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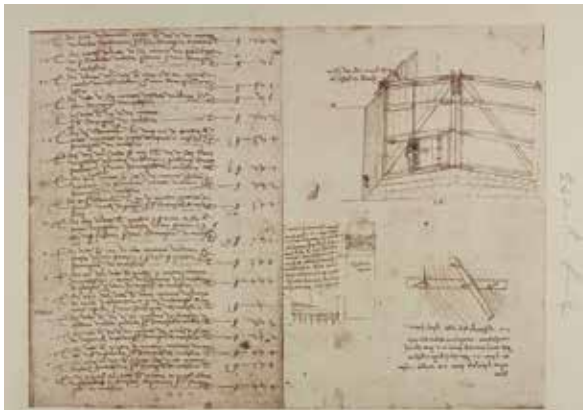

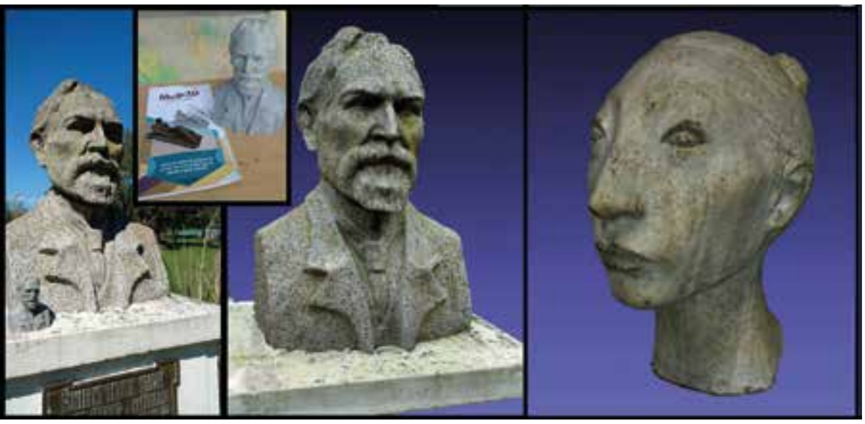

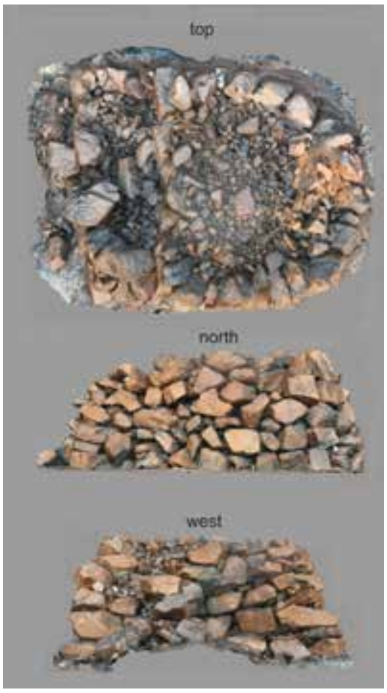

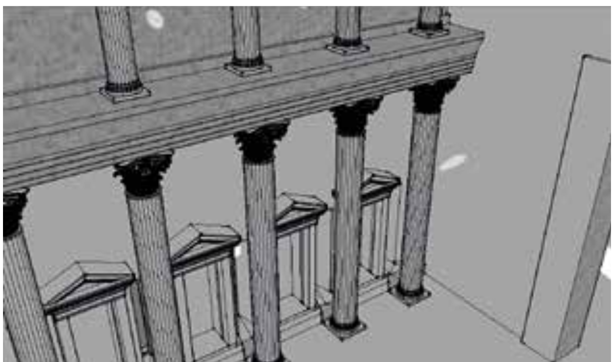

DIGITAL RECONSTRUCTION, 3D-PRINTING AND AUGMENTED REALITY

ACCESSING AND INFORMATION SYSTEM

Notizie e informazioni

DIGITAL RECONSTRUCTION, 3D-PRINTING AND AUGMENTED REALITY

The re-erection of Old Kingdom offering chambers in the Neues Museum Berlin

Thomas Lucker

Past epochs, just like presence and future, are cultural constructions. Historians, archaeologists, curators, and restorers are the constructors. And also novels, movies, and magazines contribute to how past cultures are pictured today, by creating mass effective images of these epochs. This illusionary image depends on various factors, but it is always time-related. Mediavist Valentin Groebner says: "History is a wishing machine [...] The only image we have of medieval times is that which we are confronted with around us today, in academic reconstructions, in literature and architectural fictions and artifacts, in moving pictures and in the media flashes. In our minds: which means, we create it ourselves" [Groebner, 2008]. And Karlheinz Flechsig writes: "Cultures are not a reality, but are produced as social reconstructions of a reality" [Flechsig, 2006].

So, how do we see a particular epoch, and what kind of picture do we want to draw? Are we pretending to know exactly how the world was like hundreds or thousands of years ago or do we show how incomplete our knowledge is, based on hypotheses of a long gone past? Do we complete the damaged picture or just present the fragments?

The Neues Museum Berlin

After the reunification of Germany, the Egyptian collections in East and West were also reunited. In 1998 the British architect David Chipperfield won the multi-level competition for the rebuilding of the Neues Museum. His concept contained the careful conservation of all preserved areas and surfaces of the ruinous structure. Instead of an exact reconstruction of the destroyed parts, all new additions to the

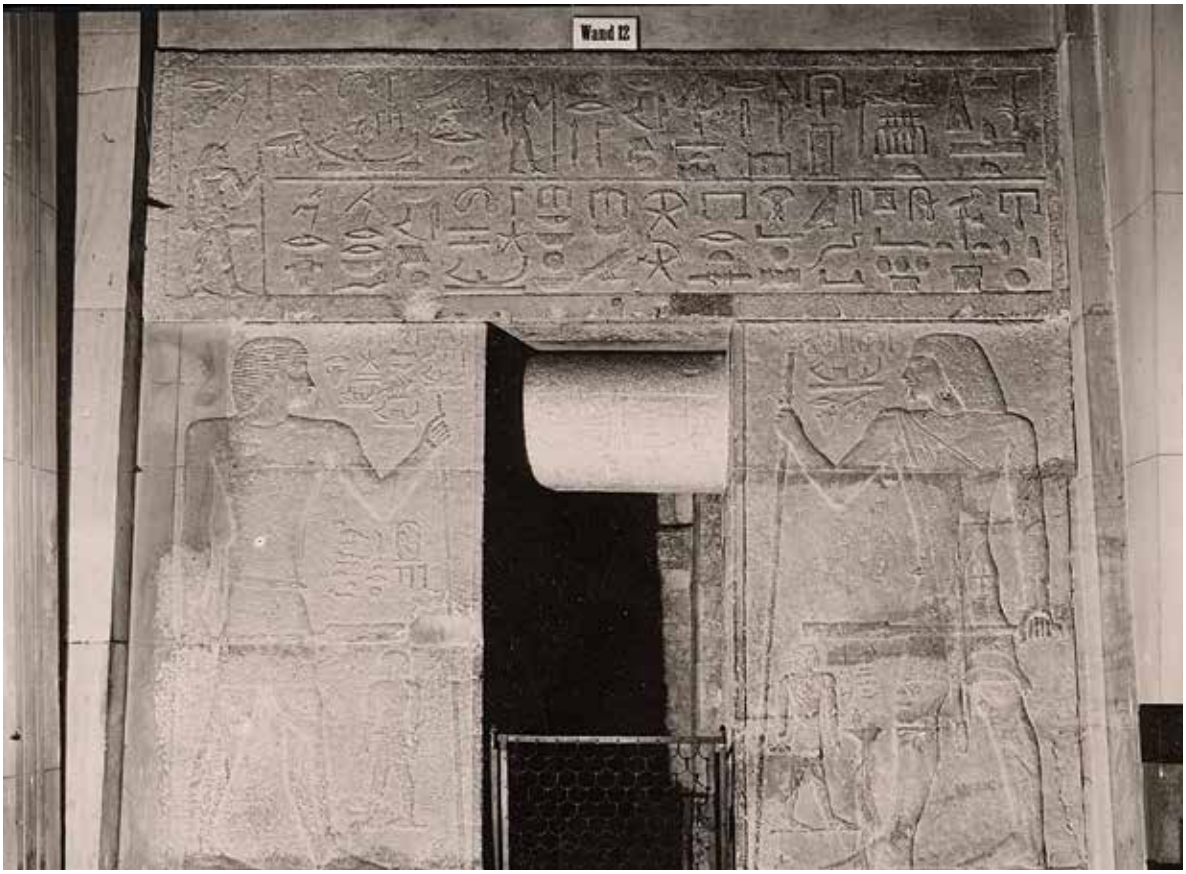

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Fig. 1. First presentation of the offering chamber of Merib. *Photo Ägyptisches Museum Berlin.*

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architecture should correspond to the original volumes and be clearly recognizable as new, without reference to the historical design details. Chipperfield's approach was meant to express respect to the architect of the Neues Museum, Friedrich August Stüler (1800-65). Even before the inclusion of the Museum Island in the World Heritage list in 1999, this approach was in line with the requirements of UNESCO.

Three offering chambers of the Egyptian Museum Berlin

For the re-opening of the Neues Museum in 2009, three offering chambers of the Old Kingdom, which had been on show already in the 19th century, were re-erected according to a new concept. The offering chambers belonged to the structurally fixed exhibits since they had to be included in the building planning due to their size and weight. They were provided for a permanent installation and not suitable for lending.

The history of the chambers

The offering chambers of the Old Kingdom originate from the tombs of the Giza and Saqqara residence cemeteries and date back to the early 4th to the early 6th Dynasty (ca. 2575-2335 BC). They are richly decorated with reliefs and hieroglyphs, and the interiors are often painted in detail. The chambers are built with narrow cross-shaped or rectangular groundplans. The building is made of local limestone. In the years 1842-45 the Prussian king, Friedrich Wilhelm IV sent an expedition to Egypt, which was led by Richard Lepsius. The three offering chambers were a gift from the Khedive of Egypt. Lepsius had them dismantled on site by his stonemasons and sent to Berlin amongst other things. They were finally reassembled, after having been subjected to various measures for preservation and desalination in the Tomb Room of the Neues Museum.

To protect the touch-sensitive surfaces of the interior walls, and because of the limited space and relatively narrow entrances – barely 70 cm wide – of the chambers, the museum management closed off the offering chambers to visitors by barriers which only allowed a glance of the interior decoration. Unfortunately, since these decorations were actually the highlight of the chambers. To address this issue, the offering chamber of Manofer was completely dismantled in the early 20th century to be presented in parts as an internal elevation along an exhibition wall. However, at the cost of the architectural-spatial component (fig. 1).

During the Second World War two of the chambers, those of Manofer and Metjen, were dismantled and put in storage. The offering chamber of Merib remained in the ruins of the Neues Museum until 1990. After the end of the war, the two dismantled chambers were deported to Russia and finally returned to the GDR in the mid-1950s.

Existing conditions

In the course of dismantling, and a little later in preparation for transportation to Germany, the original blocks were reworked to more manageable formats. Traces of this intervention, that are still visible and clearly distinguishable from ancient Egyptian tool traces, bear testimony to this intervention; the limestone originals were thinned and hollowed out for reasons of volume and weight reduction wherever this seemed possible. Sometimes this led to absurd forms, as in the case of the originally cubic blocks of the offering chamber of Merib, which nowadays appear L- or U-shaped depending on the number of their faces. These drastic interventions have caused numerous cracks up to complete breakouts and as a consequence of various structural consolidation measures. It can be assumed that the blocks were further adjusted during the first reassembly and construction within back walls made of brick in the Neues Museum.

Conservation issues

The state of preservation in terms of substance of the original blocks could be considered as good. Conservation issues mainly faced the salt contamination of the material and the damaged surfaces. Consolidation treatments to enhance the strength of the limestone, which are generally regarded as irreversible, were strictly limited to actually weakened areas that could mainly be found on the direct surface. The materials employed were chosen carefully and adjusted to the existing conditions. Laser cleaning was provided in areas of highly endangered surfaces under exclusion of zones where traces of the original colour scheme were preserved. Discolouration of surfaces by yellowed coatings, such as the PVAC which could be found in the offering chamber of Manofer, were to be accepted if their removal was to endanger the original surface. Recent mortar additions were to be removed towards a future uniform presentation.

The new presentation of the offering chambers

As part of the renovation of the Neues Museum, the level of the basement floor was lowered somewhat so that not only the two large courtyards but also the rooms surrounding them could be used for exhibition purposes. While these, as well as some additional rooms on the upper floors, receive little or no daylight, a large part of the exhibition rooms have large windows or are illuminated by means of the light ceilings above the courtyards. In contrast to earlier Egypt exhibitions, which had often staged their finds in a mystical atmosphere, the Neues Museum offered light-flooded rooms. In the religion and everyday life of ancient Egypt, the sun played a central role, and even today's visitors of Egypt cannot escape the ubiquitous presence of the sun. The idea of a museum presentation of Egyptian artifacts in bright daylight seemed obvious, and now not only the exhibits from Amarna period with the Aton cult are shown in a bright setting, but also many testimonies of other epochs.

Also, the offering chambers of the high officials, Metjen, Merib, and Manofer had been exposed to bright sunlight as parts of the *mastabas* in the pyramid districts of Giza and Saqqara for almost four-and-a-half thousand years until Lepsius brought them to Berlin to put them in a museum. In the new presentation, the offering chambers should no longer be placed in the narrow Tomb Room, which had housed them originally. They were now designated for the

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Fig. 2. Simulation of the presentation of the three offering chambers in the Historical Room. *Simulation RAO.*

spacious Historical Room on the ground floor of the war-wrecked and by Chipperfield newly built Northwest wing. The hall was equipped with large windows and its size and orientation allowed the three offering chambers, in analogy to the tombs of the Old Kingdom, to be erected in a row, with east-oriented entrances.

The walls of the offering chambers in Berlin embody representations and inscriptions of high quality and great artistic value, thus are of unique cultural significance. The life story of Metjen, a high official of Pharaoh Snofru, is depicted in his offering chamber, which represents the earliest known narrative text of ancient Egyptian literature. The legibility of the representations, which are engraved only a few millimeters, was naturally at the center of scientific interest, and access to all decorated walls was desirable. Since the exhibition hall was large enough to give up the previous wall-bound installation, it was initially considered to present the walls units of the offering chambers individually. For this purpose, it was planned to fix the blocks and fragments to a supporting metal structure, housed in with opaque glass walls. However, this way of presentation would again have been suppressive to the architectural quality of the exhibits.

At the beginning of our planning, the main issue was how to present these architectures in the Neues Museum. How would they compete in a museum from the mid-nineteenth century that was restored and rebuilt in the 21st century? And how could we deal with the complexity of these important sacred buildings torn from their context in an appropriate manner?

The inventory undertaken by us showed that the offering chambers were preserved almost completely. Only the lower rows of blocks were missing since there was no decoration and therefore left behind by Lepsius. Apart from that, few more blocks were missing, and the remaining pieces showed partial damage and breakouts. The main interference to the original, however, was the reworking of blocks in the 19th century, which left them very thin and sometimes strangely shaped.

During the mock-up phase, we soon found that we wanted to set up the offering chambers as self-supporting structures, without secondary constructions or claddings. Visitors should feel thrown into the architecture of the Old Kingdom, which should be self-explanatory as far as possible. Apart from focusing on the architectural character, the important reliefs and hieroglyphs had to be made accessible. We wanted to emphasize that these are not just buildings, but interior spaces. Moreover, we thought that it was important to leave the somewhat brutal reworking of the originals by Lepsius' stonemasons recognizable.

Fundamental to our plan for the presentation were the original dimensions and construction principles. In order to rebuild the chamber's stone by stone, it was necessary to supplement the thinned blocks to obtain sufficient depths, and missing pieces had to be replaced. Because of the narrow character of the chambers, a construction above the original floor plan was not possible if all interior were to be accessible. Alternatively, a presentation by opening the structure would have impacted on the original architectural dimensions.

In our final design we stuck to the Old Egyptian floor plans but suggested to expand the interior space along the diagonals, to enlarge the architecture of the chambers and create an entrance and exit. As a result, visitors could walk through the chambers and see the decorated walls without causing traffic jam (fig. 2).

The original narrow entrances could remain closed, without interfering with the character of an interior space, and, moreover, the impression of being in a chamber. Repairing the thinned blocks by insertion of stone additions, a self-supporting set of walls could be erected without any supporting structure. Since the original thickness of blocks was not known, the size of stone additions required was determined randomly. When designing the reassembly of blocks with new stone elements, we worked with changing thicknesses to imitate keys and slots, in a way the wall sections could have been integrated into the bigger structure of the *mastaba*. The picture created on the exterior opposed to the idea of an intact building, and at the same time aided the perception of an interior space.

Integration and completion

When it became obvious that the use of stone integration was required for the reassembly of the offering chambers, general criteria were defined. With the aim to emphasize the original and to create a clear line for the reconstruction, the use of stone additions had to be limited to the required extent. They were foreseen to be used where necessary for structural purposes of the self-supporting walls, towards a homogenous appearance where needed to improve legibility of the images – or to highlight essential aspects of the exhibits, such as proportions or functions.

Using a uniform integration material, based on white cement with calcitic aggregates, and employing consistent design principles, a homogenous appearance of the re-erected ancient Egyptian architecture could be achieved. Colour and structure of the retouching material were based on the average colour tone of the original. The repair aimed to consolidate and to harmonize aesthetically, thus no reconstructions of the carvings were planned. To blend in the repaired areas, surfaces would be slightly roughened to mediate the various preservation states and surface finishes present. Finally, the new integrations – sometimes large-scale – should be reluctant and consistent in appearance, to remain optically in the background and thus discreetly support the original.

The inhomogeneous finish of the blocks at the exterior of the chambers – a mixture of ancient tool traces, traces from dismantling the chambers by Lepsius' stonemasons, and the cubic new additions were intended to underline the history of the object.

In a first step, this conceptual approach was verified in a mock-up. For this purpose, required additions and insertions were prepared for one segment of the offering chamber of Metjen. This included precisely worked insertions for damaged originals, and replacements for completely missing components. After designing an optically and physically suitable artificial stone, we took negative molds from the surfaces of the originals, produced positive molds and poured the supplements. Even though the additions looked good in terms of colour and structure, and had a good fit to the originals, the weakness of the method became evident during this mock-up: the required precision for the set-up, in regard to dimensions of the additions and the extremely fine joints, was not to obtain by producing single block additions. We were faced with several gaps between the components. Although the appearance of the architecture of the Old Kingdom is highly precise, the individual blocks are not necessarily right-angled, the joints are not exactly perpendicular or horizontal, and the surfaces are not plane. It turned out that we would not be able to master a construction that was to meet the original impression using traditional methods. In addition, the molding of the original posed a considerable stress to the delicate limestone surfaces, which we wanted to exclude from the project.

A new planning tool

The need for a new planning tool was obvious, if we were to implement our concept. After first small-scale experiments, we learned that it was possible to measure damaged or missing areas in complex architectural structures through a scanning process and to calculate highly precise additions on this basis. The physical additions could be produced using the obtained data, without touching the antique originals.

To illustrate the precision of the Old Egyptian architecture even in the re-installation in the Neues Museum, both the whole construction and the execution of the integration had to be carefully planned. This seemed possible applying the innovative 3D scanning technique, which seemingly had not been used in this dimension in comparable museum projects until 2004. After some research and mistakes, we finally found the right method and the competent teams we needed. With an accuracy of 0.1-0.3 millimeters, we measured the original blocks and fragments all-round with strip-light scanners.

The non-contact measurement data provided the basis for the development of three-dimensional computer models. Based on the drawings and dimensions of the excavator Richard Lepsius, the measured original pieces were combined to virtual models of the offering chambers (fig. 3).

These virtual models formed the basis for the determination of suitable additions and necessary new blocks. During the entire planning process the degree of supplementation and the overall appearance of the offering chambers could thus be checked and corrected in consideration of Egyptological, technical and aesthetic aspects as well as in terms of conversation.

The single data of each loss would be taken from the model and then be used for creating precise replacements. Since stone additions were prepared in cast technique, models had to be produced using a computerized controlled CNC multi-milling machine. Smaller shapes could alternatively be produced with 3D printers.

This method employed us with a tool to define all required integrations precisely in the planning process. Due to the complexity of geometries and morphologies present in the numerous fragments of the offering chambers, obtaining exact data by individually measuring each surface and fragment by hand would not have been possible (fig. 4).

Since the direct molding of the fragile and sensitive limestone surfaces was problematic, the development of a gentle and contact-free method for the completion of fragmented and sensitive exhibits was a great success.

To take measurements from all four sides of the objects, single units were turned and positioned in the depots or later in the workshops of the restorers who carried out the preservation, supplementation, and erection. The development and review of the complete models were carried out interdisciplinary, including members of the Egyptian Museum and our planning team. Data required to produce the additions and replacements were provided to the restorers who used them to produce negative molds. Thus, the originals came into contact with the supplements when they were connected, only.

Conclusions

After the Second World War, the Neues Museum remained a ruin for almost fifty years. The rebuilding under the aegis of David Chipperfields, showered with awards, made it a functional and contemporary museum building. Like in an architectural collage, it presents its own time layers, fragments, and newly built areas. The museum with its collections provides a sometimes overwhelming abundance of impressions, an almost baroque opulence. Exhibits are competing with fragmented murals, ceilings, terraz-

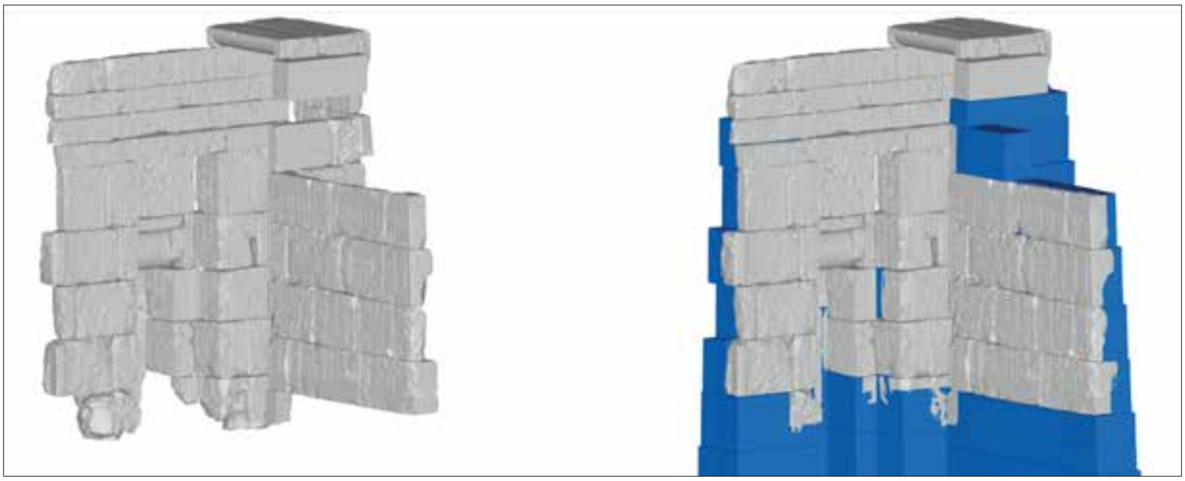

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Fig. 3. Offering chamber of Metjen: employing the 3D scan data, each architectural element could be individually calculated and virtually put together to a complete model. With this model, the new pieces could be planned, calculated and produced. *Screenshot ArcTron*.

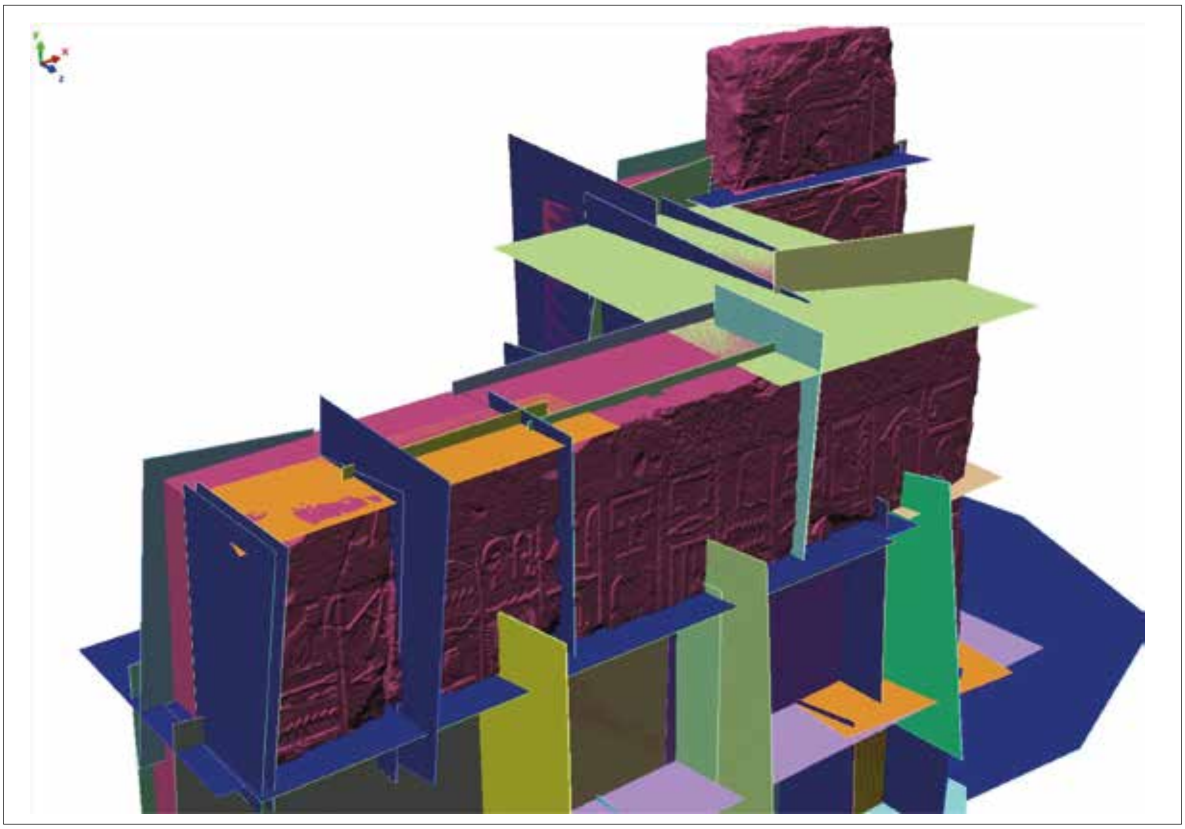

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Fig. 4. Offering chamber of Metjen: collision model. *Screenshot ArcTron*.

zo floors and columns, and often the building is described as an exhibit itself.

The fact that the Historical Room was chosen to house the reassembled offering chambers made us very happy. This new exhibition hall, which is made of a light artificial stone, offers the perfect calm background to fully appreciate and understand the Old Egyptian architecture in this new way of presentation. The prosaic design of the room does not detract attention from the exhibits opposed to rooms with rich decoration remained. In addition, the material used by Chipperfield for the ceiling, the walls and the floors harmonizes perfectly with the limestone of the offering chambers and their artificial stone additions.

The fact that our concept for the presentation of the offering chambers differed very little from Chipperfield's design for the entire museum emerged in an early stage of our planning process. The way to appreciate the original, and to design necessary new additions was quite comparable. Besides the sometimes threatening conservation issues, it was of particular interest to us how the chambers would interact with the Neues Museum in terms of ambiance. The visitor's encounter with the offering chambers should be close to the immediacy of archaeological sites. The challenge was to present the chambers as if in a bright daylight walkable architecture, to show the historical construction and decoration, and also to present the recent history, which includes the dismantling in Egypt in the middle of the 19th century to the current re-erection. And last but not least, we wanted the exhibits as self-explanatory as possible.

When we developed our idea for a new museum presentation, the questions of construction principles

Fig. 5. The offering chamber of Merib in the Historical Room of the Neues Museum. *Photo RAO.*

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and how to deal with losses were of outrageous importance in terms of scientific, technical and design aspects. At that time, however, we did not yet have the right tool to implement our idea. The 3D scanning technique, this useful instrument, was introduced to the project at a later stage only. Thanks to the virtual models produced by the 3D scan technique, the offering chambers could be planned and re-built in a very precise manner, obtaining sculptural architectures, which today are exhibited in the Historical Room of the Neues Museum. Moreover, a gentle and non-contact production of additions for missing parts could be implemented using this technique (fig. 5).

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THE AUTHOR

Thomas Lucker
Restaurierung am Oberbaum GmbH (RAO), Berlin.

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Neues Museum, camere delle offerte, Antico Regno, produzione senza contatto, Richard Lepsius, Friedrich Rathgen, David Chipperfield

ABSTRACT

THE RE-ERECTION OF OLD KINGDOM OFFERING CHAMBERS IN THE NEUES MUSEUM BERLIN
After the Second World War, the Neues Museum Berlin remained a ruin for almost fifty years. The rebuilding under the aegis of David Chipperfields made it a functional and contemporary museum building. Like in an architectural collage, it now presents its own time layers, fragments and newly built areas. For the reopening in 2009, three offering chambers of the Old Kingdom, which had been on show already in the 19th century, were re-erected according to a new concept. To meet the complexity of these four and a half thousand years old buildings a new planning tool had to be implemented. Based on 3D scan technique, virtual models of the chambers were developed. These models were used for designing the appearance of the offering chambers in the exhibition hall as well, as for the contact free production of necessary integrations.

LA RIEREZIONE DELLE CAMERE DELLE OFFERTE DELL'ANTICO REGNO NEL NEUES MUSEUM DI BERLINO
Dopo la Seconda guerra mondiale, il Neues Museum di Berlino è rimasto in rovina per quasi cinquant'anni. La ricostruzione sotto il patrocinio di David Chipperfield lo ha reso un edificio museale funzionale e contemporaneo. Come in un collage architettonico, ora presenta i suoi livelli temporali, i frammenti e le aree di nuova costruzione. Per la riapertura nel 2009, tre camere delle offerte dell'Antico Regno, che vennero esposte già nel XIX secolo, sono state rierette secondo una nuova concezione. Per soddisfare la complessità di questi edifici che risalgono a quattro mila e mezzo anni fa doveva essere implementato un nuovo strumento di pianificazione. Sulla base della tecnica di scansione 3D, sono stati sviluppati modelli virtuali delle camere. Questi modelli sono stati utilizzati sia per progettare l'aspetto delle camere delle offerte nella sala espositiva, sia per la produzione libera contigua per necessarie integrazioni.

DIGITAL RECONSTRUCTION, 3D-PRINTING AND AUGMENTED REALITY

Virtual reconstruction of a historical design exhibition

Donatella Biagi Maino, Michela Gazziero, Giuseppe Maino

We present a virtual restoration consisting in the three-dimensional reconstruction of an artwork that does not exist anymore but is still documented.

The use of image processing graphics with 3D modeling software and raster graphics, allows us to obtain pictures and videos to be shown in exhibitions or in a museum, describing a restoration or the hypothetical original aspect of an artifact alongside with the original object, but by these tools it is also possible to preserve the historical memory of a cultural value that is no longer physically present, according to the today commonly adopted definition of virtual restoration [Biagi Maino *et al.*, 2017].

Within this theoretical framework, the 3D graphics rendering is performed of the "living environment" (*Ambiente di soggiorno*) staging – shown in figure 1 – of the great Italian architects and designers, Achille and Pier Giacomo Castiglioni brothers, presented in the exhibition "Colori e forme della casa d'oggi" held in 1957 in Villa Olmo, Como [Gelpi, 1957].

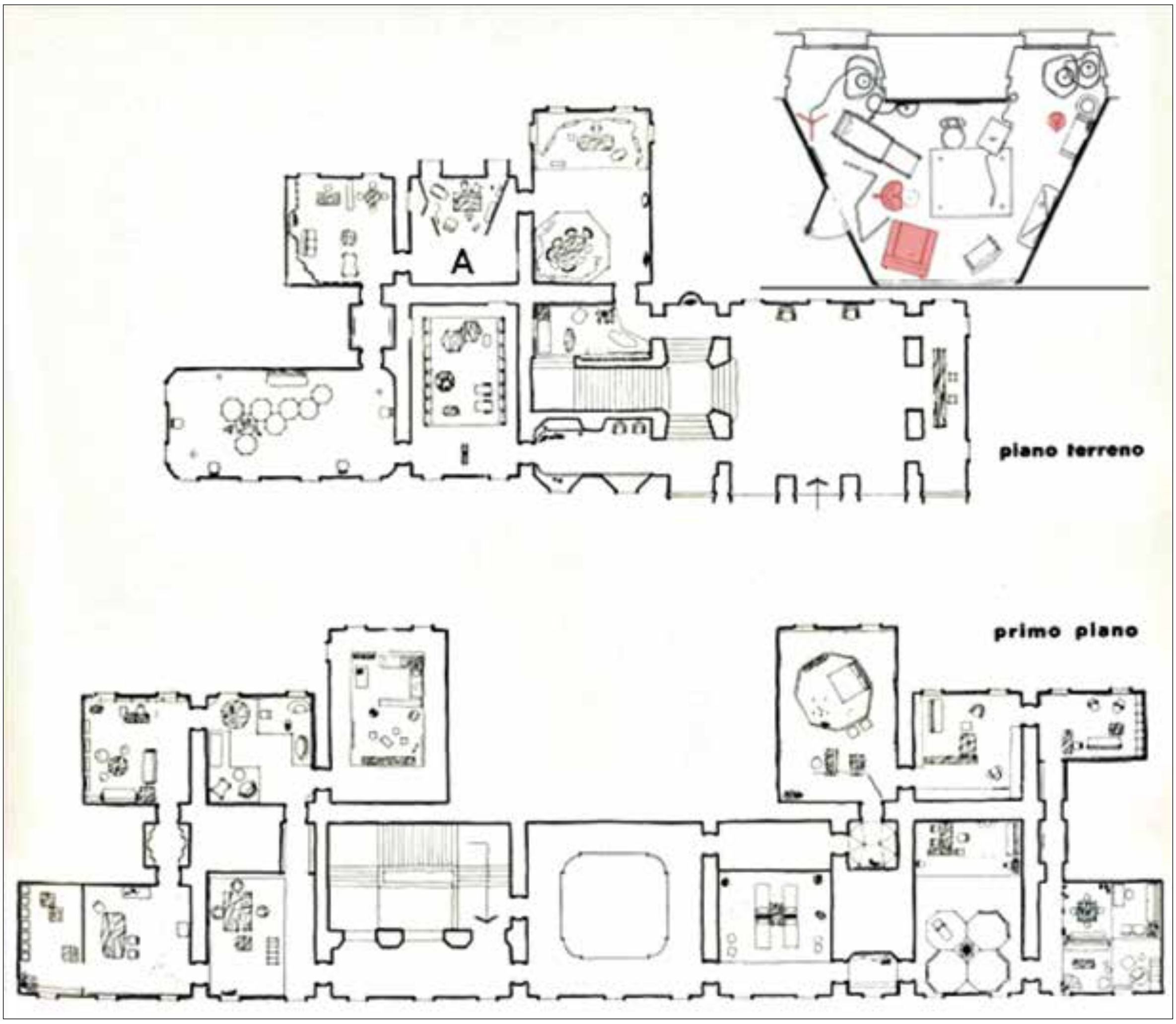

Fig. 1. Planimetric scheme of the exhibition at Villa Olmo: the Castiglioni's room is labeled "A" and shown enlarged in the top right corner. *From Gelpi, 1957.*

This historical exhibition – where a completely modern house has been built by the most renowned architects of that period, each one planning and realizing a single particular room – has been set up inside the Villa and as such has been of short duration, no longer visible, today remembered only through a black and white photographic documentation of objects and environments. The layout of the Castiglioni brothers, was of great value and importance because of their innovative ideas, arousing curiosity and interest, even today (figs. 2, 3). The whole exhibition aimed to an attempt at synthesis among architecture, art and industrial design, inviting the most important Italian designers to propose environments in collaboration with artists and companies. Therefore, due to the presence of artists such as Lucio Fontana, Mario Radice, Francesco Somaini and Salvatore Fiume as well as architects such as Giò Ponti, Bruno Munari, Franco Albini, Angelo Mangiarotti, Marco Zanuso, Enzo Mari, BBPR group (composed by Gian Luigi Banfi, Lodovico Barbiano di Belgiojoso, Enrico Peressutti and Ernesto Nathan Rogers) and Castiglioni brothers, the exhibition begun an act of consecration of the modern Italian Design.

The 1957 Villa Olmo exhibition

As you walk through Villa hall's entrance, suspended in space for the entire height of the Villa's hall, a white plastic of Bruno Munari realized as a "mobile" by Alexander Calder, welcomed visitors. The exhibition was sponsored by the town of Como, the Lombardia region and the committee chaired by the mayor of Como, Lino Gelpi. Promoted by several companies[1], the exhibition proposed the most advanced and innovative results of the new Italian Design industry, that will be well-known and appreciated in the whole world within a very short time. The participation was an invitation by the Executive Technical Committee; free participation was allowed only in the case of groups of designers, artists and industrial firms or crafts. The projects were selected by the jury, established by the Executive Technical Committee, directly responsible of the program for the exhibition itself.

That was the first attempt to bring the quality so far achieved in the technical research, in the modern, industrially produced, design of the house. The furniture of living rooms had been previously experienced only in the unique craftsmanship. Moreover, intent of the exhibition was to make a positive contribution to the formation of a taste and a sensitivity corresponding to contemporary life. The event was intended to awaken the spirits around the vast cultural and productive sector that developed after the war, especially in the city of Milan that had involved cultural phenomena related to a broader social and territorial area.

All the architects working on with the exhibition provided a documentation as a reference of common interest and exchange of ideas among professionals. Each architect chose freely among her/his collaborator's graphics, sculptors or painters to create a complete picture of functional environments. The theme of the exhibition was the relationship between the modern and ancient environments in a house, where only some of the invited architects, including the Castiglioni brothers, were involved in the conception and practical realization of living rooms.

In the exhibition catalogue, all the rooms set up in 1957 are shown, but only a few black and white photographs have been taken to document the thinking and the activity of the participant architects.

Rebuilt other times, proposing the same characteristics of the environment and the same utilized objects, the Castiglioni room of the "modern house" was presented in 1966 in the Fly Center of Milan, in 1977 in the Kappa Center in Noviglio, Milan. Then, it has been proposed in the traveling exhibition, "The Castiglioni", started from Barcelona in 1993 (from which it was possible to deduce the colours of the whole display, as shown in figure 4, since the relevant images of previous years were always in black and white) and landed at De Beyerd Museum in Breda at the end of 1998. Finally, it stopped at the Vitra Design Museum in Switzerland and at the MoMA in New York [Mazzé, 1994; Gazziero, 2011].

The environment of Castiglioni was distinguished among all others since their proposal was inventive and fun, but also the most revolutionary, very unusual for the spirit of that time. The attention to details and the particular care in choosing the exposed objects and the furniture whetted the curiosity and it is still thought-provoking. The presence of new objects designed by themselves was

Fig. 2. The Castiglioni room at the Villa Olmo exhibition, 1957. *Photo Studio Museo Achille Castiglioni*.

Fig. 3. The Castiglioni room from a different point of view. *Photo Studio Museo Achille Castiglioni*.

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Fig. 4. A picture of 1993: Achille Castiglioni inside the "living environment", reconstructed for "The Castiglioni" exhibition in Barcelona, Spain. *Photo Studio Museo Achille Castiglioni*.

fundamental and gave life to the planned area. All of them were well chosen and have become standard products, yet produced today by industries.

The Castiglioni architects present a living environment, meaning the living space as the sum of individual objects, partly taken from their own production, in part of an anonymous design, to express a new form of living, between tradition and modernity (fig. 5). The environment – according to Castiglioni's choice – must be filled with the right things to go along well, providing particular attention how things are used. Therefore, the living room hosts objects such as *Cubo* armchair, the *Sella* and *Mezzadro* (fig. 6) chairs, the *Luminator* lamp, the library roof, along with the cardboard screen, the *Thonet* chair no. 14, even the stool for milker!

There were also classic objects like the wicker basket or the wooden folding chairs, finally, it is worth noticing the presence of water with a fountain in cast iron. "In every room there is electricity, but there is also water, which is rather useful for watering plants or paint with watercolours. [...] The table is a simple one that lends itself to being "ruined", the children can draw with markers and then – when they have done playing – it is covered with a tablecloth of Flanders", as Achille Castiglioni said in a 1988 interview [Mazzé, 1994]. There was also a mobile television hanging from the ceiling with wires and downs.

The floor was made of cooked dry, like the terracotta tiles of a barn (built as the floor of the showroom of Dino Gavina in San Lazzaro, Bologna [Gavina, 1998]), in colouring contrast with the white walls and objects' colours. The room also contains a painting of Castiglioni's father,

5

Fig. 5. Objects are shown in the Castiglioni room at Villa Olmo exhibition, 1957; these images show the original objects, now preserved in the Studio Museum Achille Castiglioni, Milan. *Photo by the authors*.


6

Fig. 6. The *Mezzadro* chair, 1957. *Photo Studio Museo Achille Castiglioni*.

Giannino Castiglioni, dated 1908. The mural decoration made by Giuseppe Ajmone was performed with openwork preconceived moulds, that can be produced in series.

During the exhibition, rebuilt in Barcelona, some colour photographs have been taken[2] [Polano, 2006: 82-127, 277; Ferrari, 1982: 53; Polano *et al.*, 2002: 119-121], and from them, it was possible to deduce the colours of the environment and its wall decorations. The original objects, conserved in the Foundation were photographed by us with a digital camera and then reproduced in 3D models, as explained in the following section.

3D virtual reconstruction of the living room

We consider essential a suitable documentation and preservation of the cultural value that this project of living room still expresses in the field studies of design projects, and thus we intended to virtually reconstruct the room by using Autocad 3D Software. Then, we realized a rendering photorealistic view by means of Cinema 4D Software.

The computer-aided design of any object employs a geometric virtual processed model through the use of specific software and hardware for mathematical modelling of surfaces and solids. The use of Autocad program based on CAD (Computer Aided Design) system is a standard solution, where one can replay the supposed geometry of the artifacts through digital representation and manipulation procedures. It was thus possible to create the shapes of objects placed in the size scale within the virtual environment, adequately developed to open 3D virtual scenarios and perspectives for getting printable digital images, from a virtually existing model through the detection of spatial coordinates.

The virtual model of the space (in the present case, the living room) has been then produced in an editable DXF format, but a huge amount of information has to be further elaborated. We can obtain virtual models for static or dynamic simulations of the interaction of the users with designed objects and environment. Once obtained the virtual model of each object in its details of shape and size, the 3D rendering of the environment is carried out according to the photos of the original assembly in Villa Olmo and those in colours relevant to the exhibition rebuilt in Barcelona in 1997 when Achille Castiglioni was still alive.

Each object has then reproduced its structure in digital format with a texture reproducing the original materials at best. This processing is performed with specifically graphics programs of image processing, namely Cinema 4D, capable of powerful features, that allow the definition of surface materials through simulations and colour attributions such as hue, saturation, brightness and transparency, as well as the application of coatings, bosses, embossing, etc. Other algorithms allow the resolution of optical parameters such as the lighting of the environment through differently positioned virtual light sources – deduced from the b/w images taken at the time of the Como exhibition –, reflections and shadows in different colours of environmental points, or even spots. An exact calculation of reflections and refractions of the materials can be thus obtained.

Therefore, the virtual project of the "living environment" so implemented, is the initial step to a possible development of increasingly sophisticated projects that could also lead to the creation of a real model in 1:1 scale of objects (made for example in resin by means of a 3D printer). Moreover, one can use our result as an exemplary website exhibition bearer of a cultural value worthy to improve a communication and dissemination to large numbers of users, without the risk of damaging the original objects since they are prototypes worthy of a proper and accurate conservation, and therefore cannot be used and handled.

The images of figures 7-9 represent the phases and the results of the present work.

Concluding remarks

Nowadays, "knowledge of a cultural item" means to define it not only in its material (tangible) terms but also immaterial ones (intangible cultural heritage). The virtual restoration or reconstruction of an artistic work or its context is essential in order to provide a cultural exchange.

One of the most interesting digital processes applied to the cultural heritage is the virtual restoration. For instance, accurate separation of the different colour components allows evaluating the relative intensities of various colours on the artwork to be restored and to learn about the different components and make appropriate assumptions about the different materials and compounds to be used in the restoration itself. All this information is of basic importance as an aid in preparation for a effective restoration, but also to check the quality of a previous intervention.

The virtual restoration is not limited to these activities, but also extends to the reconstruction, through appropriate programs and algorithms, of some damaged or missing parts of an artistic work. Some techniques can also be used to recognize latent or hidden parts and to bring them to light for a deepest interpretation of the artistic work and its execution techniques.

7

Fig. 7. The virtual model of Castiglioni "living environment".
Photo by the authors.

8

Fig. 8. Another view of the virtual model of Castiglioni "living environment".
Photo by the authors.

9

Fig. 9. Details of the wall decoration.
Photo by the authors.

Moreover, as shown in this article, the objective reality of 3D simulations provides observable representations in an interactive way from different points of view. You can get a virtual navigation, that is a virtual tour of a place reproduced with captivating realism. This augmented value enlarges our vision and knowledge of the cultural heritage, with benefits on the enjoyment and on the content of information. Through 3D techniques, one can also reach the reality in "four dimensions" when the historical (time) dimension is added to the space simulation, namely the perception of what was present in the past virtually reconstructed to live virtually today.

The results of the virtual prototyping are photorealistic images of the type that could eventually lead to experience the presence of an object designed in a virtual world. By this way, the memory of a cultural value is preserved and a visitor is able to interact with it even in the absence of a physical reality.

NOTES

1. Like Anic, Arflex, Arteluce Bassani Ticino, Cassina, Fiat, Kartell, La Rinascente, Olivetti, Piaggio, Poggi, Sambonet, Techno and Zerowatt.

2. Today they are preserved at the Studio Museum Achille Castiglioni in Milan.

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ABSTRACT

VIRTUAL RECONSTRUCTION OF A HISTORICAL DESIGN EXHIBITION

Art exhibitions, theatre performances, concerts and ballets are an important part of our cultural heritage and their essential representation is preserved through appropriate records that, however, still offer a partial refund of the event. 3D modeling can be an interesting alternative and a complement to traditional still recording. In this article, we present a virtual reconstruction of a domestic environment, designed and built by Achille and Pier Giacomo Castiglioni architects, on the occasion of the earliest and most important exhibition of Italian Design, held in the year 1957 at the Villa Olmo, Como.

RICOSTRUZIONE VIRTUALE DI UNA MOSTRA STORICA DI DESIGN

Mostre d'arte, spettacoli teatrali, concerti e balletti costituiscono una parte importante del nostro patrimonio culturale e di essi la rappresentazione essenziale viene conservata attraverso apposite registrazioni che, tuttavia, offrono solo un aspetto parziale dell'evento. La modellazione 3D può rappresentare un'alternativa interessante e un complemento alle tecniche di registrazione tradizionali. In questo articolo presentiamo una ricostruzione virtuale di un ambiente domestico, progettato e realizzato dagli architetti Achille e Pier Giacomo Castiglioni, in occasione di una delle prime e più importanti mostre di design italiano, tenutasi nel 1957 a Villa Olmo (Como).

KEYWORDS

3D model, virtual exhibition, design, cultural heritage, virtual restoration

modello 3D, esposizione virtuale, design, patrimonio culturale, restauro virtuale

THE AUTHORS

Donatella Biagi Maino
Dipartimento di Beni Culturali, Università di Bologna; Scuola di Lettere e Beni Culturali, Ravenna Campus.

Michela Gazziero
Dipartimento di Beni Culturali, Università di Bologna; Scuola di Lettere e Beni Culturali, Ravenna Campus.

Giuseppe Maino
Dipartimento di Beni Culturali, Università di Bologna; Scuola di Lettere e Beni Culturali, Ravenna Campus.

GRU Gruppo Restauratori Uniti

ANEDBC

DIGITAL RECONSTRUCTION, 3D-PRINTING AND AUGMENTED REALITY

Rilievo ed elaborazioni 3D per il restauro

Esperienze dell'Opificio delle Pietre Dure di Firenze

Laura Speranza, Mattia Mercante

Premessa e concetti di base

L'impiego di scanner digitali tridimensionali nel campo dei beni culturali è ormai pratica consolidata ed è per questo motivo che l'Opificio delle Pietre Dure si è voluto dotare di una moderna strumentazione per l'acquisizione digitale di dati morfologici e di immagine. È una strumentazione volta principalmente al rilievo di manufatti scultorei, ma utile anche per superfici architettoniche[1] e opere su supporti planari[2].

Il settore "Materiali ceramici, plastici e vitrei" ha voluto investire in tecnologia utile per l'acquisizione 3D, rendendosi autosufficiente nel conservare, consultare ed elaborare informazioni sul bene culturale a un livello più profondo di quello consentito dalla campagna fotografica tradizionale.

I dati ottenuti non si limitano alla mera rappresentazione della forma e superficie del manufatto, ma consentono una lettura trasversale e complessa dell'opera. Tutte le informazioni spaziali sono disponibili, aprendo la ricerca a molteplici campi di applicazione.

Le finalità sottese alla pratica di implementare le tecniche di rilievo, modellazione e restituzione per i beni culturali presso i laboratori dell'Opificio delle Pietre Dure di Firenze confluiscono in sette principali motivazioni:

- indagini metriche, ovvero l'acquisizione dei dati dimensionali e morfologici;
- creazione di archivi digitali per una completa ed esauriente consultazione, anche in remoto, di informazioni "multilivello", ovvero sovrapponibili e interconnesse tra loro;
- indagine sulla tecnica artistica e sui materiali costitutivi;
- monitoraggio e valutazione del degrado;
- progettazione dell'intervento di conservazione e restauro;
- creazione di "calchi digitali" e loro traduzione fisica a scopi di ricerca e didattica, creazione di integrazioni materiche per il restauro;
- produzione di documentazione multilivello per la fruizione e valorizzazione dei beni culturali con finalità didattica e di comunicazione.

L'Opificio delle Pietre Dure sta intraprendendo, in modo continuativo e strutturato, l'integrazione delle suddette finalità nelle attività di restauro e, a partire dal 2016, si propone come fornitore di servizi anche per esterni all'Istituto.

Tecniche e tecnologie di rilievo 3D sono molteplici e coprono quasi tutte le tipologie di "oggetto" reale, sia su scala macroscopica che microscopica.

I dati acquisiti dagli strumenti vengono tradotti in "nuvole di punti", insiemi di punti non strutturati disposti nello spazio XYZ. Ogni punto può contenere, oltre alle informazioni spaziali, anche informazioni di colore e altre peculiari dello strumento di rilievo. La traduzione in termini di diagnostica consiste nel poter restituire non solo la morfologia della superficie scannerizzata, ma applicare a essa il colore dell'oggetto in modo da ottenere un dato "fotografico" sovrapposto a quello spaziale[3].

L'insieme di punti 3D viene poi "strutturato" dal software, che, con algoritmi dedicati è convertito in una superficie virtuale mediante unione dei punti a formare superfici piane triangolari. Più è densa la nuvola di punti, più triangoli verranno generati e maggiore sarà la precisione (e realismo) della scansione.

Le strumentazioni per ottenere le nuvole di punti possono essere varie e tra loro molto diverse, ma le tecniche di acquisizione su cui si basano sono principalmente due: quelle a sensori ottici attivi[4] e a sensori ottici passivi[5]. Nel primo caso lo strumento utilizza una peculiare sorgente luminosa. Un emettitore (laser o proiettore) invia segnali che vengono registrati da un sensore e codificati dal software. Le tecniche "a sensori attivi" possono acquisire dati in base a tre distinte tecniche di calcolo: triangolazione, tempo di volo[6] e differenza di fase[7].

Nel caso di sensori ottici passivi la fonte delle informazioni da elaborare parte da immagini o riprese video (mediante fotocamere e videocamere) di soggetti illuminati da luce ambientale. Il dato di partenza è quindi una serie di fotografie o una ripresa video. Esempi sono la profilometria e la fotogrammetria. Poiché le principali differenze tra sensori attivi e passivi risiedono nella precisione del dato e accuratezza della misurazione, frequente è la combinazione delle due tecniche.

TORNA AL SOMMARIO

La scelta della strumentazione

La scelta della strumentazione adeguata allo scopo è vincolata alla tipologia di beni culturali di interesse del settore di restauro. Le tipologie scultoree possono essere di dimensioni molto variabili, da pochi cm^3 fino a estese decorazioni architettoniche e apparati scultorei, essere polimateriche e avere un'ampia gamma cromatica e diverse finiture superficiali, nonché avere diversi livelli di accessibilità, cioè possono essere studiate nei laboratori o raggiungibili presso il cantiere di restauro.

Alla luce di queste problematiche la scelta si è indirizzata verso una strumentazione che avesse un'alta qualità nella resa dei dati, maneggevolezza, flessibilità d'uso e rapidità di acquisizione. La necessità di operare principalmente su elementi di statuaria, ha fatto ricadere la scelta sulla tecnologia a luce strutturata[8].

La rapidità d'esecuzione è molto spesso un fattore cruciale per determinare la fattibilità di un rilievo: nel settore della statuaria ci si trova spesso in condizioni non ideali per il posizionamento di uno scanner a postazione fissa[9], che richiede tempi protratti per una singola scansione; o tempi non adatti alle condizioni di poca stabilità e oscillazione di ponteggi e apparati per l'elevazione in quota. Inoltre scanner a postazione fissa hanno ingombri non trascurabili e limiti di manovrabilità. La scelta è ricaduta su strumentazione professionale nata per assolvere a esigenze di "reverse engineering"[10] nei campi della meccanica, produzione automobilistica e design industriale. Scanner "hand-held"[11] sono capaci di acquisire fino a mezzo milione di misurazioni al secondo, con un'accuratezza del dato di 0.3 mm/m e una risoluzione fino a 0.2 mm. La velocità e la precisione garantiti dalla tecnologia Ametek fanno degli scanner Creaform delle strumentazioni idonee alle nostre esigenze. Non è necessario mantenere una postazione fissa di ripresa e grazie alla tecnologia di auto-allineamento è possibile muovere lo scanner intorno all'oggetto: l'acquisizione viene registrata ed elaborata in tempo reale.

Questi scanner non possono sempre produrre l'intera gamma di dati necessari: occasionalmente, se richiesto nella campagna di rilievo, ci si avvale di scanner architettonici/ambientali o strumenti tarabili per micro-scansioni (o modificabili a seconda delle esigenze). Nel primo caso si opterà per scanner 3D a tempo di volo come quelli della Faro per rilievi di ampie aree, come porzioni di edifici, interne ed esterne. I rilievi ottenuti sono di minor dettaglio rispetto agli scanner a luce strutturata, ma le informazioni acquisite possono essere perfettamente sovrapposte, creando un primo rilievo "grezzo" su cui posizionare quello dettagliato. Se si necessita di scansioni di estremo dettaglio (con tempi di acquisizione maggiori e vincolo di immobilità dei soggetti coinvolti) ci si avvarrà di scanner a luce strutturata dalla configurazione e ottica modificabile, come quelli della HP (precedentemente commercializzati come David 3D Scanner della David Vision System).

Per quanto concerne la creazione di prototipi e integrazioni formali partendo da file 3D (rilevati o modellati) il laboratorio di "Materiali ceramici, plastici e vitrei" si è attrezzato di tecnologia FormLabs con stampanti stereolitigrafiche a resina liquida[12] utili alla creazione di oggetti fisici con caratteristiche diverse a seconda della tipologia di resina scelta. Ove richiesto dagli specifici progetti affrontati, ci si è anche avvalsi di servizi di stampa esterni.

Si illustrano di seguito esempi di come la compenetrazione tra diverse strumentazioni porti a soddisfare le richieste di documentazione, progettazione e intervento di restauro.

Esperienze e casi di studio

Grazie agli scanner e stampanti 3D di cui ci siamo dotati è stato possibile eseguire progetti di documentazione, ricerca, approfondimento, calco digitale e supporto al restauro.

Alcune delle esperienze, svolte a partire dal gennaio 2016, sono state le scansioni e prototipazioni per le seguenti opere:

- settantanove pezzi di cottura costituenti i dieci tondi raffiguranti putti in fasce di Andrea della Robbia, provenienti dalla facciata dello Spedale degli Innocenti, piazza della Santissima Annunziata, Firenze;
- la *Visitazione* di Luca della Robbia, San Giovanni Fuorcivitas, Pistoia, per la quale è stata eseguita anche una stampa 3D. La scansione è servita sia per la documentazione che per il progetto di restauro;
- la terracotta policroma raffigurante il Salvatore di Agnolo di Polo, Museo Civico di Pistoia;
- la terracotta policroma raffigurante la Maddalena attribuita ad Agnolo di Polo, ora esposta al Museo degli Innocenti in piazza della Santissima Annunziata, Firenze;
- una porzione del *Pannello di Cosimo III* di Grinling Gibbons, Tesoro dei Granduchi, Palazzo Pitti, Firenze;
- il *Pulpito della Passione*, opera bronzea tarda di Donatello, basilica di San Lorenzo, Firenze;
- una porzione di una formella della Porta sud del battistero di San Giovanni, Firenze, realizzata da Andrea Pisano;
- interni architettonici della *Grotta del Cardinale*, Palazzo Venturi Ginori, Firenze; per il cui restauro sono stati realizzati in stampa 3D prototipi per le integrazioni materiche;
- alcune porzioni del verso de *L'Adorazione dei Magi* di Leonardo da Vinci;
- porzioni dell'affresco raffigurante il Martirio di sant'Antonino Re di Appamia, presso il Chiostro dei Morti in Santo Spirito, Firenze;
- la scultura bronzea *Working Model for Oval with Points* di Henry Moore, Nasher Collection, Dallas;
- cinque sculture presso il Museo Fabre di Montpellier;
- tre sculture presso il Museo Zevallos di Napoli.

Queste ultime due campagne di scansione sono servite alla realizzazione di copie tridimensionali per la fruizione da parte di non vedenti.

A queste esperienze si aggiunge quella iniziata nel 2014 con il *Dio fluviale* di Michelangelo, presso Casa Buonarroti. Il lavoro di rilievo 3D si è affiancato a quello del restauratore ed è stato realizzato un modello in scala 1:1 della scultura, ipotizzandone l'originaria posizione e forma.

TORNA AL SOMMARIO

Di seguito vengono trattati in maggior dettaglio alcuni dei casi più significativi, al fine di esporre le possibilità offerte dalle tecnologie e conoscenze acquisite.

I dieci putti di Andrea della Robbia dallo Spedale degli Innocenti

Nel portico di una delle prime architetture rinascimentali di Brunelleschi furono aggiunti, verso il 1487, dieci tondi di maiolica in rilievo eseguiti da Andrea della Robbia, raffiguranti bambini in fasce. La finalità del rilievo è stata la documentazione del bene culturale ma anche la creazione di calchi digitali per una futura possibilità di replica dei putti ed eventuale sostituzione con gli originali.

Le scansioni sono state eseguite per la quasi totalità in laboratorio, una volta che i tondi sono stati smontati dalla facciata. Rilevati tutti i singoli frammenti di cottura, recto e verso, mediante scanner digitale tridimensionale a luce strutturata a postazione fissa. Due di loro, gli ultimi in ordine di smontaggio, sono stati scansiti anche in situ, con strumentazione portatile a luce strutturata, mediante l'uso di un cestello elevatore (fig. 1).

Dopo il restauro le parti sono state rimontate e ricollocate sulla facciata: l'esauriente documentazione grafica prodotta rende sempre accessibili anche le parti delle opere ora occultate nella muratura. Inoltre si sono ottenute delle "matrici" virtuali per un eventuale futuro progetto di replica degli originali. Partire dai dati 3D consente di ovviare ai problemi correlati al calco a contatto con siliconi: nessuna necessità di applicare il materiale da formatura sulle superfici originali, disponibilità delle matrici virtuali senza necessità di immagazzinare ingombranti gessi e siliconi, possibilità di generare delle repliche ingrandite di una percentuale variabile in relazione al tipo di materiale scelto per la copia finale.

Quest'ultimo punto è di cruciale importanza se la replica dovesse essere eseguita, come auspicabile, in terracotta. Partendo da una stampa 3D ingrandita del prototipo, sarebbe possibile ricavare dei calchi in negativo con la funzione di stampi per ottenere dei nuovi positivi in argilla. Con l'ingrandimento preventivo si potrebbe ovviare alla percentuale di ritiro, nell'ordine del 9-10 %. Il pezzo cotto manterrebbe dimensioni identiche all'originale.

1

Fig. 1. Rendering della scansione del putto n. 10.

TORNA AL SOMMARIO

La dimostrazione che il calco diretto produce copie di misura inferiore è esemplificata dai quattro putti alle estremità della facciata dello Spedale, che sono copie ottocentesche della manifattura Ginori, vistosamente più piccole dei tondi robbiani.

La Visitazione di Luca della Robbia di Pistoia

Il gruppo scultureo della *Visitazione* di Luca della Robbia, in terracotta invetriata, si compone di due figure di dimensioni naturali. Fu commissionato intorno al 1445 per l'altare della confraternita di Sant'Elisabetta nella chiesa di San Giovanni Fuorcivitas di Pistoia. La campagna di scansione digitale tridimensionale ha avuto lo scopo di ottenere una documentazione utile al restauratore e allo storico dell'arte. Una generale documentazione 3D prima del restauro fornisce un'istantanea a 360° sulle condizioni dell'opera all'arrivo nei laboratori del settore "Materiali ceramici, plastici e vitrei", mentre scansioni più approfondite e dettagliate forniscono la base per la progettazione dell'intervento di restauro.

Lo scanner a luce strutturata "hand-held" (fig. 2) ha consentito la ripresa dell'intera volumetria dei quattro pezzi componenti l'opera: le ridotte dimensioni dello scanner e la sua maneggevolezza hanno permesso di acquisire l'opera fin nelle parti interne, ove consentito dal modellato. In aggiunta, la possibilità di spostare lo scanner agevolmente intorno all'opera ha ridotto la movimentazione dei pezzi di cottura.

Il rilievo 3D ha consentito inoltre di creare un nuovo sistema di adeguamento statico dell'opera.

In origine le quattro porzioni della *Visitazione* erano unite mediante uno strato di allettamento in gesso o malta, al fine di stabilizzare i busti sulle gambe ed evitare slittamenti tra le parti con la conseguente scheggiatura del corpo ceramico. Le quattro parti costitutive sono modellate in modo da avere un buon incastro reciproco.

Nel nostro intervento si è preferito non impiegare una guaina di silicone, a favore di una stampata in 3D. Un approccio canonico avrebbe visto l'uso di materiale polisillossanico, steso direttamente sull'opera (previa protezione delle superfici), mentre con tecnologia di scansione e stampa 3D è stato possibile progettare e realizzare uno strato protettivo che combaciasse perfettamente con le due parti di ciascuna figura del gruppo, senza la necessità di movimentare la scultura né mettere alcun materiale a contatto durante le operazioni (fig. 3).

La nuova guaina svolge un doppio ruolo: sostenere e distribuire i pesi dei busti rispetto alle parti inferiori[13] e proteggere la terracotta e lo smalto dei bordi.

Per calcolare la corretta forma dell'elemento da realizzare è stata rilevata l'opera sia smontata che montata. Il modello digitale restituisce la volumetria e le superfici con una precisione massima di 0.5 mm, pertanto la creazione del "cuscino" ha rispettato la morfologia dell'opera, a cui si è adeguata con precisione.

Per la traduzione in oggetto reale si è optato per la stampa 3D. La disponibilità di una stampante stereolitografica FormLabs a resina liquida ha consentito la realizzazione all'interno del laboratorio. La resina (a base di esteri dell'acido metacrilico e foto-catalizzatori), una volta catalizzata, raggiunge un grado di durezza inferiore a quella della terracotta, salvaguardando la materia originale e proteggendola da urti e traumi meccanici. La parziale rigidità della stampa 3D consente inoltre di avere una posizione univoca in cui collocare i busti, senza dover effettuare spostamenti ulteriori per trovare un corretto

2

Fig. 2. Scanner 3D "hand-held" durante la ripresa e l'allineamento delle superfici, in tempo reale.

TORNA AL SOMMARIO

incastro tra le parti. Un ulteriore vantaggio nell'uso della prototipazione rapida è la possibilità di condividere il file 3D e stamparlo senza essere vincolati a una specifica macchina e luogo. Se, ad esempio, la guaina si dovesse rompere accidentalmente durante la movimentazione per prestiti a mostre, il file potrebbe essere inviato sul posto e nuovamente stampato.

Il *Pannello di Cosimo III* di Grinling Gibbons a Palazzo Pitti

Il pannello ligneo, realizzato tra il 1680 e il 1682 dall'intagliatore di origini olandesi Grinling Gibbons (1648-1721), venne commissionato da Carlo II Stuart come dono per Cosimo III de' Medici per suggellare l'alleanza fra l'Inghilterra e la Toscana. Subì i danni dell'alluvione del 1966 a Firenze e di un incendio nel 1985. A causa delle vicissitudini subite e per l'estrema fragilità costitutiva, l'opera presenta alcune lacune materiche. Al termine del restauro eseguito da Maria Cristina Gigli presso i laboratori dell'Opificio delle Pietre Dure, si è scelto di integrare in modo sperimentale un'ampia mancanza di decorazione nella parte superiore dell'opera: un ricciolo vegetale con racemi e foglie. Vista la grande difficoltà che comportava l'intaglio di questo elemento, si è optato per la creazione di un ricciolo in resina stampata, realizzato grazie al rilievo 3D di un elemento speculare originale.

Rilevato con uno scanner a luce strutturata in grado di raggiungere fino a 0.2 mm di precisione, il ricciolo di sinistra è stato modificato con software di editing 3D: riflesso sull'asse verticale e adattato nella forma e posizione. La parte lacunosa è stata anch'essa rilevata con il medesimo scanner al fine di avere un file con le esatte condizioni di contatto tra integrazione e forme esistenti. Il nuovo elemento è stato rimodellato interamente sulla base della scansione, preservando quindi le soluzioni formali e tecniche dell'artista (fig. 4).

Non vi è stata alcuna invenzione o aggiunta, limitandosi ad adattare quanto rilevato nella nuova posizione. Le parti in contatto sono state eseguite per sottrazione di volumi geometrici, ottenendo raccordi estremamente precisi. Infine il modello digitale è stato reso fisico mediante prototipazione con resina stereolitografica. L'integrazione è cava internamente, in modo da contenere il peso.

Vincolato mediante incollaggio e un piccolo perno interno, il nuovo elemento è stato accordato cromaticamente al contesto (fig. 5). Tutte le operazioni, dal rilievo al montaggio, sono state svolte all'interno dell'Opificio.

Il *Pulpito della Passione* di Donatello della basilica di San Lorenzo

Il *Pulpito della Passione* è una delle ultime opere autografe di Donatello, databile alla seconda metà del XV secolo. Presenta fregi su pannelli bronzei con gli episodi dell'Orazione nell'orto, di Cristo davanti a Pilato e a Caifa, della Crocifissione, del Compianto e della Sepoltura.

Il pulpito è stato rilevato con un triplice scopo: documentare il bene culturale, analizzare il modellato studiandone gli aspetti compositivi e prospettici e fornire delle basi per la creazione di nuovi supporti.

I rilievi sono stati eseguiti con strumentazione a postazione fissa laser[14] e con scanner portatili a luce strutturata. Lo scanner laser ha fornito una base a bassa definizione dell'interno ed esterno del pulpito, mentre lo scanner SL ha permesso di rilevare il modellato in bronzo in tutti i suoi dettagli. Le scansioni complessive a bassa risoluzio-


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Fig. 3. Base della scultura con sovrapposizione della guaina stampata in 3D presso l'Opificio.

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Fig. 4. Rendering del file rimodellato sulla base delle scansioni, pronto per la stampa.

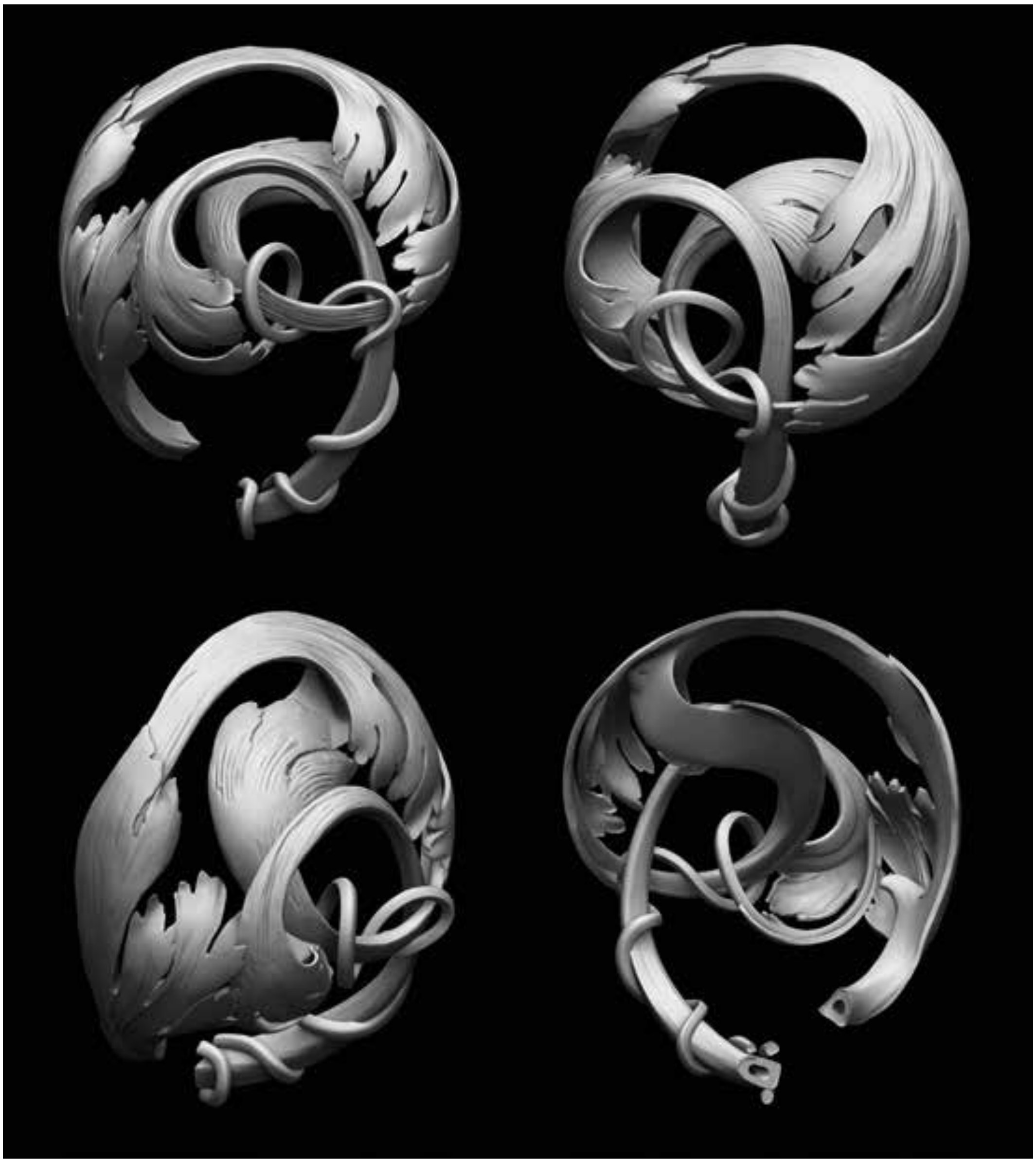

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Fig. 5. La stampa 3D in resina stereolitografica prima dell'accordatura cromatica.

5

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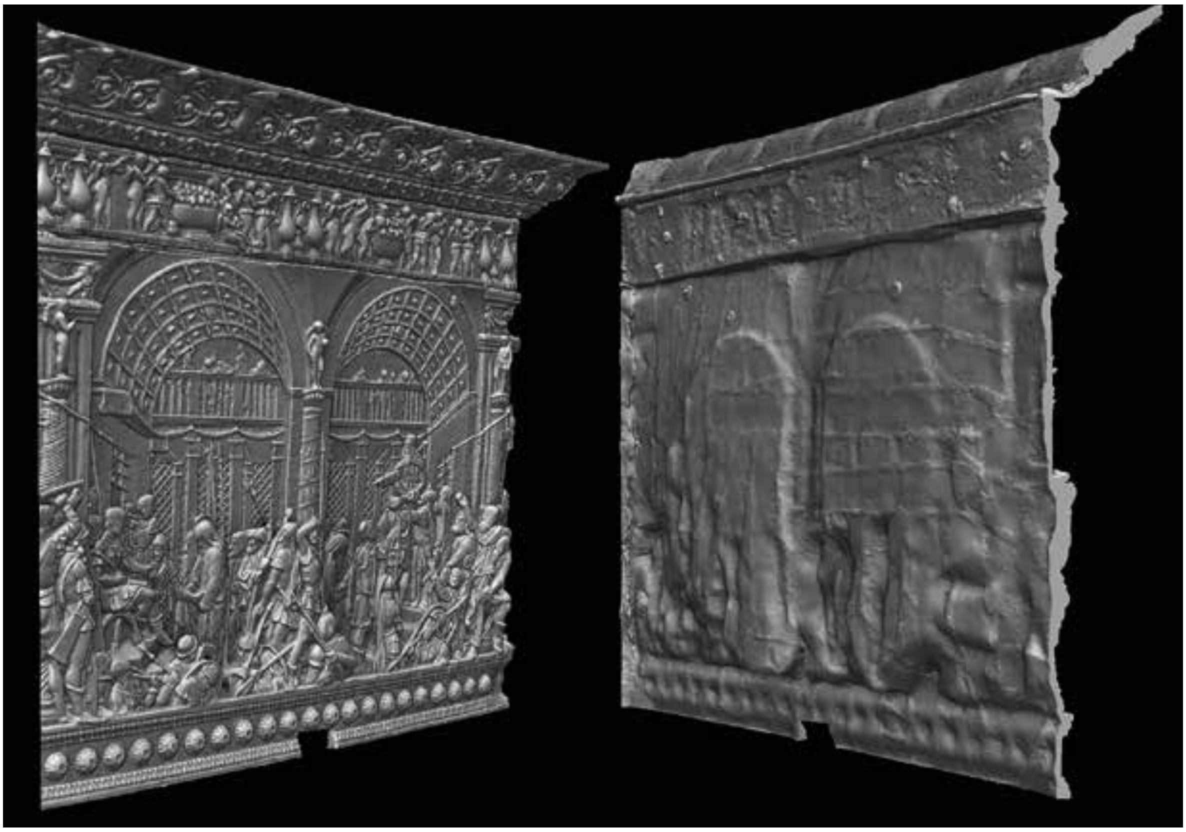

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Fig. 6. Rendering del recto e del verso del pannello raffigurante Cristo davanti a Pilato e Caifa.

7

Fig. 7. Elementi di sostegno metallici sagomati grazie ai dati da scansione 3D.

ne sono servite da base di allineamento per le scansioni dettagliate.Tale procedura assicura l'esattezza del rilievo in tutte le sue parti, la quale si è dimostrata cruciale per la fase di intervento diretta alla creazione di un nuovo sistema di supporti (fig. 6).

Partendo dai rilievi interni del bronzo, sono stati progettati dei sostegni che aderissero perfettamente alla superficie originale. Mediante la gestione delle scansioni e modellazione di nuovi elementi in 3D, sono state realizzate, a taglio laser, delle "lame" in acciaio riportanti i profili di contatto con l'interno dell'opera e posizionati in corrispondenza degli originali fori dei perni[15].

La sagomatura è avvenuta sottraendo il volume rilevato, con precisione massima di mezzo millimetro, ai nuovi sostegni metallici, calcolando una distanza di compensazione di qualche millimetro per poter interporre delle guaine protettive. I bordi dei pezzi realizzati hanno aderito perfettamente alle forme del bronzo e hanno consentito una efficace e uniforme distribuzione dei pesi rispetto a una fermatura puntiforme (fig. 7).

Il rilievo 3D ha consentito inoltre di progettare il nuovo sostengo nel rispetto delle normative antisismiche: il calcolo di pesi e volumetrie del bronzo ha fornito dati utili per la scelta delle strutture e materiali da realizzare.

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Fig. 8. L'opera *L'Hiver*, in primo piano, replicata in materiale plastico per lo spazio espositivo dedicato ai non vedenti presso il Museo Fabre di Montpellier.


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Calchi digitali per i non vedenti. L'esperienza presso il Museo Fabre di Montpellier e il Museo Zevallos di Napoli

La scansione e la stampa 3D nel campo dei beni culturali possono essere utilizzate anche per consentire ai non vedenti la fruizione di opere d'arte. Dal 2016 sono state condotte due campagne di acquisizione per la creazione di repliche dedicate ai non vedenti. La volontà del Museo Fabre e del Museo Zevallos di creare copie tattili ha portato l'OPD, su incarico del TactileStudio di Parigi, a realizzare scansioni di sculture in terracotta, marmo e bronzo di Jean-Antoine Houdon, Emile-Antoine Bourdelle e Vincenzo Gemito.

Scannerizzate con dettaglio massimo di mezzo millimetro, le opere sono state restituite plasticamente mediante fresature con macchine robotizzate. Seguendo lo

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stesso procedimento della scultura lapidea, l'automazione procede per livelli a togliere materia, fino a raggiungere la definizione desiderata. Il percorso che le frese seguono nel loro lavoro di intaglio è basato sulla scansione 3D fornita dall'Opificio.

La restituzione dei modelli finali in scala 1:1, preparati e trattati per lo scopo, rispecchia il dettaglio delle opere originali.

Installati presso i locali dei musei, i calchi virtuali offrono al visitatore non vedente l'unico strumento di fruizione del bene culturale ma permettono anche agli altri visitatori di amplificare l'esperienza conoscitiva tramite il tatto (fig. 8).

NOTE

1. Porzioni contigue di modeste dimensioni, non superiori ai 3 x 2 metri.
2. Carta, tele e tavole dipinte.
3. Texture fotografica, ottenuta dall'interpolazione dei dati colore (RGB) della nuvola di punti o tramite acquisizione da sensore fotografico.
4. Range-based, basati sull'uso di fonti luminose artificiali, operanti nel visibile e non.
5. Image-based, basati sull'uso di luce visibile.
6. TOF (time-of-flight). Il calcolo viene eseguito valutando il tempo intercorso tra l'invio e la ricezione del segnale laser. Maggior tempo di calcolo ma ampie distanze rilevabili.
7. La differenza di fase consiste nella comparazione tra l'onda trasmessa e quella ricevuta. Minor tempo di acquisizione ma minori distanze rilevabili.
8. Structured Light scanner (SL). Un videoproiettore proietta sulla superficie una serie di immagini codificate (patterns, ovvero sequenze di immagini con elementi grafici diversi a seconda dello scanner), mentre un sensore ottico, una fotocamera o videocamera, catturano le proiezioni e inviano le immagini al software, il quale le elabora e traduce in nuvole di punti.
9. Per postazione fissa si intendono le strumentazioni che richiedono un posizionamento su supporto fisso, come uno stativo fotografico, e che necessitano di assoluta immobilità dello scanner rispetto al soggetto rilevato.
10. Ingegneria inversa, ovvero analisi del funzionamento, progettazione e sviluppo di oggetti e dispositivi. Gli scanner 3D spesso vengono utilizzati per confrontare il prototipo, o il prodotto finale, con il progetto iniziale. Dalla comparazione si ottengono dati utili per la correzione del processo produttivo.
11. Ovvero tenuti in mano dall'operatore, senza vincolo di stabilità.
12. Form1+ e Form2: www.formlabs.com. L'opera prima del restauro vedeva i busti appoggiati direttamente sulle gambe: nonostante il sapiente gioco di incastri tra forme creato dalla bottega robbiana, pochi erano i reali punti di contatto su cui gravava tutto il peso.
13. L'opera prima del restauro vedeva i busti appoggiati direttamente sulle gambe: nonostante il sapiente gioco di incastri tra forme creato dalla bottega robbiana, pochi erano i reali punti di contatto su cui gravava tutto il peso.
14. Scanner FARO Cam 2 Focus, messo a disposizione dal restauratore Antonio Mignemi, MIMARC s.r.l., via G. Carducci, 30, L'Aquila: www.mimarc.it.
15. Lavorazione eseguita dalla ditta MIMARC s.r.l.

ABSTRACT

SURVEYING AND 3D DATA PROCESSING TO SUPPORT RESTORATION . EXPERIENCES OF THE OPIFICIO DELLE PIETRE DURE IN FLORENCE

The Department of Ceramic, Plastic and Vitreous Materials of the Opificio delle Pietre Dure, Florence, has invested in 3D acquisition and printing technology, to be autonomous in the conservation, consultation, and elaboration of data and information regarding cultural heritage artifacts.

The recent activity of documentation and conservation of artworks by Luca and Andrea della Robbia, Donatello, and Michelangelo, for example, resorted to technologies and skills focused on the creation of instruments and methods that could increase the knowledge of the artworks and offer the conservators new solutions for the intervention.

The experiences described, which have been realized since 2016, illustrate the objectives of an updating process which is still ongoing.

The Opificio has undertaken a new practice, with the purpose of developing a service for its own laboratories and offering also its professional services by means of collaborations with other institutions, to develop new solutions and methods for the documentation, fruition, and conservation projects of cultural heritage artifacts.

RILIEVO ED ELABORAZIONI 3D PER IL RESTAURO. ESPERIENZE DELL'OPIFICIO DELLE PIETRE DURE DI FIRENZE

Il settore Materiali ceramici, plastici e vitrei dell'Opificio delle Pietre Dure di Firenze ha investito in tecnologia per l'acquisizione e la stampa 3D al fine di rendersi autosufficiente nel conservare, consultare ed elaborare informazioni sul bene culturale. La recente attività di documentazione e restauro di opere di Luca e Andrea della Robbia, Donatello e Michelangelo, ad esempio, si è avvalsa di tecnologia e professionalità dedicata alla creazione di strumenti e metodologie per approfondire la conoscenza delle opere e fornire ai restauratori nuove soluzioni di intervento. Le esperienze proposte, svolte a partire dall'anno 2016, vogliono illustrare le finalità di un processo di aggiornamento tuttora in corso.

L'Opificio ha intrapreso un nuovo percorso volto a sviluppare un servizio interno ai laboratori ed estendere la propria professionalità a collaborazioni esterne, per sviluppare nuove soluzioni e metodologie di documentazione, fruizione e progettazione di restauro di beni culturali.

KEYWORDS

3D printing, 3D scanning, cultural heritage, documentation methods, conservation project

scansione 3D, stampa 3D, patrimonio culturale, metodologie di documentazione, progetto di conservazione

GLI AUTORI

Laura Speranza
OPD, Firenze.

Mattia Mercante
OPD, Firenze.

TORNA AL SOMMARIO

DIGITAL RECONSTRUCTION, 3D-PRINTING AND AUGMENTED REALITY

An Augmented Reality system for assisting art conservation and restoration

Marcello Carrozzino, Raffaello Brondi

Augmented Reality (AR) is a technology based on the visual blending of virtual and real digital content, aiming at augmenting the human perception of the surrounding environment. For these unique features, Augmented Reality [Van Krevelen *et al.*, 2010; Carmigniani *et al.*, 2011; Yovcheva *et al.*, 2012] has proven to be an ideal tool to assist the human activities in several application sectors such as industry, medicine, education, and tourism. AR has been recently used also in the field of cultural heritage, mostly to provide new forms of interaction between visitors and cultural sites [Vlahakis *et al.*, 2001; Brondi *et al.*, 2012], usually with the objective of showing these landscapes in the shape they had in the past, or museums [Debenham *et al.*, 2011; Wojciechowski *et al.*, 2004; Miyashita *et al.*, 2008], mainly aimed at overlying information about a certain asset when the visitor is actually looking at it. However, the potentiality of Augmented Reality for a professional use in CH is still unexplored.

This paper focuses on the artwork restoration sector, whose activities commonly present the need to produce and access documents during the various tasks and, therefore, would arguably benefit from the adoption of AR systems. Such systems can in fact assist operators providing contextualized information directly in place. Moreover, AR interfaces can be designed in order to enable users creating new digital information spatially referenced on

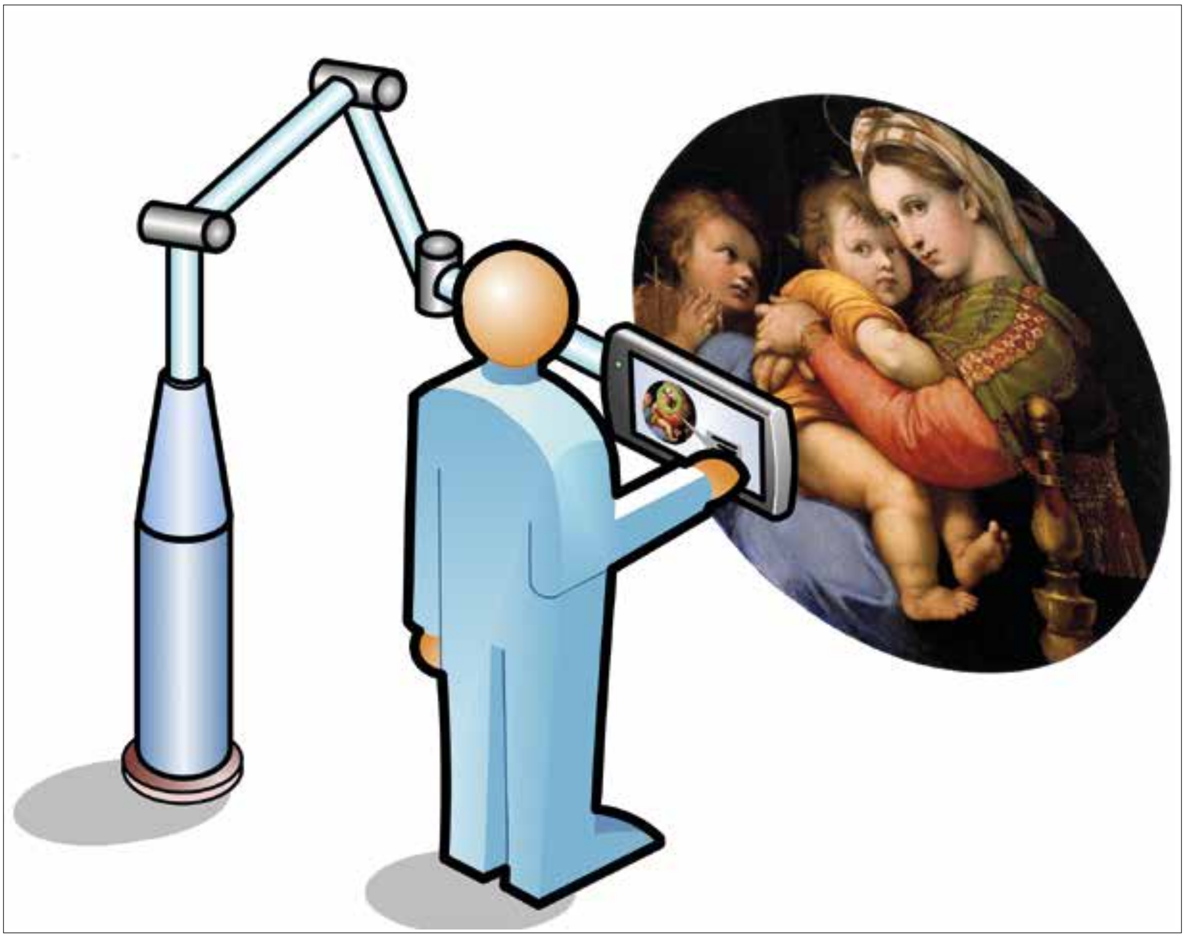

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Fig. 1. A conceptual sketch of the ARTworks system.

the artwork. Since documentation is the base on which the collaboration between restoration professionals take place, an easier and richer way to produce such material would also improve the collaboration among restorers. Current attempts to structure the use of this information go commonly under the name of Cultural Heritage Information Systems (CHISs), adaptations of GISs especially devoted to CH applications. An example is SICAR [Baracchini *et al.*, 2003], a Web-based GIS for the management of the information gathered during restoration analysis and intervention. The system allows to store information day by day and to easily retrieve relevant documents (such as diagnostic images, chemical analyses, maps, etc.), linked to a specific area in the digitalized ortho-image of the object under treatment. Despite being extremely powerful compared to other solutions, CHISs are nevertheless not yet widely adopted in the sector. They are mainly designed for bi-dimensional data manipulation/visualization, although recent projects try to address also 3D artworks [Pecchioli *et al.*, 2011; Torres *et al.*, 2013]. However extending methodologies and procedures from 2D to 3D is not trivial, not only because user interfaces are commonly designed for 2D contexts but also because of the peculiarities of 3D artworks and related conservation-restoration procedures.

User needs analysis

As evident, artwork restoration is a huge and diversified application field. It spans from architectonic restoration of buildings to micro interventions on paintings. Activities can take place on the same site where the object is, or indoor in laboratories. All these different aspects must be considered when designing an instrument conceived to assist such activities.

We have therefore carried out a survey among conservators and restorers in order to identify the real needs in the sector addressable by an AR system. Thirty-seven specialists, ranging from wood carving to architectural restoration, frescos, paintings, murals, and paper, participated in a survey subdivided into three sections. The first part aimed at identifying the sample group of restorers and at better defining the typical work environment of such professionals. The sample resulted in being mainly represented by middle-age experts with more than 10 years of experience, the majority (76 %) composed of females. Most of the interviewees assert to work commonly in indoor laboratories (75 %), and a wide majority (76 %) has the possibility to connect to the internet in their workplace. All the restorers assert that they constantly produce new documentation while carrying out activities and use some kind of software to archive this information, mostly consisting of photos. Presentation slides are often used at the end of an operation for purposes of promotion or raising awareness. Diagnostic images, like RX, IR, XRF, etc., provide extremely valuable information about the artwork, however, they are not so widely adopted mainly for cost reasons. Interventions are commonly documented on a logbook that is updated constantly after each operation. The use of CAD is common when dealing with large assets, such as buildings or large paintings; however, these tools are more frequently used for communication (e.g. in symposiums) or documentation (before and after the activities) whilst their use during the intervention is unusual. Younger professionals know or use even dedicated GISs/CHIs enabling the integrated management of the documentation; however, they often report a certain difficulty in mastering the software. Simpler tools, such as word processors and image editors, are instead more frequently used in order to produce non-structured documentation that can be easily exchanged among professionals. A large majority (86 %) uses the documentation resulting from the work for educational or collaboration purposes. The collaborative restoration of an asset mainly consists of a sequence of interventions performed by different experts. Restorers who resume the work left by another colleague need to be informed about the current status of the artwork and the history of interventions previously performed. This information is usually exchanged orally, sometimes integrated by photos or textual descriptions of the job.

Subsequently, we tried to assess which activities specialized AR tools can efficiently assist. Answers identified the overall documentation phase, the visualization of pre-operative and intra-operative material, the promotion of interventions, and the didactics. Restorers are mainly interested in using digital pictures (97 %) and textual annotation (78 %) while working, while they consider less important video (67 %) and audio (43 %) resources, which are deemed more suitable for post-intervention promotional or educational activities. Although some are worried that the augmented content might distract or hinder the operator, the majority of the interviewed restorers (51 %) asserts that saving localized information on the asset would be extremely useful.

An AR system for restorers

Following the indications coming from the survey, we have designed the prototype of a novel Augmented Reality system composed by a mechanical interface and an Android tablet. ARTworks (Augmented Reality Trackhold for artworks restoration) is intended to assist the restorer both during the operation phases, providing contextualized information in place without the needs of a continuous switch of the visual context between the artwork and the documentation, and during the documentation, allowing the insertion of new digital information referenced on the asset. The system has been designed to address the particular application field of restoration and to be cost-effective. The interface, following needs emerging from the survey, provides a self-sustained structure in order to leave the restorer's hands free. This mechanical structure consists of a serial kinematic chain made using aluminum profiles, providing 3 degrees of freedom. The result is a planar manipulator with three revolute joints as sketched in figure 1. Each revolute joint is sensorized with a potentiometer connected to an electronic board.

The mechanical interface is completely passive: the user is free to drag the end effector over the surface to

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Fig. 2. The ARTworks Android app.

be augmented. The end-effector terminates with a slot that accommodates an Android tablet whose screen is used as a video-through display providing the augmented view of the artwork placed below. Moreover, the tablet processes/manages data coming from sensors in order to calculate the position of the end effector, applying the direct kinematics of the mechanical interface to the angles read by the potentiometers. A feature[1] matching Computer Vision algorithm is then used to estimate the position of the artwork with respect to the tablet camera. The complete registration process is accomplished merging the information coming from the mechanical interface with those resulting from the CV algorithm.

The table runs an Android app developed in order to allow users to interact with the system. Figure 2 shows a screenshot of the ARTworks application. On the left side a command dock groups the available options, while in the main central area the video stream acquired by the camera and the augmented content is displayed. Information inside ARTworks is organized into Virtual Layers (VLs). A Virtual Layer represents a combination of uniform data registered on the asset, coded in a JSON[2] file. Currently, three different type of data are encoded and managed by the application:

- punctual elements,
- polygonal elements,
- images.

Punctual elements are defined by a set of points to which a colour is assigned. Polygonal elements are defined by a sequence of points connected by a line. The surface enclosed by the line represents the polygon area. Both the line and the surface of the polygon are linked to a specified colour. Images are parallelogram surfaces associated with an image. A caption can be optionally linked to each element of a VL. Virtual Layers can be preloaded on the tablet, or created by the user during a working session. New layers can be loaded by simply copying them into a public folder on the tablet SD-card. When the application starts, it looks for available VLs in the SD-card. The name of each available layer is shown in a list on the command dock. A VL can be enabled or disabled using the associated switch button. When a layer is enabled its content is shown overlaid on the video stream of the camera. The order in which the VLs are listed in the command dock represents the depth-order used to draw them. The user can change the position of each layer by dragging each element of the list in a different position. The "Create layer" button in the command dock allows creating new registered VLs. As a first step, the user has to choose the type of layer to be created. Then the new VL is created by simply tapping on the screen. When the layer has been composed, it can be saved in order to be subsequently loaded. When a layer is enabled, if the user taps on a part of it the linked caption is displayed in the command dock.

Tracking capabilities has been tested with three different paintings. On the current prototype set-up the error settles among 3 mm to 5 mm, depending on the distance between the artwork and the tablet camera, and on the number and the quality of features detected. During the interviews it was asked to restorers: "Which level of precision the augmentation must reach for your intended use in restoration?" 35.7 % of the sample asked for a required precision below 2 mm, 26.3 % between 2 and 5 mm, 19 % between 5 and 10 mm, 19 % more than 10 mm. Given the average error resulting from the tests, the current ARTworks prototype is therefore able to satisfy more than the 60 % of the restoration professionals.

The tracking performed using the mechanical interface kinematics is therefore able to correctly estimate the end-effector position with a reasonable error. The result is stable, as most of the noise coming from the sensor readings is low-pass filtered on the electronic board, and provided at the frequency of about 60 Hz, which is fine for the needs of the AR system (the graphics loop runs at a frequency of about 20 Hz).

As pointed out by all the interviewed restorers, one of the main problems in adopting these new technological instruments is related to the limited budget commonly available. For this reason ARTworks has been designed in order to be as cheap as possible: the overall ARTworks prototype costs less than 600 euros.

Conclusions

ARTworks is the prototype of a novel interface specifically designed for the needs of conservator-restorers. The system provides digital information spatially referenced on the artworks using the paradigm of Augmented Reality, making it an easy and powerful tool to create and manage new digital information fostering a structured documentation process. Moreover, it might enhance the collaboration between restorers, enabling new forms of communication based on digital information. ARTworks has been designed in order to meet the needs emerging from a series of interviews conducted among several sector professionals. This information made it possible to identify the main aspects and issues typical of this application field. The interface design and development have been therefore lead by these guidelines in order to respond to actual requirements of restorers. The main mechanical structure is solid and easily portable. The Android tablet used as augmented display can be easily updated with more powerful models.

Restorers participating in the survey were presented ARTworks features in order to evaluate how useful was such a system estimated when used on the job. On average the interface was deemed potentially very useful during the practical activities of restoration to access existing information. More clearly, restorers consider ARTworks a valuable instrument to create new localized documentation. Interestingly, almost all the interviewees (97 %) agreed that an AR system like ARTworks could be also used in museums for promotional or educational purposes. Localized documentation would therefore be used to punctually communicate the activities carried out during the intervention.

Finally, restorers were asked to guess the main problems they envisage in such a system. The following potential issues were identified: clumsy interaction with the interface; the size of the structure can be cumbersome and not suitable for small operating locations; the augmentation can distract operators or hinder the usual operation; limited budget.

ARTworks currently exists as a working prototype. The final user interface has been tailored to the restorer needs to make it simple and easy to use. New digital input will be introduced such as audio, video and three-dimensional meshes to enrich the information that restorers can use and share using this interface. We plan to improve the precision of the registration and to integrate the system with existing GISs/CHIs in order to load and store digital information directly from/to these software applications. The kinematics of the mechanical interface will be expanded to reach the degrees of freedom required in order to achieve a three-dimensional workspace and to enable using the system also with 3D assets, such as sculptures.

NOTES

1. A feature is defined as an easily recognizable part of a digital image.

2. JSON (JavaScript Object Notation) is a lightweight data-interchange format. See http://www.json.org/.

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ABSTRACT

AN AUGMENTED REALITY SYSTEM FOR ASSISTING ART CONSERVATION AND RESTORATION
Augmented Reality (AR) is a cutting-edge technology gaining more and more consent in several application sectors such as medicine, industry, tourism, and entertainment. AR is becoming increasingly popular also in the cultural heritage field, particularly as a tool for communication, education, and information. However, existing applications mostly focus on end users, while opportunities provided by AR to the sector professionals remain largely unexplored. This article introduces an AR system designed to assist conservators and restorers both during their operations, by providing contextualized information directly on top on the asset under analysis, and during documentation, allowing the insertion of new digital information spatially referenced on the asset itself.

UN SISTEMA DI REALTÀ AUMENTATA COME AUSILIO PER LA CONSERVAZIONE E IL RESTAURO
La Realtà Aumentata (AR) è una tecnologia all'avanguardia che ottiene sempre più consenso in diversi settori applicativi come medicina, industria, turismo e intrattenimento. L'AR sta diventando sempre più popolare anche nel campo del patrimonio culturale, in particolare come strumento di comunicazione, educazione e informazione. Tuttavia, le applicazioni esistenti si concentrano principalmente sugli utenti finali, mentre le opportunità fornite da AR ai professionisti del settore rimangono ampiamente inesplorate. Questo articolo introduce un sistema AR progettato per assistere i conservatori e i restauratori sia durante le loro operazioni, fornendo informazioni contestualizzate direttamente sulla parte in analisi, sia durante la documentazione, consentendo l'inserimento di nuove informazioni digitali riferite spazialmente sull'attività stessa.

KEYWORDS

Augmented Reality, documentation, restoration, conservation
realtà aumentata, documentazione, restauro, conservazione

THE AUTHORS

Marcello Carrozzino
PERCRO, TeCIP Institute, Scuola Superiore Sant'Anna, Pisa.
Raffaello Brondi
PERCRO, TeCIP Institute, Scuola Superiore Sant'Anna, Pisa.