MONITORING OF THE CONSERVATION STATE OF THE INTERNAL WALL SURFACES OF ROOM WITH GOLDEN VAULT IN THE DOMUS AUREA

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Abstract

This project describes the monitoring campaign developed jointly with the Archaeological Superintendence of Rome and performed *in situ* with the collaboration of Konica Minolta Sensing Europe, in order to verify the actual conservation state of the internal wall surfaces of the Room with Golden Vault in the *Domus Aurea* in Rome. Particularly, the main aim of this work was to evaluate the problems caused by aggressive environmental conditions (combination of low air temperature and high relative humidity).

During this survey, characterized by the integrated use of two and three-dimensional techniques, the environmental conditions were carefully monitored.

Reference sample regions of the vault were acquired by means of the 3D laser scanner Konica Minolta Vivid 9i (optical triangulation-based) that allows capturing morphological details of the stucco decorations with a good resolution. Moreover, each detailed scan was supplied with related high resolution images taken by a digital reflex camera Olympus E-510 rigidly connected to the scanner. In Cultural Heritage monitoring applications it is important to integrate the data acquired with different instruments and techniques. Therefore, by this methodological approach, it has been possible to integrate both two and three dimensional data by the projection of the acquired images on the corresponding digital model. In order to complete the cognitive framework of the vault, systematic measures of spectrophotometry by means of the portable spectrophotometer Konica Minolta CM-2660d were also carried out.

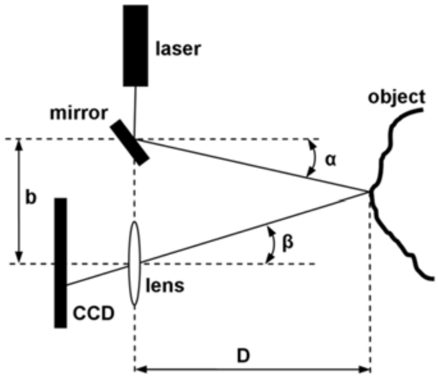
The digital data, collected and elaborated by this monitoring campaign, allowed to create a database of morphological information, high resolution digital images, colorimetric values and reflectance curves that may be used in the future as reference data to periodically monitor the conservation state of the surfaces.

1. Type of technology/methodology

In the monitoring campaign of the Golden Vault of the *Domus Aurea*, different technologies were employed in order to achieve a first cognitive framework of this monumental room.

The main aim of this project is the 3D digital reconstruction of the vault by capturing all the morphological details of the stucco decorations to create a reference database (1), (2), (3), (4).

For this purpose, the decorated surfaces of the vault were scanned by means of Konica Minolta Vivid 9i. This non-contact laser scanner, based on optical triangulation measurement method, projects thin laser stripes onto the surface of the object. The laser beam is then reflected and recorded by a CCD (charge-coupled device) sensor so that the distance D of the points on the surface can be evaluated because the relative position between emitter and sensor is known (baseline b), as shown in Figure 1.



$$D = \frac{b}{\tan(\alpha + \beta)}$$

Figure 1. Working principle of optical triangulated based 3D laser scanner.

The Konica Minolta Vivid 9i, working with a wavelength of 690 nm, is 412 mm high, 221 mm wide, 282 mm deep and weighs approximately 15 kg. It can be mounted on a tripod to find better position and orientation during the acquisition. The scanner is provided with three different, interchangeable lenses: TELE, MIDDLE and WIDE. These lenses can be selected and attached to the scanner according to the size and distance of the object to be scanned. The focal distance (f) for the TELE lens is 25 mm, for MIDDLE is 14 mm and for WIDE is 8 mm. The closer the object is to the scanner, the greater the measurement accuracy. It can work in a variable measurement range with a distance to the object from 0.6 to 1.0 m (in Standard Mode) and from 0.5 to 2.5 m (in Extended Mode). The measuring time is 2.5 s and 307,200 geometrical points can be captured at each scan.

The post-processing of the data collected from the 3D scans (5) – registration and merging of the point clouds, simplification and editing of the digital model – can be carried out with the Polygon Editing Tool (PET 2.21 ®, Konica Minolta Sensing Inc.). Therefore, this software for 3D scan data processing can convert point cloud data into a final polygonal mesh model.

Moreover, the Konica Minolta Vivid 9i allows collecting both geometric and colour data. For each scan, the corresponding texture (640*480 pixels) can be also captured and edited by Polygon Editing Tool to obtain a final textured model.

However, due to the well known continuous request of Cultural Heritage world to have more and more detailed 2D images supporting 3D geometric data, an innovative methodological approach was followed. At the same time of the scanning acquisition an *ad hoc* photographic campaign was also conducted. For each scan, the related high resolution image was provided by a digital reflex camera Olympus E-510 (10 Mega pixels) coupled to the scanner.

Aim of this process is to replace the original texture (640*480 pixels), directly taken during the scan, with the higher resolution image of the digital camera on the corresponding 3D model. This operation improves the quality of the final 3D model resulting by the integration of both two and three dimensional data.

Since the *Replace Texture* function of the Polygon Editing Tool software allows replacing the original texture with a texture having same aspect ratio, for each scan, a perfectly matching texture, taken by the digital camera, is needed for this replacing operation.

To achieve this result a customized device was designed and produced for rigidly connecting the digital camera to the scanner. In particular, this device should be able to guarantee the correct alignment of the optics of both camera and scanner. Therefore, after mounting the objective Olympus Zuiko Digital, (14-54 mm, 1:2.8-3.5), laboratory tests allowed setting the correct optical parameters of the digital camera, such as the focal length of the zoom, to acquire the same image recorded by the scanner.

Finally, systematic measures of spectrophotometry (reflectance spectra and the related colour data) by means of the portable spectrophotometer Konica Minolta CM-2660d were also carried out and elaborated with its software SpectraMagic™ (6), (7), (8), (9), (10), (11), (12). Spectra measurements, taken having care to place the device reading head in planar contact with the surface, are characterized essentially by: diffuse reflectance on homogeneous spot areas, d/8° geometry, wavelength range between 360 and 740 nm (1 nm = 10^{-9} m), wavelength pitch 10 nm.

2. Type of parameter that is preferentially measured and of material monitored

In order to verify the actual conservation state of the Golden Vault the internal wall surfaces were monitored during the campaign. In particular, some reference areas characterized by deterioration, salt emerged on surface and graffiti were selected (Figure 2).

Figure 2. Reference areas characterized by deterioration (left), salt emerged on surface (center) and graffiti (right).

For the reference areas the scan data were integrated with high resolution images (Figure 3), colorimetric values and reflectance curves.

Figure 3. Shaded model of a reference area (left), textured model (center) and corresponding high resolution image (right).

3. In situ application

The *Domus Aurea* (13), whose construction started at 64 A.D. by means of the work of the architects *Severus* and *Celer* on the *Domus Transitoria* ruins, was commissioned by Nero as his beautiful residence. It extended on an area much greater (about 100 hectares) than the currently accessible area near the Oppian hill (a building cluster of about 150 rooms and in its East section the room with Golden Vault is placed, monitored in this project). In this palace the architectural and pictorial elements were harmoniously integrated, the last ones created by the artist *Fabullus*, who realized the ornaments of the wide rooms with frescoes and stuccoes belonging to the fourth Pompeian style. After the Nero death, only the pavilion of the Oppian Hill survived and from 104 A.D. it was filled with earth in order to serve as foundations for the construction of Trajan thermal baths. When these were left, during Middle Ages the place was cultivated with gardens and vineyards, until, in the Renaissance, the *Domus Aurea* buried ruins were progressively discovered again. The troubled history and the great dimensions of this ancient palace covered with earth point out emergency conservative problems, as e.g. static safety of the structures, advanced degradation state for the pictures and stuccoes, due to penetration of the rainwater from the ground of the upper gardens and the conditions of the rooms with about 10°C and nearly 100% of humidity. This difficult situation has been faced by means of a complex program of studies, researches and restorations, in particular under the leading management of the Archaelogical Superintendence of Rome and of the Istituto Centrale per il Restauro.

Figure 4. The Golden Vault.

In this research project, the methodological approach tested in laboratory to combine 3D e 2D data was applied *in situ* to obtain a high resolution textured 3D digital model of the Golden Vault (Figure 4).

During the first monitoring campaign, a reference region of the vault was acquired by means of the 3D laser scanner Konica Minolta Vivid 9i. Each scan was also supplied with the related high resolution image taken by the digital reflex camera Olympus E-510 rigidly connected to the scanner by the customized device properly designed and produced (Figure 5).

Figure 5. Left: Konica Minolta Vivid 9i. Right: Olympus E-510 rigidly connected to the scanner.

Moreover, professional illuminators Lupo Starlight 2X55W and Spot Daylight 800, both with a temperature colour of 5400°K, were used during the photographic survey, settling accordingly the white balance of the camera. This was necessary to capture the correct chromatisms of the decorations, perceived in a distorted way due to the kind of artificial illumination of the room studied in order to inhibit the microbiological attacks.

On the ground of a first examination of the vault, 30 sample regions have been chosen and then subjected to a spectrophotometric analysis in diffuse reflectance. The main goal of this campaign has been to start with a periodic monitoring (e.g. once in a year) of the vault surface conservation state, so to create a database formed by the reflectance curves from the near UV to the near IR and by the related colorimetric data.

All the measurements, some of them not easy to obtain due to presence of stuccoes with overhangs, are so characterized: specular component included (SCI), UV component of the light source included (UV 100%), homogeneous spot areas of 8 mm in diameter (MAV: Medium Target Mask), each datum is the average of three measurements, D_{65} is the illuminant condition (day-illuminant whose apparent colour temperature is 6504 K), 10° is the observer condition (standard CIE 1964 observer). Here only a few data are showed as illustration, in particular related to two regions where red hues are present (Figure 6): in the color space CIELAB 1976 for the samples n. 1 and n. 7 one has respectively L*=39.78, a*=17.12, b*=11.99 and L*=47.50, a*=17.26, b*=12.64.

Figure 6. Reference areas analyzed by means of the spectrophotometer Konica Minolta CM-2660d: sample n. 1 on the left and sample n. 7 on the right.

The related curves of the reflectance percentage (R%) versus wavelength (λ) are in Figure 7: on the whole the behavior appears the same, in particular in the region where the spectra are rapidly growing, while the absolute values are greater for the sample n. 7. These facts could be due to varying dilution of the same red pigments, probably cinnabar (HgS), as a comparison with reference spectra in the wide database at http://fors.ifac.cnr.it seems to suggest. However, in order to verify this conclusion, other analyses also destructive are necessary.

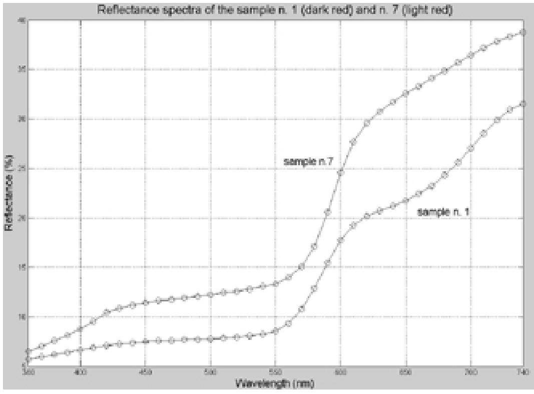


Figure 7. Reflectance curves for the samples n. 1 and n. 7.

Finally, during this survey, the environmental conditions were carefully monitored to evaluate the problems caused by the aggressive combination of low air temperature and high relative humidity. The monitoring of these conditions gave a temperature range between 12.5 and 13.1°C plus a mean value of 98.58% for the relative humidity.

4. Evaluation of methodology/technology used

The elaboration of the data collected during the monitoring survey of the Golden Vault, allowed to underline some important results.

Firstly, the methodological approach followed to improve the quality of the textured 3D digital models is described. This result was obtained by replacing the original texture (640*480), directly taken during the scan, with the texture having same aspect ratio but with a 4x higher resolution (2560*1920), taken by the digital camera, rigidly connected to the scanner.

However, due to the not perfect alignment of the digital camera with respect to the scanner, some additional editing operations were needed to perfectly match the two images (low and high resolution). The reason of this misalignment was principally due to the position of the target that is closer to the digital camera than to the scanner. The alignment was also affected by errors in the orientation of the camera.

Therefore, before operating the *Replace Texture* function of the Polygon Editing Tool software, the high resolution images were edited by Photoshop software to reach the perfect matching with the corresponding low resolution textures. The 4x higher resolution textures (2560*1920) were moved and resized with respect to the original ones (640*480), to find the best matching. The non correct areas, limited to a maximum of 10% of the whole texture, were painted in red for an easy identification (Figure 8).

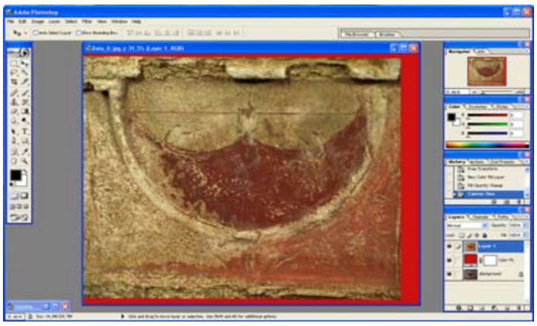


Figure 8. The high resolution textures (2560*1920) edited to be perfectly matching to the original one (640*480): the red area is induced by the misalignment of the digital camera with respect to the scanner.

After replacing the textures on the 3D digital model, the triangular faces of the mesh with erroneous colour information, clearly identified by the red areas, were deleted. Due to the wide overlapping regions between the connected point clouds, the final model was not affected at all by this loss of data (Figure 9). Moreover, due to the control of the colour temperature (5400°K) during the *ad hoc* photographic campaign, the final 3D textured model provides better results also in terms of chromatisms.

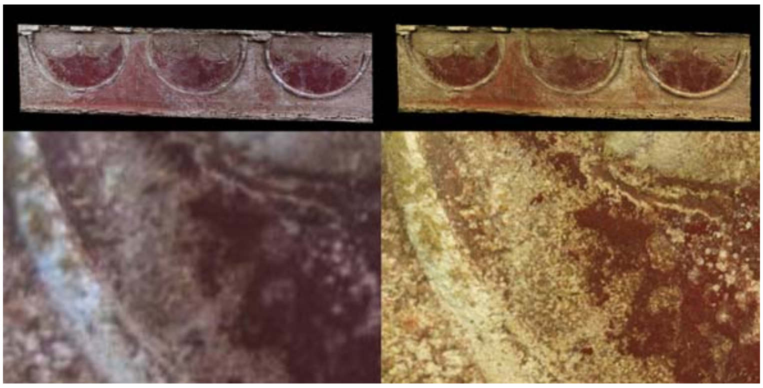


Figure 9. Left: 3D model with the original textures (640*480). Right: 3D model after replacing the original textures with the higher resolution ones (2560*1920).

Actually, the designed tool to rigidly connect the digital camera to the scanner is just a first prototype. This device should be optimized in order to decrease the errors due to the not perfect alignment of the digital camera with respect to the scanner. The data collected during the in situ application could be a useful guide to improve this methodological approach. In particular, by comparing the corresponding low and high resolution images, it should be possible to better register the digital camera to the scanner.

Another innovative result was achieved by comparing the 3D models of a reference region acquired before and after the cleaning treatment to remove the salt emerged on the surface (Figure 10).

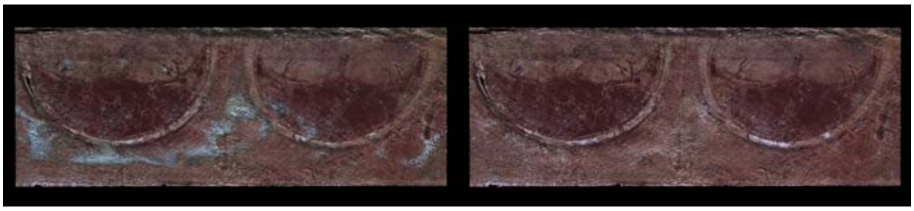


Figure 10. 3D textured models of a reference area acquired before and after the cleaning treatment to remove the salt emerged on the surface.

The presence of salt on the surfaces of the Golden Vault is due to the aggressive environmental conditions (combination of low air temperature and high relative humidity). Therefore, the restores involved in the maintenance of this building, have to periodically carry out cleaning campaigns to safeguard the decorations of the vault. The results of these maintenance operations can be clearly highlighted by the analysis of the 3D digital models.

The first step of this approach involved the registration of 3D models representing the reference region before and after the cleaning treatment (Figure 11-Left). Then, the analysis of the shell-shell deviation between the two registered models was performed. In particular, the parts depicted in white (greyscale map) clearly identified the areas in which the salt was emerged (Figure 11-Right).

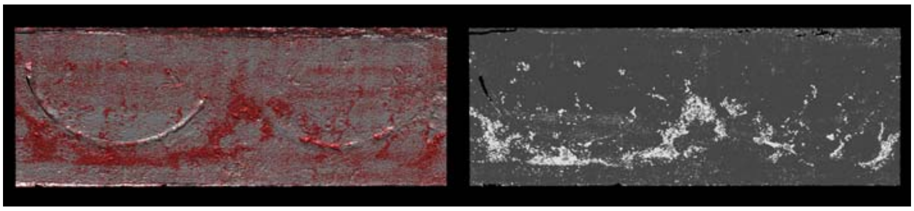


Figure 11. Left: registration of the 3D models before and after the cleaning treatment. Right: shell-shell deviation analysis by grayscale map.

Therefore, the periodically monitoring of the surface of the Golden Vault by means of scanning technologies should supply useful information on the preferential areas for the formation of salt deposits and on their amount.

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