Transmission of cultural heritage through time and space by digital 3D models

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Abstract:

The article would refers some interesting experiences of the research team Larifo, BEST Department, Politecnic of Milan, Italy, in the field of cultural heritage digitalization about the creation of archives and tridimensional representations which are finalized to the knowledge, the documentation and the fruition of the artistic and architectural heritage. We will see how it's possible to create 3D models sculptures of medium size (i) with the application of laser scanning method and the integration of photographic/ photogrammetric survey to fit out virtual spaces wherewith show rebuilding hypothesis of places or past events, (ii) to document restoration, allow the reversibility of interventions during the time and (iii) to realize digital copies which are accessible through web navigation. On the following pages we will discuss about the acquisition modalities, the modeling and the visualizations used in three different projects that have significant buildings of Mantua and Sabbioneta, both of them heritage of humanity by 2008, as intervention sites. The purpose is to demonstrate the applicability of TLS systems and the importance of digital 3D models in the processes of knowledge, management and valorization.

1. INTRODUCTION

The documentation of cultural heritage through the acquisition of digital data and the realization of 3D models currently can count on many procedures and survey instruments which have been developed in the last decades and still more specialized for the acquisition of metrical information with high resolution levels, reliability and precision.

The acquired data can be archived, georeferenced, managed and questioned in numeric database whom, properly developed, allow to get real (digitalization), realistic (reconstruction) and interactive 3D artefacts representations0. The literature of the last years quotes many examples where, through the generation of multi-resolution digital 3D models, is possible to get geometrical, spatial, radiometric and multispectral correct contents about the examined objects for their knowledge and conservation. Just think at some complex elements and architectures or survey projects where they have to be registered and represented small and large scale elements: in those cases only a tridimensional approach to the survey [2], in whom we have the integration of many methodologies, allows to catch the forms and the artifact features and the contest where it is. Many documented works reports this fact but in this article we are mentioning only some of them [1][4][5].

In case of medium or small objects as statues, decors, frescoes, ecc., the survey can be done by image-based or range-based systems which exclude the direct contact with the object whom, for the correct conservation of materials and surfaces or for his collocation, can't be detected by touching instruments usually used in industry [5]. The accuracy is that one requested in the close range survey with 0.01-0.1 mm precision [6], or in the architectural survey for scales of 1:10, 1:20, 1:50 detail rappresentations with a 1-10 mm accuracy.

The digital images, often acquired with non-metric photographic appliances, and the active laser sensors (by triangulation, by phase-difference, by pulse) lead to the generation of grids or point clouds which, once registered and structured, can be elaborated for the creation of mesh surfaces or solid models made in CAD applications. After many processes of integration, segmentation, reduction, simplification, errors resolution

and holes closure, we can pass at the render phases (with or without textures) of digital 3D models and at the interrogation or analysis phases. Obviously more the case is complex more the total automation of the process described is complex, leading a necessary interaction by the user.

There can be also some occlusions due to geometric complexity or, as often it happens, there can be problems due to the different material responses or to the surfaces reflections. Those facts cause topological or coarse errors and sometimes data deficiency. These problems can be overcame with a multi source data modeling approach [2][5][9], that is actually becoming the most important process used by research teams.

Once those models are obtained is possible to create 2D and 3D representations and georeference on them many informations resulted from different research fields: historical-archival, chemical-physical, material-stratigraphical, ecc. In this way the models can truly become space indicators of a 3D GIS which reports all the peculiar information of the case study [3].

This article reports three case studies, that it is possible to obtain point clouds with adequate resolution and accuracy by the use of an only terrestrial shift-phase laser scanner system and a photographic survey using amateur cameras (self-calibrated). The 3D models created are suitable for the purposes they were thought. Thanks to the features of the detected objects, it wasn't necessary to employ other kind of range-based instrument and the photogrammetry was used to create textures for the 3D models.

2. SCULPTURE DIGITIZATION: THREE CASE STUDIES

Following there are reported three applications cases about digitization of medium sized sculpture (in plaster or wood) with close-range laser scanning techniques. The development of 3D surface and solid models of architectural contexts represents both an unalterable documentation of Cultural Heritage and a data which can be integrated with other surveys during the time for preservative conditions monitoring or for verify the actions adopted during the restoration. Moreover these instruments are excellent supports for geometric, formal, constructive and storical-artistic analisys.

a. The detection of the Caryatids of the *Palazzo Te* in Mantua (Figure1) and the *Imperial Hall* of the Ducal Palace (Figure 2) for the reconstruction of the event and place where it is assumed was staged the musical work "Orfeo" by Claudio Monteverdi for the first time in the 1607.
b. The survey of Caryatids and Telamons of Guerrieri Palace's façade, by A.M.Viani between late 1500 and early 1600, in support of restoration and digital documentation of transformations adopted in order to their reversibility over time.
c. The detection of Vespasiano Gonzaga's equestrian statue in Sabbioneta (Mantova). A 3D navigable model production for the documentation and cataloguing of Cultural Heritage in order to set up a virtual museum of the city.

In the first case (a), the survey was realized as part of a thesis in Architecture, in which it was processed an historical virtual reconstruction of the *Imperial Hall* in the Isabella d'Este's widow apartments. One of many hypotheses, not yet proven by historical documents, was supported for which in that place it could be performed the first important Opera of the 1600's. After an analysis of many places in the Ducal Palace in Mantua and an analysis leaded by musicology experts, we tried to suggest the type of set and consequently the place in which the Monteverdi's "*Orfeo*" was probably put in stage for the Duke Vincenzo I and his court.

Figure 1-2: The laser scanner data of the Caryatids's room of *Palazzo Te* in Mantua and the panorama picture of the *Imperial Hall*

Therefore it was surveyed the Imperial Hall of the Ducal Palace and it was proposed an historical reconstruction with a 3D digital model, taking into consideration informations from archives and the transformations happened in the course of centuries. In this regard it is certain that the majorty of the plaster decorative system, present in the room in that period and attributed to the architect Giulio Romano, were removed at the beginning of 1800 and carried in another important renaissance palace of Mantua, Palazzo Te, to decorate a room that subsequently was called Caryatids's Room. After an accurate laser scanning and photographic survey and the achieving of a 3D surface model by meshing, the sixteen sculptures were (re)placed into the Imperial Hall solid model.

In the second study case (b), for pinpointing the tridimensional geometry of Telamons and Caryatids of the Guerrieri Palace's façade (the current citizen courthouse), the high density 3D point survey (Figure 3-4) was made in two stages, one before and one after the restoration.

Figure 3-4: 3D point cloud database of Guerrieri Palace's Cariatyds and Telamoni in Mantua before the restoration

In fact if the shape documentation is done at different times, it automatically generates a four-dimensional database (X,Y, Z & T – space and time) so it's possible to detect and compare all processing steps, interacting with the first model created. Thus the restorers are able to understand shape, materials, construction techniques, deterioration and conservation surfaces in the best way [2]and they have tools to potentially modify the chosen actions.

In the case of twelve sculptures Guerrieri Palace's façade, it was done an interesting discovery during the execution of surfaces and materials consolidation work of the six female sculptures (the Caryatids). In a slightly later stage of their realization (early 1600), there was indeed an afterthought that led to overlapping the female nudity with clothes modeled in plaster and stucco (we don't know if by the same artist or as a result of subsequent operations of censorship, typical of the *Couter Reformation* period).

For documenting, studying and enhance this discovery, during the restoration phases, it was decided to bring to the light the ancient forms of one of the Caryatids and to eliminate part of the dresses that hid it. Therefore the laser data were modeled and the produced documentation can make reversible this decision and bring back the sculpture to the shape before restoration.

The reversibility of the restoration is a very important and disputed aspect in conservation field of Cultural Heritage [10], which for a long time and in various contexts it seeks to achieve. Thanks to a correct and detailed three-dimensional survey of main stages of intervention, it provides a suitable documentary support for this purpose, especially in that cases where many parts were removed and later it would like to recreate it with reverse engineering modalities,.

The last case (c) reports the equestrian sculpture survey of Vespasiano Gonzaga, duke of Sabbioneta (Mantua) during the 1500's. This is the first detailed and complete documentation of the artifact, either by a geometric point of view or as representation of color and surfaces features. Therefore it was performed a three-dimensional shape capture in aim to the transmissibility of the artifact through the time and space in an accessible and viewable format not only for operators in the conservation and restoration fields but also for general web users.

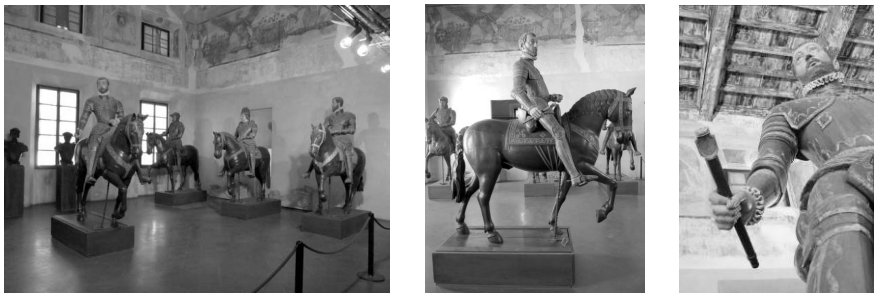

Figure 5-6-7: The Cavalcata, equestrian sculptures committed by Vespasiano Gonzaga in the 1500's

The statue we analyzed is part of a group of ten equestrian sculptures, which form the so called *Cavalcata*, desired by Vespasiano Gonzaga after 1587 to celebrate his military goodness and to attest his direct dynastic descents. The work attribution is still uncertain, but it is known that it was commissioned to a Venetian author who created it entirely in decorated and painted wood. Largely destroyed by a fire involving the Ducal Palace in 1815, now only four riders (figure 5) are fully come down to us, including fortunately the same client (figure 6-7). The characters are the most important lords of Gonzaga's and the direct descendants of Sabbioneta branch, whom Vespasiano was the main representative.

The survey joins in a wider project of digital documentation and cataloging of artistic and architectonic goods of Sabbioneta (UnescoWorld Heritage from 2008) for the future establishment of a virtual museum.

3. DATA COLLECTION AND MODELING

In all cases mentioned above, it was used a shift-phase laser scanner, the Leica HDS6000. This instrument can be used for the digitization of artistic and architectural goods with medium and small size, since it is able to return as a very dense datum, rapidly (500,000 points per second) and with good accuracy (6 mm for x, y position of a single point at a distance of 25m and 2mm modeled surface). Of course, the scanning resolution (1 point every 3 mm for distances of 5 meters, with an angle of 360° X 310°), set up in various applications quoted in this article, preclude its use when you want to investigate higher accuracies than those reported above 0.

One aspects we have handled is the different laser response to the characteristics of: distance from the object, angle of incidence, materials reflectivity and environmental conditions of humidity and lighting [7]. The constituent materials detected of the sculptures are either wood or stucco. The surfaces, except for Guerrieri Palace due to a sharp deterioration of the facade, are characterized by shiny and reflective areas or dark colors. For this reason, the data were subjected to an appropriate selection to eliminate the topological errors or outliers generated during acquisition.

3.1 The survey of the Caryatids's Palazzo Te and the Imperial Hall of the Ducal Palace in Mantua

To the detection of the sixteen Caryatids (H 1.50m x W 0.60 m), located in *Palazzo Te*, were chosen five different acquisition perspectives, which allowed to record a sufficiently dense datum, to have a proper digitization of the sculptures for their three-dimensional modeling and to entry into a 3D navigable virtual architectural reconstruction.

At the same time for making Panoramic images (360°) some digital spherical images are acquired with CanonEos 450D with 12MPX and 8mm fish-eye lens. Thanks to the application of a proper support, the coincidence between photographic set point and the phase centre of the scanner has been guaranteed for each station. This condition allows to easily orient images to the laser data for assign the correct RGB value to every point of the cloud. Many useful visualizations and orthoimages, achieved by the object projection to a reference plane and designed to a quick representation, can be obtained by the dense laser data enriched with radiometric informations.

Figure 8-9-10: The 3D reconstruction of Cariatyds and Imperial Hall of the Ducale Palace in Mantua

With the purpose of obtaining a 3D models of the Caryatids (Figure 8), it was used the software Rapidform Xo with which mesh surfaces for triangulation of point cloud has been created.

The 3D model of the *Imperial Hall* was created with a solid modeling of reference sections (Figure 9), all obtained from laser data. Once developed the model of the current status, those changing made over time and recorded in archive documentation has been deleted for retrieve the senventeenth century configuration of the hall (Figure 10).

Figure 11: The virtual stage preparation of the Monteverdi's Opera in the Ducal Palace in Mantua

After the images correction from the perspective distorsions, the textures of the frescos and decorated architectural elements have been applied to the model.

The digital 3D visualization of the model has been managed with the program 3DStudioMax2010, to produce a VRML navigable file and many renderings of the virtual stage preparation of the Monteverdi's Opera in the Ducal Palace in Mantua (Figure 11), which any consumer, researcher or simply fond of art and music could see.

3.2 The twelve sculptures of the Guerrieri Palace's façade in Mantua

Due to their position in the Guerrieri Palace's façade and their dimensions (h 3,60 x w 1,20m circa), the laser scanner survey, with Leica HDS6000, of the twelve scultures, representing Caryatids and Telamons, has been done from scaffoldings, located at different heights (from 10 to 13 m of height), on three acquisition level. On the whole 35 laser scans has been captured from so many stations in the first survey campaign (2008) and 65 laser scans during the second one (2009), due to the scaffolding occlusions. Each session employed two days of work.

The wide set of points earned was filtered, recorded and managed with dedicated software, Cyclone 6.0.3, to create a digital database of the shape and surface features and the geometry of the statues before and after restoration. The alignment of the scans was done by recognition on the facade of homologous points and surveying targets.

Figure 12-13-14: One of the twelve sculptures of the Guerrieri Palace's facades, before and after the restoration, surveyed and modeled for the documentation of interventions

3.3 The equestrian statue of Vespasiano Gonzaga in Sabbioneta (Mantua)

For the equestrian statue of Vespasian Gonzaga (2.52x2.18x1.10meters) the decorative and geometrical shape were taken from five stations with different angles and heights (Figure 12).

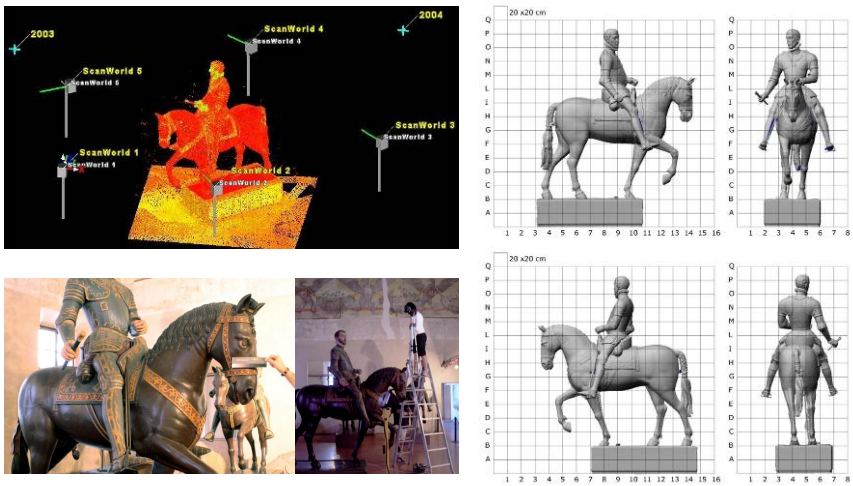

Figure 12-13-14: Acquisition phase with laser scanner and photogrammetry, and the Vespasiano's 3D model

There were numerous outliers in the laser data, due to the color and reflectivity of the material, which were mainly eliminated by automatic procedures, but also interventions by the operator. The points, resulting after the cleaning phases and area selections, were around 11,5 million. To control the scans alignment procedure, based on the recognition of homologous points, were acquired topographically 5 targets (standard error on targets, 0.001m). The modeling procedure using surface meshes (RapidformXO software), followed the first segmentation step of laser data in the main components of the handiwork (knight; horse's head, tail and body, stand, etc.) and a further points reduction depending on the complexity of the molding, looking for the best combination among the points/mesh number and the triangular surface.

The subsequent removing of the main topological errors, occurred with unstructured data, was done automatically, but a manual intervention especially in the most complex cases (twisted tail of the horse, the rider's hands and feet) was provided. Before getting the complete 3D model another step has been necessary to close vary types of "missing" parts, using automatic filling holes algorithms. Once this step finished, it was applied a rational mesh decimation and its resampling to further regularization. Then the development of the model concluded with the joining of the previously separated components and the surface smoothing (Figure 14). The model mapping step with photographs taken from different angles and controlled lighting conditions, is the latest (but not necessarily the simpler) step before virtual navigation on web platform or rendered images (Figure 13).

The representation mode aimed to knowledge and analysis, for degradation mapping or to monitor deformations and injuries is very important in the Cultural Heritage fields. An images misalignment compromises the accuracy and the feature identification. Hovewer if the aims of the work are simply the displaying and navigation of data for educational purposes, the degree of precision and adherence to reality may be lower, allowing the editing on the lights, colors and missing pieces of RGB information. Some methods were suggested for automatic alignment of multimodal and multispectral images based on the 3D model depth map [11] in addition to "traditional" image-based texturing techniques as Direct Linear Transformation (DLT) and the identification of homologue points between the model and image.

The second modality was adopted in our cases, in which the selection of suitable images for coating the entire 3D model and the points identification has been long and complex. In fact this technique provides for the selection of more nadiral mapping images to the surface average trend, with obvious difficulties in the case of very articulated geometries. So it's needed a wide coverage of the object with photographs from different angles. Moreover, the texture mapping programs do not allow proper union between adjacent images creating border areas unresolved or poorly integrated. However, it was decided to proceed with this approach to mapping the whole model, checking the time employed and evaluating the final result. The photo-realistic 3D digital model of the Vespasiano Gonzaga's equestrian statue is therefore the result of the mapping of about 60 images, taken with digital camera Canon 1000D 10MP and linked to the model with the selection of 7-10 points per image, for a total 10-15 hours of processing (Figure 15).

Figure 15: The Vespasiano's 3D textured virtual model

4. CONCLUSION

Documentation and promotion of cultural heritage through the 3D data acquisition and modeling for representation and their use in various research fields are increasingly identifying standards and procedures in order to obtain qualitatively and quantitatively valuable products in according to the instruments and used methods, with the technical requirements, the aims to achieve and the means of data storage (Remondino et al., 200[9]. In the case of small objects such as statues and decorative elements that do not require sub-millimeter precision, you can create a database of information and formal geometric object suited to the 3D models designed for several purposes: the reconstruction of virtual environments for architectural or historical knowledge for purposes of entertainment and dislosure, collection and registration of shapes and surface characteristics of the conservative state of the art. Acquiring data over different temporal thresholds and georeferencing with respect to a common spatial reference can carry out monitoring and verification of the operations or changes on the model.

The case studies presented in this article by Larifo research group of the Politecnico di Milano, Mantua, report useful experience to understand the wide range of possibilities offered by these models and some procedures for obtaining it.

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