

HIGH RESOLUTION MORPHOMETRIC RECONSTRUCTION OF MULTIMATERIAL TILES OF AN ANCIENT MOSAIC

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ABSTRACT:

Actually scientific research in the human disciplines has been looking with growing interest towards virtual reconstruction of cultural heritage objects and handiworks, and in particular towards those which are dismembered or broken, with the specific aim of virtual anastylosis and virtual conservation of them. In this paper, we present the virtual reconstruction of a mosaic fragment, from the Abbey of Santa Giustina, Padova, Italy: the work, concerning the first part of a larger project of digital anastylosis of the mosaic itself, investigates the geometry of the fragment from single tesserae of different tiles in order to study the single mosaic structure and to reconstruct the whole mosaic. This work shows the laser scanner acquisition of a multi-material objects, requiring a good planning of the scanning phase, underlines all main problems in the acquisition of high reflectance materials and stresses out the possibility to reconstruct a whole model, allowing to measure all metrical features of tiles in a virtual space (size, volume, depth of alteration strata...) without any invasive contact.

1. INTRODUCTION

The mosaic fragments comes from the Abbey of Santa Giustina, Padova, Italy; this church is a monumental abbey which was founded in the V century, in memory of Santa Giustina, who died two hundred years before during the persecution of the early Christians by the Roman empire and to whom local people were very respectful. The fortune of the church allowed its enlargement during the centuries and several italic artists participated in its artistic and cultural enrichment with frescoes, paintings and wall and pavement mosaics.

The mosaic broke into a large number of fragments, including the tiles and part of the mortar on the wall, together with 1000 single tiles which fell down without mortar. The object here considered is a fragment with 30 tiles of 1 cm² circa. The tiles are very different one from the other, differing mainly in material, from natural colored stones to glassy smalti; some of them are covered with a golden lamella (cartella) and others show an iridescent altered surface strata.

These observations introduce the very first challenge to acquisition: the miscellaneous surface of the fragment implies a variable sensitivity of the fragment to the laser light and thus a variable detection of the back-signal from the scanner. The single tiles investigated are very small pieces of glassy smalti and have a high surface reflectance, implying a high dispersion of the laser signal from the tile to the detector.

All data, around 20 acquisitions performed with telescopic lens, which means around 70 MB, were post-processed in Polygon Editing Tool, proprietary Konica Minolta software. The round scans were registered all together through a rotational axis to which refer. The large amount of data along the sides of the

tiles helped their registration with the oblique scans of the mosaic surface: such abundance had anyway to be decimated in the following step, in order to facilitate the merging of all scans and to reduce the data redundancy. The acquisition and following alignment of the bottom of the fragment, including mortar only, allowed the complete virtual reconstruction of the piece, a water-tight digital model which can be exported in all CAD and design modelling software's. Then, the model was textured with photographic images making it very photorealistic.

In this paper the results about the acquisition of peculiar tesserae with different laser scanners are presented. With the Konica Minolta one, 10 scans were necessary to cover the entire surface and make a whole virtual model of the tessera. The Coordinate-Measuring Machine CMM was used in the acquisition of the faces which were thought to be exposed in the mosaic, at the maximum available resolution. Data were post-processed in RapidForm 2004 software, in which the point cloud was meshed and gave rise to a continuous virtual surface

2. LASER INSTRUMENTATION AND SCANNING

2.1 Stripe laser

The acquisition of the morphology of the fragment was carried through Konica Minolta Vivid 910 digitizer, a triangulation stripe laser scanner with a maximum resolution of 0.17 mm (under best environmental conditions) and provided with three different lenses:

1. Tele: focal length = 25 mm, max res. = 0,039 mm;
2. Middle: focal length = 14 mm, max res. = 0,068 mm;
3. Wide: focal length = 8 mm, max res. = 0,090 mm.

It is suitable for small and middle range objects and very useful in the morphometric acquisition of cultural heritage objects, for in situ measurements also. It offers the best behaviour for distances in the range $0,6 \div 1,2$ m. In this work, due the small dimensions of tesserae (about 1×1 cm), the Tele lens was used at the minimum acquisition distance with a scanned area of 111×84 mm; the geometric resolution was $0,17$ mm along X and Y directions as expected.

2.2 CMM Machine

For the acquisition of the single tessera, a Coordinate-Measuring Machine CMM was used too; it is a custom measurement machine using a point laser and featuring a maximum resolution of 0.012 mm. This instrument is for laboratory analysis only and is more useable for almost plane surfaces than structured objects. The laser head is a Wolf&Beck OTM3A-50/h/PC, with an average power of 3.5 mW in 3B security class. The complete instrument is placed on 10 cm thickness basement, which is mounted on an optical bench in order to minimize the vibrations. The surface scanning is performed specifying the start and stop points, the rows number and the points number of each row; the resulting route is like a square wave.

2.3 Scanning

The fragment was put in the middle of the rotating stage to facilitate the covering of the entire surface; new scans was performed every 30° , acquiring the mortar basement and lateral views of the tessera.

The lateral acquisition was even made more difficult by the fact that cusps (like the straight edges of the tiles) help dispersing the signal giving no feedback – no points – of the surrounding areas. The acquisition of the upper side was very challenging because of its multi-material nature and sometimes required the operator to scan the same view of the object even more than twice, with different intensity of laser beam, in order to fulfil the acquisition of all included materials. More glimpse views were performed on the same surface.

3. MATERIALS

3.1 The pale gold leaf tessera

The Konica Minolta laser scanner was used to acquire (Figure 1) the pale gold leaf tessera Au 01; this kind of tessera is quite different from the other ones, because the structure is more complex and multi materials (tile, gold, glass). Furthermore, this tessera has evident deterioration patinae (Figure 2).



Figure 1. The main face of pale gold leaf tessera (Au 01)

The pale gold leaf is placed on a glass basement, usually transparent, and it is covered by a small glass folder. For this specimen all the faces were acquired in order to reconstruct the virtual model of the irregular solid. From this global model all kinds of metric information are gained like, for example, the tickness of the glass folder or the volume of the tessera itself.



Figure 2. Tessera with pale gold leaf (Au 01): the lateral faces with deterioration patinae

3.2 The transparent colourless tessera

Using the CMM a transparent colourless tessera Ti 01 was acquired (Figure 3). Two scans were performed on the main face: the first one using the standard mode, and the second one at the same sampling rate ($0,012$ mm) using chalk powder to obtain an opaque surface.



Figure 3. The main face of the transparent colourless tessera; all the body has deterioration patinae

This sample has the main surface with strong deterioration patinae, whether opaque or iridescent. The goal of the scanning is therefore the characterization of the patinae from the metric and material point of view.

This tessera present a small linear fracture (top, left), an iridescent patina in the left part and two smaller opaque patinae in the right part.

4. PROCESSING LASER DATA AND TEXTURE

The data coming from the Konica Minolta laser scanner was processed with *Polygon Editing Tool* (PET).

This software runs the acquisition phase too: first of all the instrument performs autofocus and computes the laser beam intensity. Due to the peculiar iridescent main surface for both tesserae, the beam intensity, after some test, was set up to very low values in order to optimize the acquisition.

From the raw data, a preliminary surface model is obtained (Figure 6). This kind of irregular quadrangular network is very useful to investigate the surface itself and to localize “false” information. The software environment is PET, where some metrics can be evaluated. So the areas due to reverberation effect between the object and the basement (small triangles in Figure 4) can be removed.

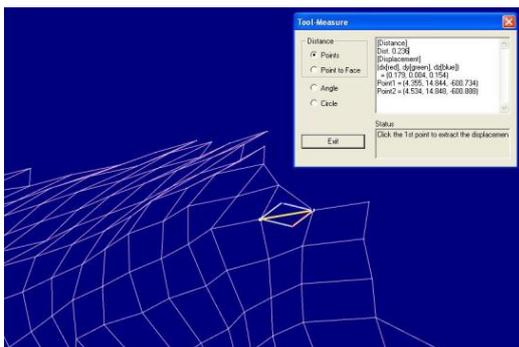


Figure 4. Representation of irregular quadrangular network with false information; from the window the user performs some metric measurements (PET environment)

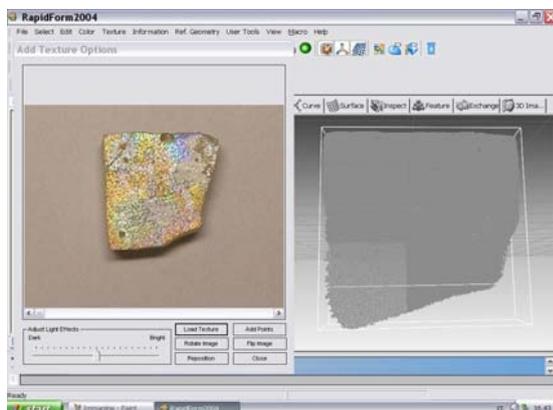


Figure 5. Texture application on the grid for the transparent colourless tessera using RapidForm 2004 environment

The scans are filtered in order to remove needless information; after they are registered to align different meshes in a single coordinate system. Finally the virtual model is created.

From the CMM a point cloud is extracted, where each point is in term of x, y, z coordinates. Using RapidForm 2004 environment, this ASCII file of coordinates is loaded and transformed in a triangulated grid.

Furthermore, the model can be visualized as a point grid with photographic information. In this case the texture is applied starting from a single digital shot; the chosen software environment is RapidForm 2004. Like for the registration phase, also in this phase at least three corresponding points must be selected on the grid and on the related photo (Figure5).

5. PALE GOLD LEAF TESSERA

For the pale gold leaf tessera multiple scans were needed, acquiring six faces through the rotation of the tessera itself. The presence of iridescent deterioration patina has produced scans with many lacunas or data holes. Therefore the sample’s surface was covered with a very thin layer of chalk powder; the mean size of this powder is infinitely small in respect to bubble’s size and patina’s thickness.

The virtual model was obtained registering seven scans, where three scans are needed to completely cover the bended face. Figure 6 shows the global model obtained assembling the previous scans; in the same software environment all metric can be acquired and rotating the model in the virtual space more detailed study about the main face’s surface can be performed, also in terms of superficial deterioration and cracks analysis at micro scale.

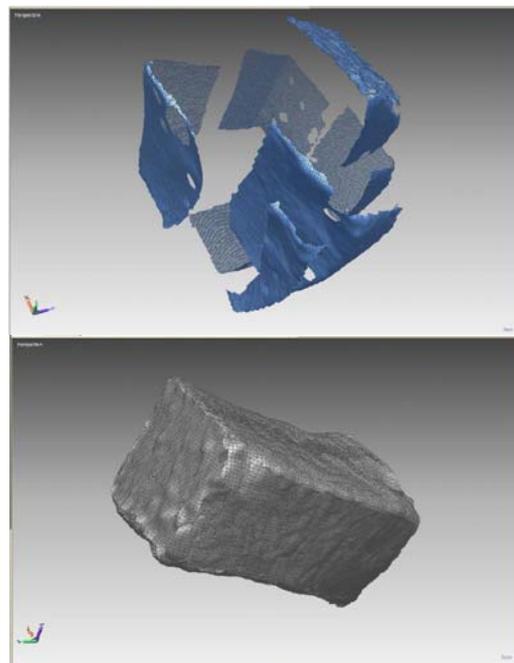


Figure 6. Global model of tessera Au 01; the seven scans are exploded and all scans are registered

Cross section analysis also can be performed (Figure 7) in order to compute the average section for the global model or for a single mesh. Using a lateral view the profile of the face with gold leaf is visible as perpendicular to section's plane.

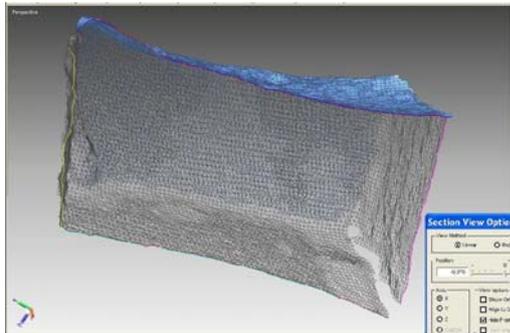


Figure 7. Cross section analysis for Au 01 tessera; the face with gold leaf is at left

6. TRASPARENT COLOURLESS TESSERA

The transparent colourless tessera was acquired via two scans under different conditions and using the CMM laser system in order to analyze the deterioration patina and to evaluate the interaction laser-glass for this kind of tessera.

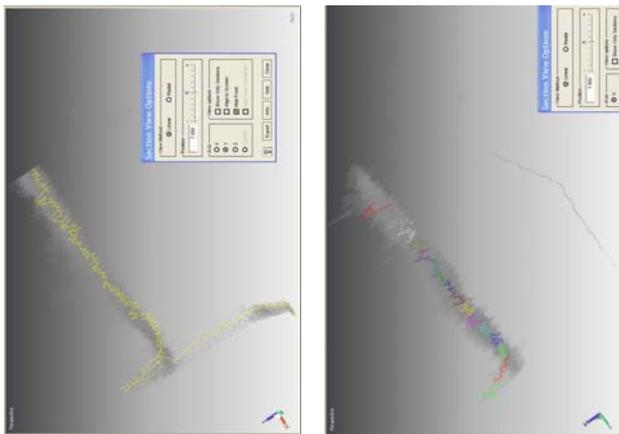


Figure 8. Direct acquisition of the transparent colourless tessera: cross section respect to x axis (left); cross section respect to y axis (right)

The first scan, with sampling rate of 0,012 mm, was acquired on the surface directly: the points cloud represents a very irregular surface (Figure 8), where a zig-zag effect is due to interaction between the laser beam and the deteriorated glass. The glass is passed through by the laser beam, which comes out with refraction: usually the beam, hitting a surface, is reflected. But in this case, it has crossed the glass and the "answer" has been modified by the deterioration patina on the surface. So the beam is reflected either to sensor or to tessera: like an eco is created and small effects could be acquired by the sensor.

For the second scan, also this tessera was masked using chalk powder on its surface, to avoid problems due to the iridescent patinae, which are very large in terms of area coverage. The results are very different (Figure 9) and the zig-zag is no more visible. Furthermore, in thi scan the start and end points have

been selected outside the tessera to have a complete surface description and a reference plane for the base.

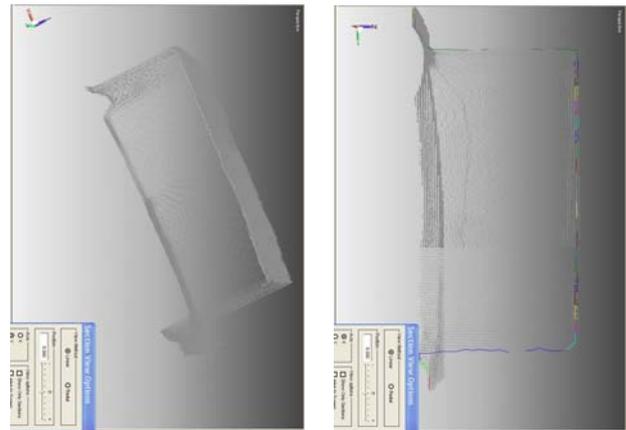


Figure 9. Transparent colourless tessera: acquisition via CMM using chalk powder; cross section respect to x axis (left); cross section respect to y axis (right)

The cross section analysis has been performed also on this tessera (Figure 10), showing how the different scanning methodology (without and with opaque coverage) interact between them. In fact, the zig-zag is present also "inside" when chalk powder is not used.

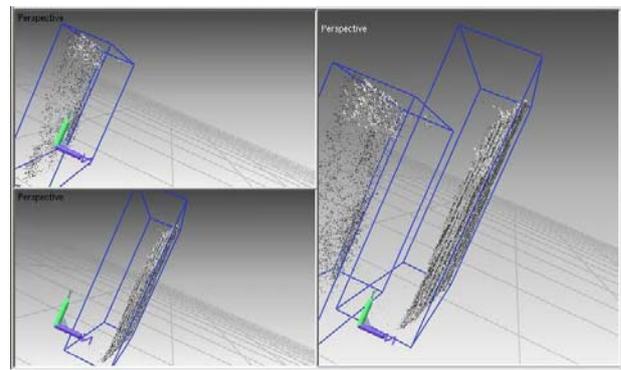


Figure 10. Scans registration for the transparent colourless tessera; the zig-zag effect is present "inside"

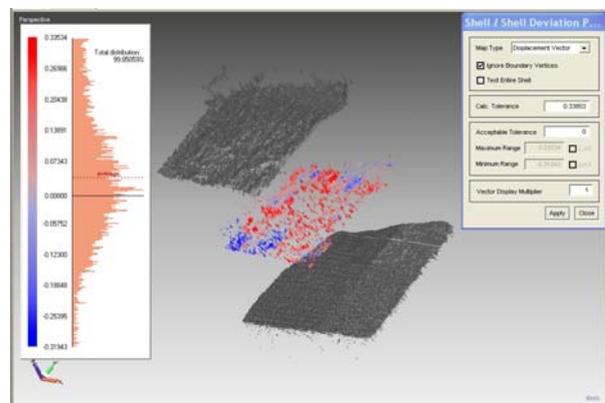


Figure 11. Shell to shell deviation analysis for the transparent colourless tessera and gaussian distribution of distances between two scans

This effect is also confirmed by the shell to shell deviation, which computes the distance between corresponding points for the two scans (Figure 11); the frequency for each distance value is computed and the Gaussian behaviour shows a very good alignment.

7. CONCLUSIONS

The first challenge of this kind of acquisition shows how the presence of many and different materials in the same object involve a variable sensitivity of the surface to the laser light and, in presence of glass, a variable back-signal.

Some problems in the acquisition of high reflectance materials are presented; working with opaque surfaces is a requisite to avoid “eco” signals.

Finally, two different laser scanning are been used stressing out the ability to produce global models of very small objects where the measuring of all metrical features (size, volume, depth of alteration strata...) in a virtual space is possible without any invasive contact.

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