of 3x3cells was used, that means the possibilities to discover 9 different patterns over a grid of 130 cells.

IV. RESULTS

The most meaningful patterns found with SOM are described in fig. 4 and in tab. 1, where it is possible to compare, together with cluster also the bar trend in one representative cell of the GPR grid, the Standard Deviation (SD) inside each GPR cell of the DEM, of the thermograms t0, t8' and t16' and of the raster t0-t8', t8'-t16', t0-t16'. In particular some of the most significative patterns are:
-   Cluster 1, where there is a high amplitude in GPR. This is due to a high reflectance probably caused by gaps, unevenness, cracks. This is confirmed also from the high values of the SD t8-t16' and of the SD t0-t16'
-   At the opposite Cluster 4 are probably areas more safe at the different deepness, confirmed by the diagram bars, by the DEM and the MIRT variations.

Table 1. Diagram bar, Standard deviation of the DRM, the three IRT thermograms considered and the difference between thermograms, inside each SOM cluster.

Cluster	Elements No	Bars ■ i at depth 0-1-2-3-4-5cm ■ i at depth 0.2-1.2-2.2-3.2-4.2cm ■ i at depth 0.4-1.4-2.4-3.4-4.4cm ■ i at depth 0.6-1.6-2.6-3.6-4.6cm ■ i at depth 0.8-1.8-2.8-3.8-4.8cm	SD DEM	SD t0	SD t8'	SD t16'	SD t0-t8'	SD t8-t16'	SD t0-t16'
1	56		Low	Low-Medium	Low-Medium	Medium	Low	Medium-High	Medium-High
2	10		High	High	High	High	High	High	High
3	15		Medium	Low	Low	Low-Medium	Medium	Medium-High	Medium
4	12		Low	Low	Low	Low	Low	Low	Low
5	14		Low-Medium	Medium-High	Medium-High	Medium-High	Low-Medium	Medium	Medium-High
6	11		Medium-High	Medium-High	Medium	Medium-High	Medium-High	Low-Medium	Medium
7	7		Low-Medium	Low-Medium	Low-Medium	Medium	Low-Medium	Low-Medium	Low
8	7		Medium-High	Medium	Medium-High	Medium-High	Medium-High	Medium	Low-Medium

| 9 | 4 | | Medium | Medium | Medium | Medium | Medium | Low | Low-Medium |

Figure 4. Results of the SOM (in the corner at the top-right).

V. FINAL DISCUSSION AND OUTLOOKS

In this paper we studied only the behaviour of GPR data, treated in a particular "geographic" scale with a particular spatial resolution. Even if a first trial, it let us guess new opportunities in the field of GPR interpretation. In fact geovisual analytics could constitute an effective Support Decision System to find decay patterns or particular anomalies meaning a problem under the surface of the fresco. The understanding of these data would come from a more analytical approach and not only by personal experience.

- Some open questions that could be tackled in further studies:
  1. Could visual analytics be effective by improving spatial resolution and/or which is the best spatial resolution (by considering both the value and the shape of pixel) for the analysis?
  2. Could they help us by analyzing not only the GPR data, but also an heterogeneous dataset containing MIRT, DSM or in case other information?
  3. How do visual analytics considers border effects if there exist any?

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