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AN INTERDISCIPLINARY FIELD CAMPAIGN FOR MODERN INVESTIGATION AND MONITORING IN PRESERVATION AND RESTORATION

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Abstract

This paper describes the good practice demonstrations and results of an open restoration site organized at Tismana Monastery, Gorj County. For about two weeks an interdisciplinary team consisted in student restorers and research scientists joined their efforts to apply and demonstrate a model of good practice in modern restoration. This model is based on the infrastructure offered by the mobile laboratory ART4ART deployed on-site. The activities comprised non-invasive and non-destructive investigations and monitoring in several working areas with various casuistry. The list of modern technology used includes: laser induced fluorescence, multispectral imaging, 3D laser scanning, digital microscopy and ground penetrating RADAR. A long term monitoring of the microclimate (temperature and relative humidity) was also maintained. The purpose of the mixed working groups was to exchange knowledge between restorers and scientists through on-site course-like presentations and demonstrations. There were also tested the possibilities of Internet accessibility to infrastructure in areas with low or no GSM signal. In this paper will also be presented some of the results and the conclusion after this experience.

Keywords: *Artwork conservation-restoration; Mobile laboratory; Open laboratory; On site courses; Open restoration site*

Introduction

Today we are witnessing an increasing speed of technological advances in a wide range of disciplines. Along with each new development there appeared a need to link disciplinary fields in order to obtain better, faster and more efficient results and answers. Recent studies [1] are defining interdisciplinary research as any study or group of studies undertaken by scholars from two or more distinct scientific disciplines. This kind of research should be based on a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any particular field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process [2-5].

This study is related to a wider ongoing project which aims to emphasize of an advanced research infrastructure that allows:

- stratigraphic physic-chemical characterization at atomic and elemental level of the surface of an object by using non-contact, non or micro-invasive methods;

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- interpretation of experimental data obtained by laser spectroscopy (particularly by LIBS) in order to get a chemical quantitative characterization;
- identifying the heterogeneity in objects with complex structures, with regard to the maximum protection of the object, by remote point by point scanning of the object.
- know-how transfer to the current casuistry seen in the restoration of monuments, art gallery items, artwork warehouses, collections etc., also to the casuistry specific to the archaeological and restoration sites.

This project is innovative because it proposes the development of the first scientific investigation laboratory for conservation-restoration that can be accessible online. This accessibility opens new perspectives, such as the live remote visualization of the working procedures, the monitoring of intervention project compliance. It also allows the request/offer of consultation for operation regime optimization (depending on the case) or for the primary interpretation of exceptional or atypical results.

We should stress that the project dramatically reduces the time and effort usually made by the research groups to transfer the knowledge or technology to the potential users, thus directly benefitting of the heritage. Unquestionably the research results generated by modern working services and facilities (equipment and methods), in the first stage, are not correctly appreciated. To be widespread, these methods should surpass the cost prejudices, and then the "known ways" prejudices. Therefore, if they are disseminated in the academic media during the validation and testing stages, promoted to the young groups, the new results will not be considered inaccessible anymore, but will even be requested. To this point we must add the efficiency improvement of the research activity, by increasing the operation time of the state of the art infrastructure and by implementing the newest results.

The online opening of an advanced laboratory, facilitating the access to the infrastructure, whether it is the lab itself or the on-site mobile laboratory, is a form of support for research, of continuous professional training and major development of the means of academic professional training. It is well known that the multiplication of research labs (especially those that contain original setups in continuous development) are not justified, but equally known is the tendency of certification of research through testing in multidisciplinary consortia. Consequently this project presents the preliminary results, well defined, of the first project of its kind in Europe.

The mobile laboratory ART4ART in its actual state is the result of several interdisciplinary research projects. Its concept is based on the selection of the techniques that create a new concept of art restoration with no sampling assay or preparation and with real-time results delivery [6]. With a modular configuration it can be equipped with a wide range of investigation, or monitoring (and even intervention) technologies that are aimed to complement the work of the conservation-restoration experts, archaeologists or archivists. The mobile laboratory allows all the equipment to be set up on site in designated working areas. We will not stress on the advantages and all the possibilities the mobile laboratory can offer on site.

This study was aimed to test the new capabilities of the mobile laboratory as an open laboratory. The upgrades consist in a secured network for data transfer between investigation equipment computers; an online platform for data management; IP camera support for online courses, streamed live from the working sites. For this purpose we organized a two-week field campaign at the Tismana Monastery (a historical monument, class A of importance in Romania) in collaboration with a team of restorers.

The mobile laboratory was deployed at the entrance of the monastery and all the investigation equipment was installed in each working area. Overall there were a total of 7 working areas: in the narthex ground level (LDV), the first level of scaffolding (LIF, multispectral imaging, digital microscopy) and the top level (3D laser scanning), the archives (digital microscopy), in the warehouse (LDV, digital microscopy, multispectral imaging), the nave (3D laser scanning) and the surroundings of the church (3D laser scanning of the church exterior walls, ground penetrating RADAR). Each working area was assigned to a team of technical operators and student restorers. Thus, they had to cooperate and exchange knowledge, complementing each other, following a model of good practice in modern restoration.

Although there were many areas investigated, in this paper we will be present only some of the results, in order to draw the bigger picture of what this field campaign meant.

Multispectral imaging

Multispectral imaging is a portable, non-invasive and non-destructive technique used in the field of cultural heritage in the process of documentation and investigation [7]. This technique reunites several modes of recording. The basic principle of this imaging analysis is given by the characteristic properties of each material to absorb and to reflect electromagnetic radiation, on certain wavelengths.

This technique was applied in four different cases, all of them located in the narthex of the Tismana Monastery's church, as follows: The Annunciation scene, The Martyrdom of the forty martyrs of Sebaste, Saint Martyr Euphemia (all located on the eastern wall), and the tympanum, which corresponded to the narthex entrance, decorated with a representation of the Virgin and Child (the western wall).

For each scene seven different acquisition modes were performed, namely: Visible Color, Visible Black & White, NIR 1, NIR 2, UV reflection, UV fluorescence and False Color Infrared.

The most interesting details were outlined in the case of The Annunciation and Saint Martyr Euphemia, scenes located very near to one another.

In order to obtain high resolution images, defined by a proper quality for our study, the scene was divided into eighteen sections, grouped in three columns, each having six rows.

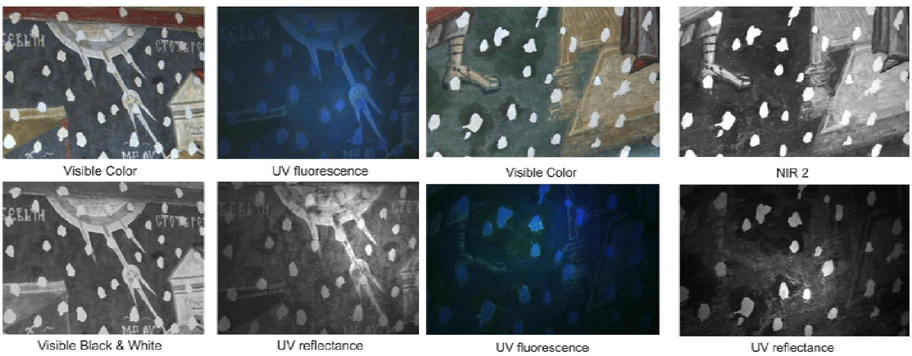

Fig. 1. Comparison of different recording modes used on the Annunciation scene

In UV reflectance mode we noticed two types of deposits. The first type is characterized by its staining aspect (these deposits are located next to the gaps produced by the hammer), while the others, small in size, with fragmented aspect and dark tonality, are disposed unevenly on the surface of the paint layer. It is important to notice that this scene was already cleaned during the restoration process. Both types of deposits, undetectable in the visible mode, are characterized by their high absorbance of UV radiation, a fact which may indicate the presence of an organic material. In this regarsd, additional investigations are required in order to confirm this supposition.

In UV fluorescence mode yellowish fluorescent halos were highlighted (they are not detectable in the visible spectrum). This fact indicates the presence of a material located at the surface of the paint layer, a material which is characterized by the property of being fluorescent when excited with UV radiation. By comparing and analyzing the multispectral recordings with the coordinator-restorer we concluded that these halos were produced by a historical restoration intervention (dating from the second half of the 20th century) in which they used an organic consolidant, based on calcium casein.

In the second case, **the UV reflectance mode** revealed a high UV radiation absorbance of the stains located next to the restored lacunae.

In the UV fluorescence mode it is emphasized a yellowish fluorescence of the stains. Like in the previous case (corresponding to the upper part of the central area) these stains were produced during an historical intervention, where it was used calcium casein as consolidant for the mural painting.

In the second case, the stains were highlighted in both Visible and UV domains, a fact which could be explained by the high concentration of consolidant on the surface.

The NIR 2 (near infrared) acquisition mode enables an ideal means to document the chromatic integration stage. This intervention, which is part of the restoration process, was performed in the case of paint layer lacunae (gaps) – with water based colors (reversible intervention).

Digital Microscopy

The microscopy investigations were carried out, following procedures implemented in past experiments [8], on 17 areas of interest, which were selected either after multispectral investigations, or due to some interesting visible characteristics. Two of these areas are presented in figures 2 and 3.

Fig. 2. Microscopic images (25X) for one of the filled gaps

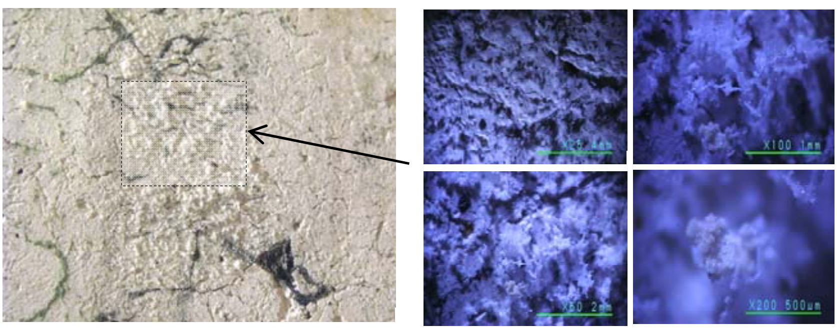

Fig. 3. Efflorescent salts – microscopy images at 25X, 50X, 100X and 200X magnification

The concentration of the salts present was determined by using a conductivity detector with a temperature sensor, needed for the calibration of the acquired data at standards' temperatures. The analyses were made on a surface of 1250mm^2 and the salt concentration was calculated at 1400mg/m^2.

Laser induced fluorescence investigations

In the narthex on the first level of the scaffolding we chosen several scenes from the murals to be investigated with LIF. On the eastern wall we chose the St. Euphimia scene (Fig. 4).

Fig. 4. St. Euphimia scene selection

The bottom of the region of interest is located at 2 meters above the scaffolding level floor. The LIF system had to be installed at a height of 1.5m about floor level and at 1.2m from the surface of the mural. The investigations had to be done during the night in order to have the required darkness for fluorescence investigations. Several fluorescence spectra were recorded on special areas as indicated by restorer experts. Unfortunately the low energy laser (1.25μJ/pulse at 266nm) was not enough to obtain a good and strong fluorescence signal from the murals.

Monitoring processes

Microclimate

The positioning of the microclimate sensors (Fig. 5) aimed to measure the temperature and the relative humidity in different areas of the church. Seventeen synchronized sensors were used for monitoring with a recording frequency of 30 minutes. The data acquisition covered the period October 2013 – June 2014, obtaining a total of approximately 160,000 records. Minimum and maximum values of the two phenomena measured by each sensor are shown in Table 1 and Figure 5.

After analyzing the data we observed that all the sensors, except for one (S0 – from the temperature graph) show the same variation curve. Temperature variations were of 15-18°C during the 8 months of monitoring.

The most important factor leading to the degradation of mural paintings is humidity. During the monitoring period high values, reaching 87.5%, were recorded. If high values of humidity are maintained for a long period of time salt migration and recrystallization phenomena may occur, decreasing the structural integrity of the color layer and causing separations in the form of exfoliation. Also high values of humidity along with other factors can lead to biological attacks (emergence and growth of microorganisms).

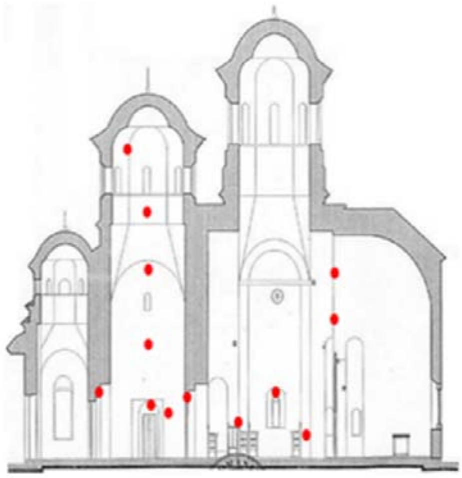

Fig. 5. Microclimate sensors positions

The data obtained from monitoring the Church of Tismana Monastery revealed large temperature variations. Negative values of temperature and very high humidity inside the building are factors that can lead to degradation.

Table 1. Minimum and maximum values recorded by each sensor

Sensor ID		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Temp. [°C]	*MIN*	-0.5	7.5	7	7.5	7	6	7	7	7.5	7.5	7	7.5	7.5	7.5	7	7	7
	MAX	24	25	27.5	24	22	22.5	24	24	24	24	24	23.5	23.5	23.5	25	23.5	24
R.H. [%]	*MIN*	34	26	25	30.5	37	49	29.5	30.5	30.5	30.5	30.5	30.5	30.5	31	30.5	30	29.5
	MAX	87.5	70.5	73	70.5	74	80.5	63.5	62.5	62.5	62.5	62.5	62.5	62.5	62	62.5	63.5	62.5

Ground penetrating RADAR

In the Tismana campaign we also made investigations with the ground penetrating radar, in order to identify possible soil discontinuities around the church. This non-invasive equipment's operating principle is the emission of electromagnetic waves towards the ground, followed by recording and studying of the radiation reflected by the discontinuities encountered [9].

As seen in our past experiments, but also in other case studies [10-18] using similar technology, the recordings where made using two antennas with different central frequency, 500 and 800MHz. The frequency affects the depth of penetration of radiation inversely and directly proportional the vertical resolution of scanning.

Three were taken three concentric turns of recordings were made at increasing distances from the church walls (Fig. 6), with each antenna, thus obtaining a number of 110 measurements. During scanning we observed that in the N-E side of the church there appeared more perturbations of the wave propagation, this leading to the decision of making another 30 investigations in this area, to gather more detailed data. After the processing and interpretation of all data, we noticed discontinuities of the soil dielectric characteristics and the appearance of some reflections in the shape of hyperbolas. The reflections represent the presence of some buried structures in the soil. There is a tendency of uniformity of the soil from the depth of 0.9 meters in almost all radargrams. The discontinuities that can be observed up to this depth may be due to older excavations carried around the church.

Video transmissions and teleoperation tests

The GSM signal is very poor in the area of the Tismana Monastery as it is positioned in a valley between the mountains. In order to operate remotely through the Internet we needed a high bandwidth [19]. Around the site we identified a few areas with better GSM signal. The strongest signal was detected in the church's bell tower, on the third level of the scaffolding (7.5 meters above ground, 5 meters above the working area). Therefore it was there that we installed the Internet modem. We made connection speed tests for download and upload through both cable and wireless in different spots of the working area. In the table below we listed the connection speed recorded in the working areas. Outside the church GSM signal could not be detected.

Table 2. Internet speeds within the network

Area	Mode	Ping [ms]	Download [Mbps]	Upload [Mbps]
Level 1	Wireless	56	1.90	0.46
Ground level	Wireless	51	1.20	0.31
Level 1	Cable (5 m)	130	1.47	0.43

Due to the low upload speed, the tele-operation tests from outside the network proved to be useless. Instead we made tests within the network in different case scenarios. The device used in the tele-operation tests was the LIF (Laser Induced Fluorescence) setup. The user-friendly graphic interface of the system receives commands from the operator that are sent as text instructions to the operating elements of the device. At the same time the system gives the user a feedback (text data, images, live video images) of its status.

Likewise, the video transmission for the online courses tests was measured within the network. The IP camera was installed in a working area where one of the operators presented a short course and demonstration of one of the investigation devices. Remote users were able to view the demonstration within the same network on different devices (personal computers, tablets or smartphones).

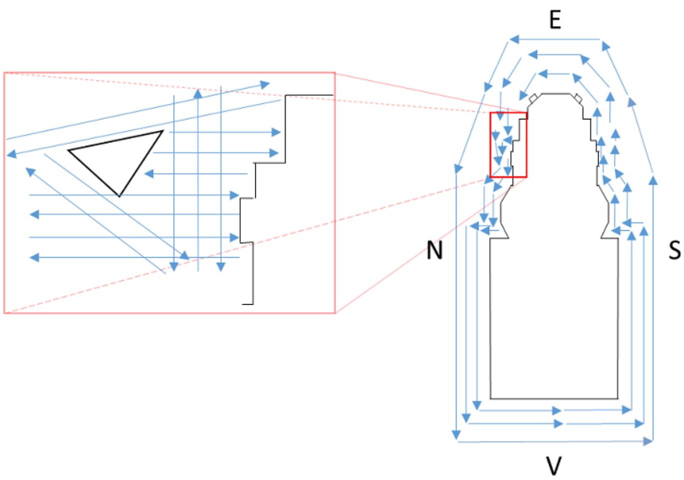

Fig. 6. Map of the recording tracks

Fig. 7. 3D scan section

3D laser scanning

Scanning the interior of the Tismana Church is an activity that began in 2010 by measurements made in the narthex of the church and altar. Both sets of recordings were made before mural painting restoration [20]. Nevertheless we observed that some areas were not digitally captured and found two reasons for thoese errors. Firstly, the low reflectivity of the walls at the wavelength of laser radiation (690nm at 15mW power), absorbing much of the used light, so the reflected radiation, which carries the information on the relief of the surface, did not have sufficient quantity to be detected using by the 3D scanner.

In addition to the pre-intervention low reflectivity of the mural paintings there was the height of the perpendicular walls, which generated low incidence angles and thus, the reflected radiation was not detected by the 3D scanner.

The scanning system uses a principle of flight time, with one laser, so it cannot record RGB information about the scene, but only the object's reflectivity at the wavelength used. In the illustration you can observe the first 8 meters corresponding to the narthex painting could be recorded in gray tones (reflectivity at the wavelength of the radiation), unlike the upper areas where they could only record, in the best case, the relief of the surface.

These areas were recorded in a second set of measurements, during the campaign in July 2014, mase for the upper areas by using the scaffold, while the lower areas benefitted by the high reflectivity of the already restored walls.

Conclusions

One objective of this field campaign was to test, identify and emphasize critical elements in the ART4ART mobile laboratory proposed workflow. The chosen location had all the needed ingredients for such tests, such as the scaffolding with working areas on different levels, or the low GSM signal (for tele--operation and video transmissions) and offered a great variety of material types to be investigated with most of the mobile laboratory devices. The main conclusion of these tests was that in situations with low GSM signal it is mandatory to use an amplifying antenna and as for the infrastructure accessibility, it would be recommended to have available at least one static IP address and a router to support the connection for each of the terminals that are needed to be shared over the Internet.

Another objective had an educational purpose, regarding the familiarization of the restorer students with the modern technology they can use nowadays, to complement their activities. The created workgroups, consisting in restorer students and technical operators, performed several tasks (over several days and in different locations) that covered most of the operative capabilities of the mobile laboratory. Each investigation/monitoring technique had at least one main demonstration for the restorers as an interactive course.

The last day of the campaign was reserved for the results presentation and discussions regarding the knowledge acquired by the students and the tested elements of the mobile laboratory.

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