



NON-METRIC DIGITAL RECONSTRUCTION OF ROMAN MOSAICS EXCAVATED IN THE CITY OF RAVENNA (ITALY)

RECONSTRUCCIÓN DIGITAL NO MÉTRICA DE MOSAICOS ROMANOS EXCAVADOS EN LA CIUDAD DE RÁVENA (ITALIA)

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Highlights:

- An example of virtual restoration is presented relevant to Roman mosaics recently found in Ravenna (Italy).
- A simulated integration by the analogies of the geometric patterns present in the mosaics allows a reliable reconstruction.
- Virtual restoration results in a useful tool for enhancement, knowledge and improvement of understanding of mosaics by the general public.

Abstract:

During the excavations carried out in summer 2011 in Piazza Anita Garibaldi in Ravenna, during construction of the new underground waste containers, five rooms decorated with mosaic floors were found, probably dating back to the early Roman Empire (1st-2nd century AD). The mosaics were removed for restoration and musealisation, however –given the size of the large lacunae- it would not be possible to reintegrate them in a traditional restoration without creating arbitrary reconstructions. Therefore, we opted for a digital reconstruction of the lacunae, attempting virtual restoration hypotheses for the recovered mosaics. Subsequently, it was possible to grasp the trend of the figuration and how it could have appeared in the past. The characteristics of many mosaics, such as the symmetry and the repetition of geometric patterns, make them suitable for both a simulated integration and a reconstruction by the analogies of the pattern. As a matter of fact, we used simple and easily accessible software to perform this work. The purpose of this digital workflow was to give an example of virtual processing useful for conservators and restorers, as well as for scholars (archaeologists, art historians, etc.) that can be carried out without specific information technology expertise and computer skills. After the images were acquired digitally, we were able to proceed with the reconstruction of the floor, by taking into account the geometric motifs that make up the mosaic assembly and that made the recomposition the most reliable. The virtual restoration also provides the opportunity of simulating the type of integration and the colour so that scholars, restorers and conservators may evaluate the final appearance of the work and the different aesthetic choices. The virtual restoration is finally considered an essential tool for the enhancement of cultural heritage.

Keywords: virtual archaeology; mosaics; digital image processing; cultural heritage; documentation

Resumen:

Durante las excavaciones llevadas a cabo en el verano de 2011 en la Plaza Anita Garibaldi en Rávena para la fabricación de nuevos contenedores soterrados, se encontraron cinco habitaciones decoradas con mosaicos en el piso, que probablemente datan de principios del imperio romano (siglo I-II d. C.). Los mosaicos fueron retirados para la restauración y musealización, sin embargo –dado el tamaño de las lagunas grandes- no sería posible reintegrarlos siguiendo una restauración tradicional sin crear reconstrucciones arbitrarias. Por esta razón, hemos optado por una reconstrucción digital de las lagunas, haciendo algunas hipótesis de restauración virtual de los mosaicos recuperados. De esta manera, es posible figurar cómo podría haber sido en el pasado. Las características de muchos mosaicos, como son la simetría y la repetición de los patrones geométricos, los hacen adecuados tanto para una integración simulada como para la reconstrucción por analogía del patrón geométrico. De hecho, utilizamos software muy simple para realizar este trabajo, ya que nuestro propósito era dar un ejemplo de procesamiento virtual útil para conservadores y restauradores, así como para académicos (arqueólogos, historiadores del arte, etc.) que puede llevarse a cabo sin conocimientos específicos ni conocimientos informáticos. Una vez adquiridas las imágenes en formato digital, pudimos proceder a la reconstrucción real del piso, teniendo en cuenta los motivos geométricos que conforman el ensamblaje del mosaico y que hicieron la recomposición más fiable. La restauración virtual también brinda la oportunidad de simular en la imagen digital el tipo de integración y el color para que los estudiosos puedan evaluar la apariencia final del trabajo y las diferentes elecciones estéticas. La restauración virtual se considera finalmente una herramienta esencial para la mejora del patrimonio cultural.

Palabras clave: arqueología virtual; mosaicos; procesamiento digital de imágenes; patrimonio cultural; documentación

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1. Introduction

The cultural heritage field has undergone profound changes in recent years, because of an increasingly demanding public, but also due to the greater awareness that culture is a real and important 'good' that can generate wealth and employment. The computer expert that can manage virtual restoration software has now joined the more traditional professional figure of the restorer, in a still experimental way (Bortolotti, 2006; Bennardi & Furferi, 2007).

There are applications that, in this specific field, provide a number of interesting proposals: the virtual restoration does not act on the artwork, but simulates a visual and aesthetic improvement of the work, so enhancing it. It also gives the possibility to choose a series of solutions, before technical operations (Biagi Maino & Maino, 2017).

Electronic or digital restoration can be therefore defined as the set of digital processing of two- or three-dimensional, computer graphics (Gonzalez & Woods, 1993), allowing for visual and aesthetic improvements of the work or a hypothetical reconstruction which is not real, but virtual precisely. Moreover, it is useful to better understand a work of art (both mobile and immobile) or document archives, that for serious reasons of physical degradation cannot be easily restored in the traditional way.

This definition of 'virtual restoration' means the technical tools by which the restoration is done, rather than the methodology used. A feature of the virtual restoration is that direct action does not require real work of art, but is made on the digital image that represents it. For this fact, virtual restoration is not in competition with the 'physical' restoration but may represent an interesting procedure to support and study it (Bennardi & Furferi, 2007; Biagi Maino & Maino, 2017).

The image obtained by suitable computer processing can be useful:

- To ensure better use of cultural property;
- For teaching and training;
- As a guide to the actual restoration.

These are only some of the possibilities offered by the virtual restoration, depending on the constituent materials of works of art and of the reasons that lead to its use. In some fields, like photography or cinema, virtual restoration is a real effective restoration technique, which is recognised as a valid alternative to the traditional one. It preserves the portrayed image and its significant historical document, regardless of its material support.

We must never forget that a restoration intervention, as in itself always traumatic for the piece of art, should be carried out only in case it is necessary for the survival of the artwork. Therefore, when it is necessary to improve the readability of the image, then traditional restoration can be replaced by digital restoration, thereby conserving the integrity of the original materials: in other words, one can place side by side the fragmented piece and its reconstructed image, cleaned up or rebuilt, but only where it can be done without falling into arbitrary solutions (Menghi, Monti, & Maino 2012).

In the present investigation, the virtual restoration does not aim at foreshadowing a real restoration intervention (which is often not necessary, as a conservative

intervention may be enough), but at replacing the lacunose paintings with digital images reconstructing their missing parts, in order both to facilitate their use for educational purposes and to protect the original ones from everyday use. In fact, a virtual restoration is an essential tool for the enhancement of cultural heritage. The new kind of consumer must, in fact, find the most suitable means to understand what she/he sees. A mosaic floor with large lacunae may, in fact, resemble a ruin rather than remind the magnificent mansions that it had been part of. Therefore, a mosaic floor, decontextualised, hung on a wall and with large lacunae deprives the visitor of vital information.

The virtual restoration then, at very low cost, may intervene by proposing the reconstruction of the entire floor, thus playing an important didactic role and giving back to the mosaic its readability. In the case of the Gallinelle's mosaic (Nencini & Maino, 2011), split in two fragments, attached to a wall in a dark, narrow room, the visitor can not understand its importance: she/he, certainly, cannot imagine that same floor within the church where its position probably indicated an important ancient worship area.

In this case the presence of the digital reconstruction of the floor with camouflage mimetic integration could revalue the importance of this mosaic floor with its delicate birds, made more precious by the glass tesserae, and give back, albeit partially, its integrity and dignity as a work of art, while waiting for the conservative restoration.

The advantages of a virtual restoration rely on its specificity compared to the manual method: a digital image, "clone" of the real one, may be altered, duplicated, restored many times without endangering or damaging the real work of art. So, one can work with the maximum freedom of action, in some cases even omitting the principles of traditional restoration.

Intervention attempts may be different and may also be modified subsequently: each phase of the intervention may be registered at a different level in a photo editing software such as Adobe Photoshop, Corel PhotoPaint or GIMP (GNU Image Manipulation Program). In a way, this allows for the reversibility of the intervention and immediate comparisons between the different phases and possibly among several operational choices.

The reconstruction hypotheses digitally carried out may also be mimetic, may be performed on a different level compared to the original image, in order to guarantee their identification. It is important, though, that they are justified by a philological analysis of the piece.

2. The adopted methodology

Since specific software for virtual restoration is not generally developed, commercial software is generally used for vector or bitmap graphics. In this case, we adopted Adobe Photoshop CS (Creative Suite) and GIMP 2 to show practical examples that can be easily reproduced by restorers and people not necessarily information technology (IT) professionals. It is worth noticing that, prior to any image processing intervention, an adequate CMS (Colour Management System) software should be used to calibrate properly the computer screen and the printer. Thanks to the use of a colourimeter or a spectrophotometer, the CMS can coordinate the gamut (the set of all the colours that a

device can display), that is the colour spaces of different output devices (such as printer and monitor), in order to have the colours of the acquired photographic images correspondent as much as possible to each other and to the original artwork (Maino & Monti, 2015).

The process of virtual restoration on the mosaics and, more generally, on artistic and archaeological works consists of the following phases (Monti & Maino, 2011):

- Digital data acquisition,
- Mosaicking,
- Elaboration (balance, cleaning, reconstruction, extraction of the grid),
- Electronic filling.

Of course, the memory of each step and phase of digital processing must be kept in a different level of a Photoshop file (with a PSD extension), for instance, able to store several overlying images, saving them without compression and therefore without losing quality. The digital acquisition is generally performed using a conventional digital camera, the resolution of which today usually ranges from 8 to 24 Mpixels.

If the artefact to be photographed is very large, it can be acquired through several shots, overlapping the edges which then must be reassembled through mosaicking, in order to obtain a resolution of at least 500 or 600 PPI (pixels per inch) on the real size, required to display a screen magnification of all details and make high-quality prints.

The mosaicking consists in the perspective rectification of several shots that are then reassembled to form the image of the entire object, perfectly matching the margins. Once reassembled, not only the high-resolution photographs allow one to gain a better understanding of the artwork, but they also help to assess the conservation status and identify any previous restoration work.

A first elaboration of the image obtained in this way is to balance brightness and contrast, and to regulate dominant colours, by using for instance the <Curves> tool in Photoshop, in order to make the picture as similar as possible to the original one, since each acquisition inevitably causes overexposure or underexposure and colour toning, due to lighting conditions and the characteristics of the used sensors. In order to adequately perform these corrections, photos must be carried out by placing a colour scale next to the artwork. By doing so, one can have a reliable reference to assess the deviation of colour and brightness values of the picture from those of the original one. Otherwise, a colour checker chart can be used, an arrangement of standardised colour samples which can be used to calibrate and profile graphics devices, such as digital cameras and scanners.

By this way, it is possible not only to correct the imperfections due to image acquisition, but also the changes of colour in the case of archival documents, illuminated codes, manuscripts, historical photographs and so on.

Then, if necessary, one can perform cleanup operations (removal of stains) and intensification of the faded lines. This is a recovery of information which is not always possible to carry out with a traditional restoration intervention. Thanks to the use of information from near-infrared (NIR) and ultraviolet (UV) photography

(Maino, 2007; Maino & Massari, 2010), it is also possible to separate and give back distinctness to any palimpsests.

On the other side, the appropriate combination of imaging and diagnostic techniques has proven useful to obtain deeper information about execution techniques as in the Germolles case study (Degrignye et al., 2016), where using spatial and spectral imaging techniques in combination with more traditional analytical techniques, it was possible to gain a better understanding of the painting techniques.

The reconstruction of missing parts consists in the use of the intact parts of the image in order to recreate the shape of the lost areas, only where it is possible to do so with certainty, therefore for very small gaps and also for much larger ones, if there are other copies of the artwork to be restored. Generally, for this purpose, we can use Adobe Photoshop tools such as <Clone stamp>, <Healing Brush> and <Patch>.

The last phase of intervention consists in electronic storage of high- and low-resolution images, in order to keep the acquired images and all the subsequent elaborations, foreseeing both their consultation and any new virtual restoration based on different principles.

Therefore, we need to save images both in a format that, although occupies a lot of space, does not imply a loss of data (BMP, PSD and TIFF formats, that use lossless data compression algorithms), and in compressed format (usually using JPEG, which uses a lossy compression algorithm), which causes a loss of information but allows an easier consultation, and less waste of space and resources.

Saved high resolution images may be used to make high-quality prints for periodicals or magazines and for sales. Low-resolution ones instead may be used to make online catalogues or user-friendly virtual museums.

3. The excavation

The excavations carried out from late June 2011 in Piazza Anita Garibaldi (Ravenna, Italy) were aimed at creating new underground waste containers for the separate collection by Hera, a multi-utility company that deals with the management of water, energy and waste in Emilia Romagna region.

The probability of finding ancient artefacts during an excavation in Ravenna –city of very early foundation– is obviously very high, but in this case no noteworthy finding was expected, since it was believed (on the basis of the archaeological prospection performed during the sixties years of the 20th century) that the Fossa Augusta was located below the excavation area. The Fossa Augusta was a canal built by Emperor Augustus (27 BC-AD 14), to connect Ravenna to its harbour, Classe, which under Augustus became an important military base. The Fossa Augusta cut Ravenna longitudinally and was eventually buried by debris carried by rivers, probably towards the end of the 5th century; on its way Platea Mayor was built, today corresponding to Via di Roma.

Conversely, the excavations revealed different archaeological layers and, in particular, an imperial age Domus (Roman house) with floors decorated with mosaics (rooms A, B, D and E, respectively, see Fig. 1). This is a very important discovery that will force archaeologists to rewrite part of the Ravenna's history,

which did not foresee the presence of Roman houses in this area.

For this reason, it would have been interesting to enlarge the excavation area beyond that provided for the undergrounding of bins for separate waste collection. Indeed, this excavation unearthed only a part of the five rooms of a Domus, which clearly extends in all directions beyond the margins delimited by the sheet piles inserted to secure the excavation. Hence, for the moment, it is not possible to determine with certainty the plan of the house to which the mosaics found belong.

Further excavations would be possible, but very expensive because of the water emerging from a very superficial fault, which tends to continue flood the excavation, and therefore it requires a system of restraint of the excavation margins and continuous drainage of water.

The stratigraphic excavation, carried out under the direction of the Superintendence for Archaeological Heritage of the Emilia-Romagna region, unearthed –at first– a series of attendance levels datable to Late Middle Ages, below them the remains of a house datable to the Early Middle Ages, made of clay and wood, and those of another house datable to Late Antiquity (6th century AD, approximately).

A brick wall belongs to this latter (visible in Fig. 1, on the left, because it cuts two of the mosaic floors below). Digging again, at a depth of about 3.2 m, covered by abandonment layers, the remains of an Imperial Age Roman Domus (late 1st-2nd century AD) were discovered, consisting of five rooms decorated with mosaic floors.

There is probably a central room (C) with white mosaic and the well, shown in Fig. 2, surrounded by four other rooms. In addition to these rooms, on the Westside, two rooms were found decorated with a hexagon mosaic (room A, Fig. 3) and with the so-called “Neptune” mosaic

(room B; Fig. 5); on the East side, two rooms decorated with an octagon mosaic (room D; Fig. 7) and with a checkerboard mosaic (room E; Fig. 9).

The mosaics are made with black and white tiles; the decorative motifs are similar to those found in Faenza and in the Villa of Russi, both in the province of Ravenna (Bignami, Carnoli, & Racagni, 2000).

These mosaics were realized, as well as decorated, to make the floor waterproof and resistant to treading.

Floor mosaics spread first (since the 4th millennium BC), while wall mosaics came after (1st century AD) starting from *thermae* (bath complexes), because of their resistance to moisture.

The city of Ravenna has a long and noteworthy tradition of mosaics dating back to the Roman age and it shows its most shining examples in the Byzantine era. These new findings enrich the already large heritage of Ravenna’s mosaics; indeed, they were removed to be restored and exhibited in the TAMO (*Tutta l’Avventura del Mosaico*, All the Adventure of Mosaic) museum by the RavennAntica Foundation.

4. The virtual restoration

The digital reconstructions of the mosaics found in the excavations at Piazza Anita Garibaldi were performed on photographs taken for the excavation documentation.

Images were captured with a Nikon D90 digital single lens reflex (SLR) camera, provided with a Nikon DX CMOS sensor (12.3 Mpixel). The camera colour space is sRGB and its resolution 4288x2848 pixels.

The virtual restoration on each floor mosaic (Figs. 4, 6, 8 and 10) was performed by using Adobe Photoshop CS5 and it entailed different phases:

- Study of the figuration trend;
- Study of the site plan;



Figure 1: The overall excavation in Piazza Anita Garibaldi, Ravenna; size of the excavation is ca 10 x 6 m. Mosaic of room A is located on the left-top side; room B on the left-bottom side; and rooms D and E on the right-top and right-bottom sides, respectively.



Figure 2: Central room (C) with well and white mosaic.

- Perspective rectification of the image;
- Balancing of brightness and contrast;
- Adjustment of dominant colours;
- Suture of cracks;
- Straightening of deformed sections;
- Reinstatement of the lacunae;
- Modular repetition of the decorative motif on the entire area presumably occupied by the mosaic.

The choice of commercial software such as Adobe Photoshop CS5 arises because of our interest in the methodology of virtual restoration, rather than on the specific technical item, since our purpose is to develop a protocol useful for restorers and conservators, not for scientists.

As a general rule, every virtual restoration should avoid arbitrary reconstructions; but they are hardly avoidable if there are lacunae of great magnitude. In this particular case, however, despite the residual mosaic fragments represent probably less than one-fourth of the original mosaic surface, we tried a complete reconstruction for two reasons:

- 1) The largely predictable trend of the geometric decoration;
- 2) The purpose to make perceptible the complexity of the original decoration, the fruition of which is hampered by the extent of lacunae.

Due to the excavation size –limited to the undergrounding area for separate waste collection bins– it was not possible to reconstruct the house plan, the rooms of which might extend beyond the dimensions assumed by the reconstruction; however, the results remain valid in

their effort to give an idea of how the mosaic floor might have looked like originally.

This kind of digital reconstruction may be useful for the museum display of artefacts. Indeed, the recovered mosaics should be restored, consolidated and preserved in a museum, but it is not possible to physically reconstruct the missing parts because it would create a historical fake. The lacunae should instead be puttied with a uniform and neutral colour plaster (Fiori & Vandini, 2002). Therefore, in order to allow and facilitate the fruition and understanding of these mosaics decoration, it would be useful to place side by side –e.g. in a museum exposition– the virtual reconstruction and the mosaic fragments.

5. The four mosaics

The mosaic of the room A (Fig. 3) is characterised by a series of six petals flowers within hexagons, surrounded by braided ribbons.

More than half of the mosaic is missing; moreover, along with the upper margin, we can see an ancient restoration, carried out –as was the custom then– with black and white tesserae randomly arranged, without restoring the decorative motif. The deformation of the ground caused the opening of several cracks in the right side of the mosaic, in addition to the remarkable lowering of the upper right corner.

The first part of the virtual restoration intervened just on this problem: the mosaic portions detached from the mosaic body because of the cracks were selected and brought closer, as long as the mosaic portion deformed by the ground lowering was raised.

None of the remaining hexagons was intact, so their missing parts were reconstructed by sampling the undamaged parts of each one to bring them back on injured parts of the others.

The same procedure was applied in order to reconstruct the lacking parts of the frame and of the braided motif surrounding the hexagons.



Figure 3: Room A, decorated with a hexagon mosaic.



Figure 4: Virtual restoration hypothesis for room A (ca 2 x 2 m).



Figure 5: Room B, decorated with the so-called "Neptune" mosaic.



Figure 6: Virtual restoration hypothesis for room B (ca 2.8 x 1.5 m).



Figure 7: Room D, decorated with an octagon mosaic.



Figure 8: Virtual restoration hypothesis for room D (ca 4 x 2 m).



Figure 9: Room E, decorated with a checkerboard mosaic.

This upper part of the mosaic –so reconstructed– was then duplicated and flipped (by using the <Flip vertical> function in Photoshop) in order to recreate the lower part of the mosaic itself.

Finally, the missing central part of the mosaic was rebuilt on the basis of the same pattern. The result is shown in Fig. 4.

The mosaic of the room B (Fig. 5) is called "Neptune mosaic" due to the mask depicted in the lower left corner, reminiscent of the contemporary stylised representations of aquatic deity by the Romans.

Less than a quarter of the original mosaic decoration has been preserved. Even in this case, it was necessary to bring closer the two parts of the mosaic separated by a large crack.

Later, after reconstructing the lacunose parts by sampling the remaining ones, the mosaic image has been replicated and flipped vertically in order to recreate the upper part of the mosaic.

The two parts were then joined on the basis of the figuration trend. In this way, we rebuilt the left half of the mosaic, which has been then replicated and flipped horizontally (by using the <Flip horizontal> function in Photoshop) in order to reconstruct also the right half of the mosaic. So, also this mosaic floor has been completed on the basis of the hypothesis of a modular repetition of the motif.

The central motif of the smallest circle is unknown, while the central motifs of the two larger circles have been reconstructed on the basis of a mosaic fragment –discovered after further excavations– which shows part of a so-called "Solomon's knot", widespread in contemporary mosaics. The result, although in part hypothetical, is visible in Fig. 6.

The mosaic of the room D (Fig. 7) is characterised by eight petals flowers within octagons, surrounded by a square, lozenge and triangle motifs.

It is perhaps the most damaged of the mosaics found in this excavation: the residual surface is probably less than a quarter of the original one and the colours are very subdued (the black tesserae are faded and the white ones are greyed).

The lacunae have been reconstructed on the basis of the sampling of the intact parts. The pelte motif, situated in the four oblique rectangles, has been supposed and rebuilt on the basis of the residual figuration and of the spread of this kind of decoration in the coeval mosaics.

The lower left sector of the mosaic floor, once reconstructed, has been replicated and flipped vertically in order to recreate the upper left sector of the mosaic, and later this set has been duplicated and flipped horizontally to restore the right part of the mosaic.

The balancing of brightness and contrast (by means of the <Curves> tool in Photoshop) was required in the virtual restoration of every mosaic, in order to highlight the decorative motifs, but in this case, due to the particularly obfuscated appearance of this mosaic, it was necessary to use special Photoshop filters (such as Unsharp Mask, High Pass, Maximum and Minimum) which allowed us to further highlight the figuration, increasing the contrast between black and white tesserae (Fig. 8).

The mosaic of the room E (Fig. 9) shows a checkerboard motif consisting of black and white squares and black crosses. In the lower right corner, you can see an ancient restoration achieved with black and white tesserae randomly arranged. It is a very lacunose mosaic: perhaps just an eighth of the original mosaic decoration remains. Nevertheless, the digital reconstruction is relatively easy because of the simplicity of the figuration.

The poor residual mosaic surface was sampled in order to fill the lacunae and the rebuilt parts were replicated up to recreate the entire mosaic floor (Fig. 10).



Figure 10: Virtual restoration hypothesis for room E (ca 2 x 2 m).

6. Discussion

While stressing that the present results are only hypotheses of reconstruction of the mosaics found in Piazza Anita Garibaldi and that –anyway– small corrections are possible about the decoration trend and the size changes of the mosaic floors, we believe that these exercises of virtual restoration may be useful for the museum fruition, and as an aid to the study of the decorative motifs (through comparison with other similar mosaics), and as a basis for the possible reconstruction of the Domus plan and elevation (3D reconstruction), that will be object of a future work actually in progress.

Moreover, it is worth mentioning that the mosaic is itself a 3D structure and therefore a complete 3D virtual-reality reproduction must include this feature, as shown in Fig. 11, where an image is presented of the 3D mosaic surface obtained from a merge of five laser scanner point clouds from different angles (Maino, Orlandi, & Malkowski, 2005).

But the virtual restoration not only offers to restorers the possibility of recomposing a floor: it also provides the opportunity of simulating on the digital image with a photo editing software, the type of integration and the colour so that scholars, restorers and conservators may evaluate the final appearance of the work and the different aesthetic choices.

In the case of the Gallinelle's mosaic (Nencini & Maino, 2011) the presence of the digital reconstruction of the floor with camouflage mimetic integration could revalue

the importance of this mosaic floor with its delicate birds, made more precious by the glass tesserae, and give back, albeit partially, its integrity and dignity as a work of art, while waiting for the conservative restoration.

This case study –here described– highlights the importance of a preliminary study, as a preparation of a restoration before performing surgery. But the virtual restoration not only offers the possibility of reconstructing a mosaic to the restorer: it also offers the ability to simulate on suitable digital images, by means of a photo editing software, the type of integration and the relevant colour, as already outlined.

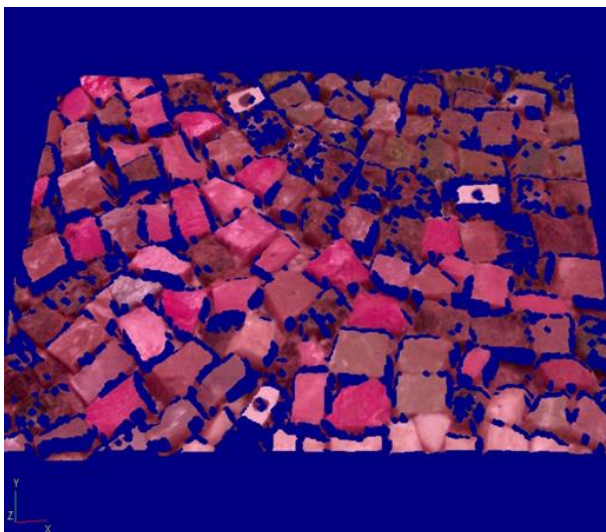


Figure 11: 3D laser scanning of mosaic tesserae (detail of room A) in false colour (ca 80 x 80 cm).

In the case of discordant colour, for instance, we deliberately chose a red-violet great impact in order to emphasise the integration. In the words of Cesare Brandi (Brandi, 1963) –the first director of Italian National Institute of Restoration– the colour of integration must be reduced to the background level and should not compose directly with the colour distribution of the surface of the work.

Moreover, a recent work has –for instance– introduced a particularly simple yet valuable procedure of digital non-metric image-based documentation of mural paintings in situ (Higuchi, Suzuki, Shibata, Taniguchi, & Galyaz 2016), which is a suitable technique also for documentation of mosaics on walls or floor, preliminary to the operations of virtual restoration. According to the authors, “each of the processes, the photographing of the mural paintings, the image processing of the shots and the description of mural condition was accomplished with the help of simple tools, such as a typical digital SLR camera, tripod, measuring tools, standard laptop computer and Adobe software. The images are non-metric and approximate but can be compared with actual mural paintings; therefore, the approach enables digital documentation for the preservation and restoration of mural paintings in situ.”

Last but not least, the virtual restoration is an essential tool for the promotion of cultural heritage. In the face of increasing and diverse audiences with different levels of cultural education, museums and archaeological sites seek more and more to create accurate and comprehensive educational courses. The new user

should, in fact, find the most appropriate ways to understand what one sees. The virtual reality technology is a useful tool to this aim and can provide a virtual visit to the presumed original environment and conservative state of mosaic decoration as shown in Fig. 12 (Maino & Visparelli, 2003) and described at http://www.sistemamusei.ra.it/main/index.php?id_pag=9&op=irs&id_riv_articolo=411.

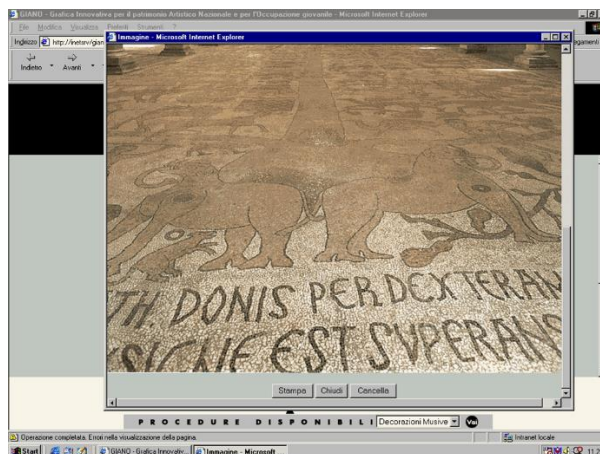


Figure 12: A view of the mosaic application in the virtual museum developed by the authors and presented in (Maino & Visparelli, 2003).

An integrated system (hardware and software) has been developed, and implemented at the CETMA (Center of Design & Materials Technologies) of Brindisi, Italy, which performs multimedia and hypertext archiving of historical-critical and technical-scientific information on mosaics and on the historical restorations to which they have been subjected over time, allowing the user access from the web to carry out data input and output operations, while at the same time offering the advantages presented by the use of innovative graphic methodologies such as computer graphics and virtual reality simulation.

The system includes two tools for data organisation: a data load manager connected to a database containing multimedia information on the mosaics, and a tool for the 3D graphic representation of a navigable architectural container (museum) and for the creation of virtual exhibitions of mosaics.

The integrated system consists of a stand-alone application, which includes a local high-definition workstation and a specific application for remote access. For the construction and organisation of the database, we have followed the standards established by the ICCD (Italian National Institute for Documentation of Cultural Heritage), giving them interactivity, updatability of data from the network, multimedia, which are profiled as critical tools just as important as the usual textual descriptions. Particular care has been dedicated to the presentation of scientific data that characterise the issues of restoration and the state of conservation of the mosaic itself.

The mosaic floors were, in fact, in the Roman Domus as well as later in churches, closely related to architecture and function of rooms: The triclinium, for example, i.e. the floor space that would house the beds had no drawing, while, at the center, was placed an emblem or a representation, positioned so as to be watched by the landlord and the guests when they were eating. In every room, then, the drawings of the floor were turned towards

the entrance, to be admired by those who entered. Then the virtual restoration, in a very effective way, may intervene in proposing the reconstruction of the entire floor, thus playing an important educational function and returning to the mosaic readability.

Finally, it is worth remarking that the concept of 'virtual restoration', despite its introduction is recent enough, is not without ambiguity of use and meaning. Founded in the field of cultural heritage, it has gradually emancipated widening the scope of its application and getting to lick even the linguistic and literary studies, yet the term 'virtual restoration', even in its variant of 'digital restoration', continues to show just the technical means used rather than a clear instance of methodology.

Recently, someone has seriously proposed abandonment of these expressions in favour of a more comprehensive definition, but still with a good degree of vagueness, such as, for example, 'iconological digital restoration' (Bennardi & Furferi, 2007).

7. Conclusions

Our purpose was to prove that even a virtual restoration can be performed by respecting the principles stated by Cesare Brandi (Brandi, 1963) for every 'real' physical restoration and overall in the world adopted, namely 1) respect for the aesthetic and historical aspects, 2) recognisability of the intervention, 3) reversibility of the materials and minimal intervention, while the fourth one, 4) compatibility of materials, is pertinent only to the real restoration.

A further point may be emphasised as regards developments of our work now in progress and that will be object of a forthcoming contribution: advanced and improved 3D laser scanning and printing devices allow users to obtain reproductions of art objects without any contact with the originals, whereas the plaster casts (or other materials) may damage the artwork surfaces (Maino, 2015; Casagrande, Maino, & Monti, 2016).

References

- Bennardi, D., & Furferi, R. (2007). *Il restauro virtuale. Tra ideologia e metodologia*. Florence: Edifir.
- Biagi Maino, D., & Maino, G. (2017). *Principi e Applicazioni del Restauro Virtuale*. Florence: Edifir.
- Bignami, S., Carnoli, S., & Racagni, P. (2000). *Il mosaico ravennate: cronistoria dalle origini ai giorni nostri*. Ravenna: Associazione Giuliano Argentario.
- Bortolotti, I. (2006). *Grafica al computer per il restauratore*. Padova: Il Prato.
- Brandi, C. (1963). *Teoria del restauro*. Roma: Edizioni di Storia e Letteratura.
- Casagrande, F., Rivola, R., Castagnetti, C., & Bertacchini, E. (2016). *Scansione e stampa 3D di un calco musivo policromo*. In V. Perzolla, & A. Colombo (Eds.), *Le Tecnologie Digitali al servizio della conservazione: Dall'integrazione scultorea al restauro virtuale* (pp. 43–55, 65–66). Padova: Il Prato e-book.
- Casagrande, F., Maino, G., & Monti, M. (2016). *3D rendering and virtual restoration of mosaics*. In M. B. Panov (Ed.), *Byzantium and the Heritage of Europe: Connecting the Cultures, Proceedings of 3rd International Symposium Days of Justinian I* (pp. 111–121). Skopje: Euro-Balkan University.
- Degrigny, C., Piqué, F., Papiashvili, N., Guery, J., Mansouri, A., Le Goïc, G., Detalle, V., Martos-Levif, D., Mounier, A., Wefers, S., Tedeschi, C., Cucchi, M., Vallet, J., Pamart, A., & Pinette, M. (2016). Technical study of Germolles' wall paintings: the input of imaging techniques. *Virtual Archaeology Review*, 7(15), 1–8. doi:10.4995/var.2016.5831
- Fiori, C., & Vandini, M. (2002). *Teoria e tecniche per la conservazione del mosaico*. Padova: Il Prato.

Conversely, 3D laser scanning does not endanger the artefact, but the acquisition of semi-transparent or reflective surfaces, as those of the Roman and Byzantine mosaics in glass paste, is rather difficult, because of the multiple reflections of the laser beam, which cannot be interpreted properly by the instrument (Maino, Orlandi, & Malkowski, 2005). However, it is possible to capture in detail the complex surfaces of some Byzantine mosaics thanks to the usage of precise triangulation-based scanners and a high number of different scans on the same mosaic panel (Casagrande, Rivola, Castagnetti, & Bertacchini, 2016; Rivola, Castagnetti, Bertacchini, & Casagrande, 2016).

Therefore, innovative 3D scanning and printing technological procedure in addition to the virtual restoration techniques previously described, allows users to get detailed copies of the mosaics, reproducing exactly the shape and the inclination, each time different, of the tesserae, the shape and the size of the gaps between the tesserae, the colour of the tesserae and of the mortar, thus providing tools that can show the appearance and executive technique of the ancient mosaics in educational courses for schools and museums (Casagrande, Maino, & Monti, 2016).

Furthermore, if part of the mosaic went irretrievably lost in case of disaster, without the possibility of being reassembled through anastylosis, it would still be possible to fill the gap with an integration printed in polychrome plaster from the 3D laser scan of the original mosaic. Thus, this kind of integration would be recognisable and reversible, according to the dictates of the modern theory of restoration.

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- Gonzalez, R. C., & Woods, R. E. (1993). *Digital Image Processing*. New York: Addison-Wesley.
- Higuchi, R., Suzuki, T., Shibata, M., Taniguchi, Y., & Galyaz, M. (2016). Digital non-metric image-based documentation for the preservation and restoration of mural paintings: the case of the Ozomlo Rock-Hewn church, Turkey. *Virtual Archaeology Review*, 7(14), 31–42. doi:[10.4995/var.2016.4241](https://doi.org/10.4995/var.2016.4241)
- Maino, G., & Visparelli, D. (2003). *Il museo virtuale dei mosaici*. In *Atti del Convegno Contesti virtuali e fruizione dei beni culturali*, Naples, May 22-23, 2003 (pp. 1–6). Naples, Italy.
- Maino, G., Orlandi, M., & Malkowski, G. (2005). *Documentare i mosaici tramite GIS*. In *La tecnologia al servizio dei beni culturali. Nuovi sistemi di catalogazione, visualizzazione e salvaguardia* (pp. 17–19). Rome: ENEA Technical Report.
- Maino, G. (2007). *Digitization and multispectral analysis of historical books and archival documents: Two exemplary cases*. In *14th International Conference on Image Analysis and Processing - Workshop (ICIAPW 2007)*, vol. II, (pp. 119–124). doi:[10.1109/ICIAPW.2007.23](https://doi.org/10.1109/ICIAPW.2007.23)
- Maino, G., & Massari, S. (2010). *Digitization and multispectral analysis of artistic objects: exemplary cases and web documentation*. In *Science for Cultural Heritage* (pp. 164–171). Singapore: World Scientific. doi:[10.1142/9789814307079_0014](https://doi.org/10.1142/9789814307079_0014)
- Maino, G. (2015). *The mosaics of Macedonia: conservation and restoration issues*. In L. Kniffitz, & E. Carbonara (Eds.), *Ravenna Musiva. Preservation and restoration of architectural decoration, mosaics and frescoes* (pp. 316–331, plates 44–47).
- Maino, G., & Monti, M. (2015). Color Management and Virtual Restoration of Artworks. In E. Celebi, M. Lecca, & B. Smolka (Eds.), *Color Image and Video Enhancement* (pp. 183–231). Cham: Springer. doi:[10.1007/978-3-319-09363-5_7](https://doi.org/10.1007/978-3-319-09363-5_7)
- Menghi, R., Monti, M., & Maino, G. (2012). Principles of virtual restoration and application to artistic and archaeological objects. In G. Vezzalini, & P. Zannini (Eds.), *Proceedings of A.I.Ar. 2012 Modena – VII Congresso nazionale di Archeometria* (pp. 618–631). Bologna: Patron.
- Monti, M., & Maino, G. (2011). Image processing and a virtual restoration hypothesis for mosaics and their cartoons. In G. Maino, & G. L. Foresti (Eds.), *Image Analysis and Processing – ICIAP 2011*. Lecture Notes in Computer Science, 6979, 486–495. doi:[10.1007/978-3-642-24088-1_50](https://doi.org/10.1007/978-3-642-24088-1_50)
- Nencini, E., & Maino, G. (2011). From the physical restoration for preserving to the virtual restoration for enhancing. In G. Maino, & G. L. Foresti (Eds.), *Image Analysis and Processing – ICIAP 2011*. Lecture Notes in Computer Science, 6978, 700–709. doi:[10.1007/978-3-642-24085-0_71](https://doi.org/10.1007/978-3-642-24085-0_71)
- Rivola, R., Castagnetti, C., Bertacchini, E., & Casagrande, F. (2016). Le tecniche geomatiche a supporto dei Beni Culturali. *Archeomatica*, 1, 34–37.