FILLING LACUNAS IN TERRESTRIAL LASER SCANNING DATA: THE “CAVALLO LIGNEO” OF THE “PALAZZO DELLA RAGIONE” (PADUA, ITALY)

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ABSTRACT:

Laser scanning methodology allows to reconstruct the metric characteristics of objects at different LOD (Level Of Detail) providing spatially dense points clouds. In particular, the terrestrial application carried out in the last years have demonstrated the potentialities of the methodology useful in many different sectors. This tecnique has been used also for the “Cavallo ligneo” of the “Palazzo della Ragione” (Padua, Italy) survey providing useful data for the restoration of the wooden horse.
Due to the morphologic complexity of the object, some lacunas were created during the points clouds acquisitions: different procedures to filling lacunas were considered and applied providing a complete 3D model of the wooden statue.

1. INTRODUCTION

Terrestrial laser scanner devices represent one of the most widely investigated instruments in many fields of architectural and archaeological surveying applications. In order to allow photo-realistic navigation and presentation of cultural heritage objects, 3D models with good geometric accuracy, large amount of details, different LOD (Level Of Detail) and high resolution texture are required (Boehler et al., 2001; Boehler et al., 2003; Bornaz, Rinaudo, 2004; Schulz, Ingensand, 2004; Roberts, Hirst, 2005; Staiger, 2005). Since several years, laser scanning techniques are used for different purposes also in the framework of cultural heritage (Bitelli, 2002; Spalla, 2003; Lichti, Gordon, 2004; Gaudini et al., 2006).
Terrestrial laser data acquisition allows to collect a very huge amount of measurements with an accuracy in the range of centimeters or even millimeters, which produces highly accurate and detailed models. On the other hand, for specific geometric conditions of survey or for the objects interposition during the acquisition, the point clouds could be not homogeneous and could have sub-areas with absence of data (holes or lacunas).
In these cases, some interpolation algorithms can be applied to reconstruct the no-data areas and to define a more uniform support grid.
In this paper, the surveying operations related to data collection and data analysis of the “Cavallo ligneo” of “Palazzo della Ragione” in Padua (Italy) are described and discussed in order to generate a 3D complete model of the wooden horse for its restoration.

2 . THE WOODEN HORSE SURVEYING

Documents which have been preserved to the present day tell us that it was built in 1466 for a roundabout, commissioned by Conte Annibale Capodilista. It was erroneously attributed to Donatello, as the inscription on the base shows, but was in fact the work of an unknown artist. It seems that the horse first appeared in Prato della Valle with an enormous horseman, proportionate to the size of the animal, on its back. Some described it as a statue of Jupiter, others as a statue of the Trojan Antenor, and thus a reference to the Trojan horse. Praised by Vasari, the great 16th century painter, architect and writer, the statue was also mentioned in a poem of 1629 by Lodovico Lazzarello Padovano, who described its ornaments.
Even Rossetti recalled that: “The trappings, arms and adornments of this famous roundabout shone from every angle with the splendour of the gold and jewels that covered them”. Transported from Palazzo Capodilista to the Salone in 1837, it was dismantled and rebuilt almost entirely; several parts, such as the head and tail, were added, the work of the sculptor Agostino Rinaldi, because, as Vasari recalls, they were already missing or seriously damaged in the 16th century.
The construction is hollow inside and built like the hull of a ship, resting on the four sturdy legs which were made using a technique similar to today’s segmented beams; i.e. the wooden boards are glued together on the long side to exploit the tractive force of the wood in full, and minimise the warping typical of solid wood as much as possible (Fischer, 2004).
The wooden horse is characterized by relevant dimension: 5.75 m height and 6.20 m circumference of the body (figure 1). The object has been planned in order to go inside and to park in quite comfortably: a trap-door allows the access inside to the body of the horse, while from the mouth air and light enter.
The hinge of equilibrium for this complex structure seems to be the cast iron sphere with a radius of about 27 cm and weight of about 615 kg. This sphere is the principal point of anchorage of the horse to the wood basement (along about 6.42 m). In 2004 the structure seemed very degrated and a complete survey was necessary to plan and to perform restoration operations for the wood statue.
The surveys were performed by means of a Leica HDS (ex Cyrax) 2500 laser scanner which provides an accuracy of 6 mm (single point) for distance ranging from 1.5 to 50 m. The single scans were acquired from eight different stationing points (located in the four corner and in the medium points of the four sides) with a mean grid size of 1 cm. Also specific reflective targets (useful for the semi-automatic identification) were acquired and used as control points; the coordinates were measured in a local reference frame by a total station Leica TC2003.
The target (5 for each scan) were positioned outside the wooden horse surface but inside the window acquisition of the laser scanner to survey the whole object without artificial element which cover some portions.

Figure 1. The “Cavallo ligneo” of the “Palazzo della Ragione” (Padua, Italy)

3. DATA PROCESSING

The allignment of the points clouds were performed using the Cyclone v. 5.4 software (Leica Geosystems) to generate the 3D global model; the software allows to co-register different scans using three different procedures: cloud registration, target registration and survey registration.

The first one needs a large overlapping percentage between two adjacent different scans in order to roto-traslate the point clouds in the same reference frame.

The second one uses the targets as reference points in order to execute the allignment and, again, a large overlapping percentage between scans must be taken in account.

In this case lower computational time is necessary and more accuracy is obtained; furthermore, more time is needed in the survey phase in order to acquire also high resolution scans of the targets.

The last one procedure needs an integration between laser data and topographic measurements: each target must be measured with a total station in order to obtain the coordinates in the same reference system.

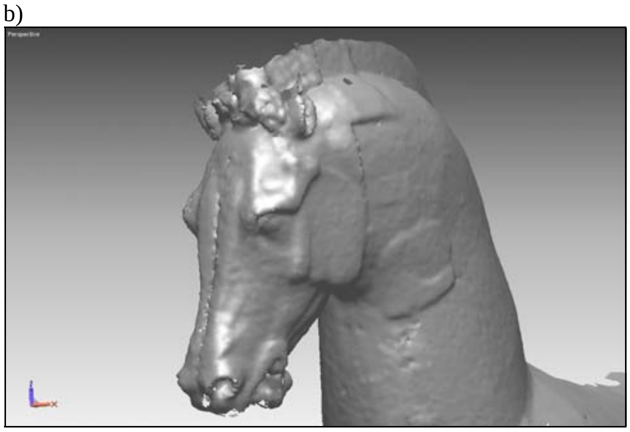
So, no relevant overlapping percentage between adjacent scans is needed; nevertheless, minimum overlapping is required in order to guarantee the model continuity. In this approach, the measurement time is increased, but also the final accuracy is upscaled. This Survey Registration Method has been used to align the “Cavallo ligneo” points clouds: each scan was roto-traslated in a local reference frame imposing the targets coordinates as control points.

The final 3D model has been processed by the RapidForm2004 software (INUS Technology): the overlap data between subsequent scans has been eliminated, performing the data fusion and extracting a polygonal mesh without errors and discontinuity. Therefore, the data was reduced of the 64% without information loss.

The figure 2 shows three different meshes obtained by points reduction of 60%, 40% and 10%.

a)

b)



c)

Figure 2. Three different meshes of the “Cavallo ligneo” head obtained reducing the point clouds: 60% (a); 40% (b); 10% (c)

4. FILLING HOLES

Due to the limited available space around the object, some portions of the wooden horse statue were not acquired by the laser scanner system (figure 3b, figure 4). Some of these areas with data gaps have no relevant dimensions, while others (for example, the back and the top of the horse) need affordable algorithms to adjust the closing of the lacunas. The reconstruction of these areas is performed using different schemes based on different interpolation algoritms; some comparisons are also performed.

Using the Inverse Distance to a Power (Franke, 1982), Kriging (Cressie, 1990), Radial Basis Function (Carlson, Foley, 1991), Local Polynomial (linear), Natural Neighbor, Nearest Neighbor (Sibson, 1981), Polynomial Regression (cubic surface) and Triangulation-linear interpolation (Lee, Schachter, 1980) algorithms, several tests were conducted on the scans of the lateral portion of the wooden horse (figure 3a); at first, a squared lacuna of 40x40 centimeters was created deleting the data inside and reconstructing the surface using 8 different methods.

The comparison between each reconstructed surface vs survey data, indicates a good agreement for the surfaces obtained by means of the Inverse Distance to a Power, Kriging, Radial Basis Function, Natural Neighbor and Polynomial Regression (cubic surface) algorithms.

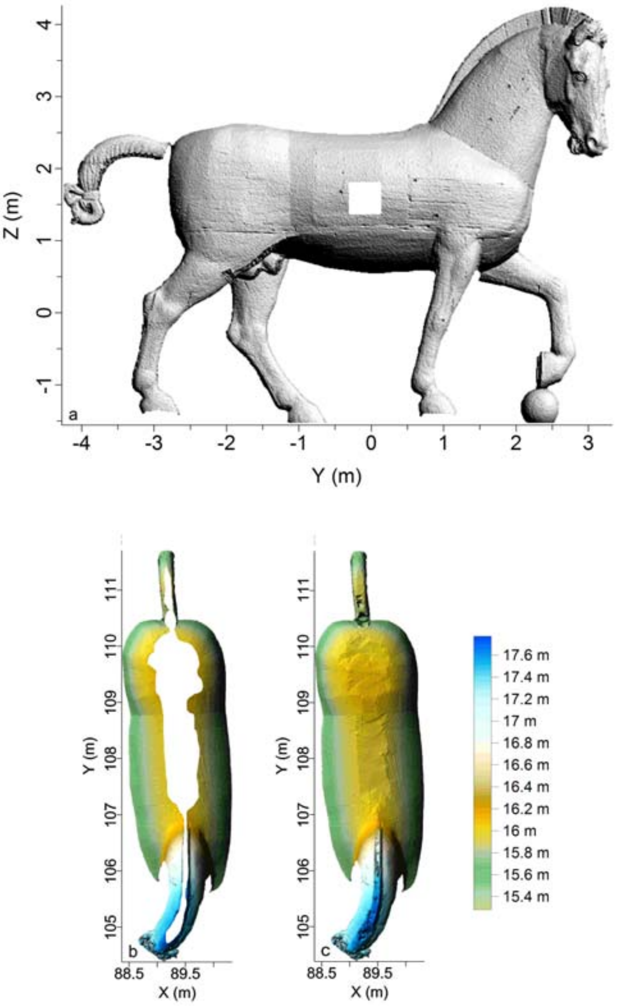


Figure 3. a) The artificial lacuna on the lateral portion of the wooden horse; b) large lacuna on the back; c) filling lacuna with Kriging

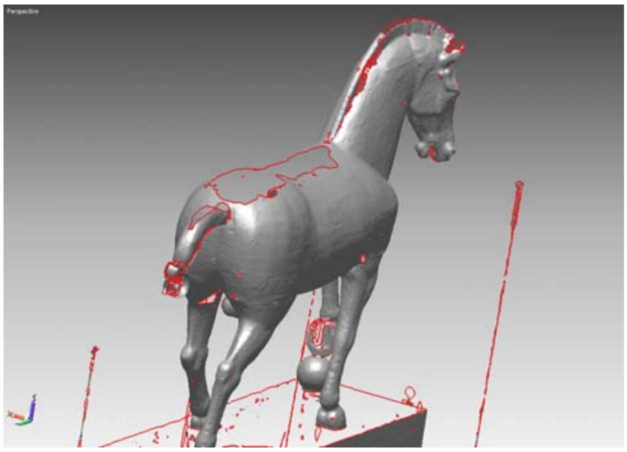


Figure 4. 3D representation of the “Cavallo ligneo”: mesh and portions with absence of data (contoured areas)

An improvement solution was obtained considering, inside the lacuna, some points derived from the surveying: in this case the comparison between the reconstructed data and the surveyed data provides differences lower of the laser scanner precision (Fabris et al., 2005). However, the application of this method for reconstructing the back and the top of the horse provides not so good results; the figure 3c shows results obtained with the application of the Kriging interpolation method.

Further analysis were conducted with the RapidForm2004 software; the lacunas filling can be performed with the automatic, manual or combined procedures. The filling of simple and small dimension holes were conducted automatically, while for the complex and large lacunas the procedure was performed with the semi-automatic modality.

The automatic procedure, applied in corrispondence of the back of the wooden horse, carried out unsatisfactory results (figure 5): the obtained surface is characterized by a non adeguate continuity with the adiacent surfaces and some topological anomalies are evident.

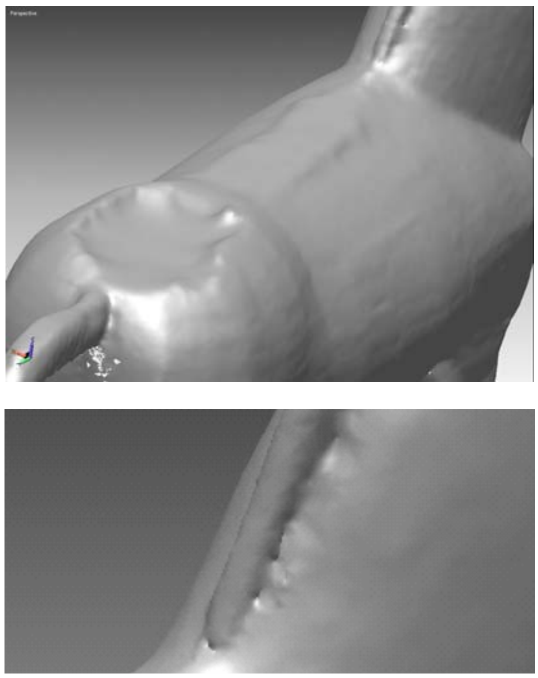
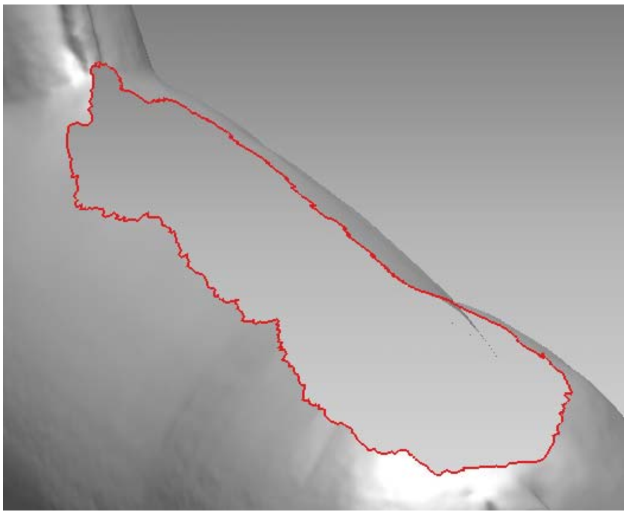
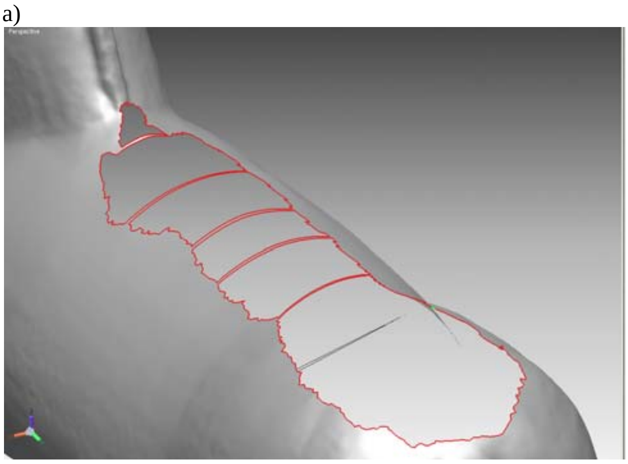


Figure 5. Automatic procedure for closing large lacunas using the RapidForm2004 software

The semi-automatic procedure allows to close the large lacunas (figure 6a) respecting the topology of the adiacent surfaces; at first, a carrying skeleton has been created by the operator (figure 6b), taking in account the curved closing of the lacuna and, subsequently, the holes, at reduced dimensions, have been closed automatically (figure 7).



a)



b)

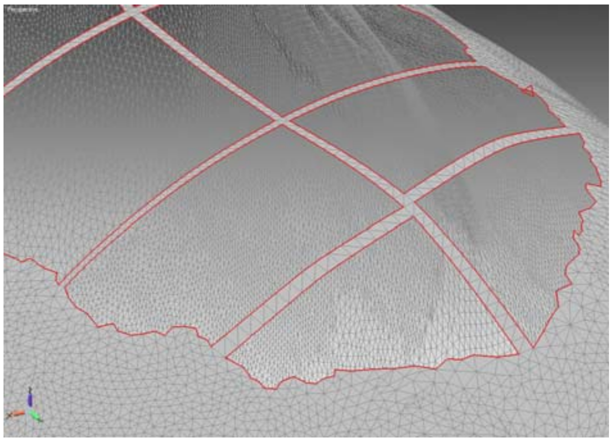
Figure 6. The big lacuna (a) on the back of the wooden horse was artificially subdivided in smaller lacunas (b) using a transversal skeleton structure

5. MESH AND NURBS SURFACES GENERATION

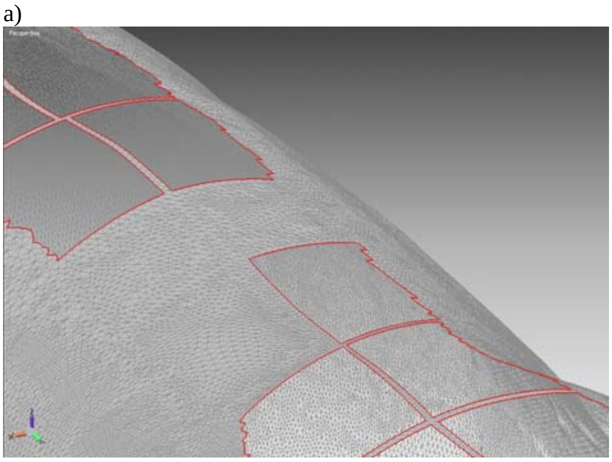
The filling lacunas has provided a global 3D model; the polygonal mesh has been simplified reducing the faces number and preserving the surface shape. In fact, the flat areas not need a large amount of data and allow to construct a lighter model with low computational effort.

Adopting a 10% mesh-reduction, an increased smoothing is observed (figure 8); moreover, the comparison between the decimated mesh and the original mesh provides residuals lower of the instrumental precision of the laser scanner HDS 2500. This mesh has been used to extract nurbs surfaces. The operation is needed because the mesh modification is a slow and laborious procedure which involve also thousands of triangular faces. Using nurbs surfaces, the procedure is easier dealing with single elements covering the object.

The nurbs surfaces extraction has been performed using an automatic procedure from the polygonal mesh; subsequently, the number and the control points distribution have been adjusted (figure 9).



a)



b)

Figure 7. a) Creation of the longitudinal carrying skeleton by the user; b) automatic reconstruction of the new gaps (small dimension)

Figure 8. 3D reference model obtained

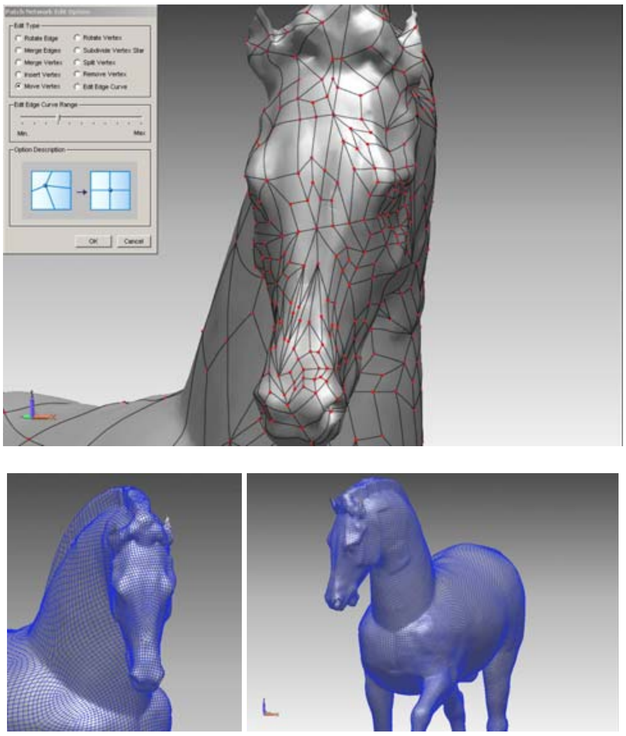
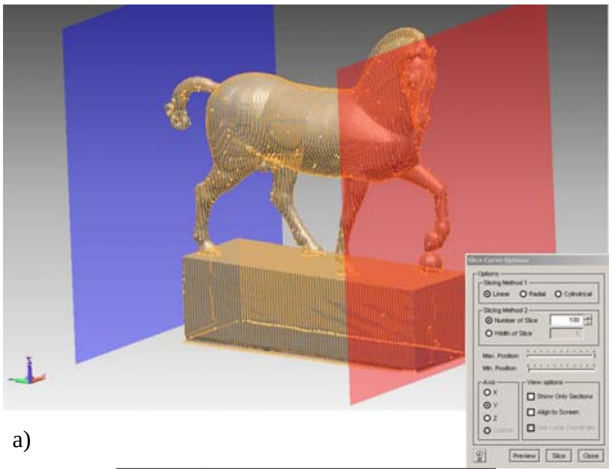
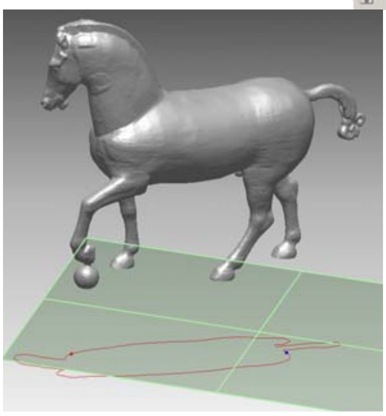


Figure 9. Management control points for Nurbs surfaces

6. CROSS SECTIONS AND PROFILES EXTRACTION



a)



b)

Figure 10. a) Generation of the cross sections by means of the intesection of the 3D model with vertical plans;
b) Profiles extraction obtained projecting the 3D model limits on the reference plans

The polygonal mesh has been used to extract cross sections by means of the intersection between the 3D model with horizontal or vertical planes in the local reference system adopted (figure 10a). Moreover, the same approach allows to generate profiles, projecting the contours of the wooden horse respect to a reference plane (figure 10b); the cross sections and profiles allow to reconstruct the metric and the features of the wooden horse in AutoCAD software (Autodesk) (figure 11) which are very useful for the restoration plan of this structure.

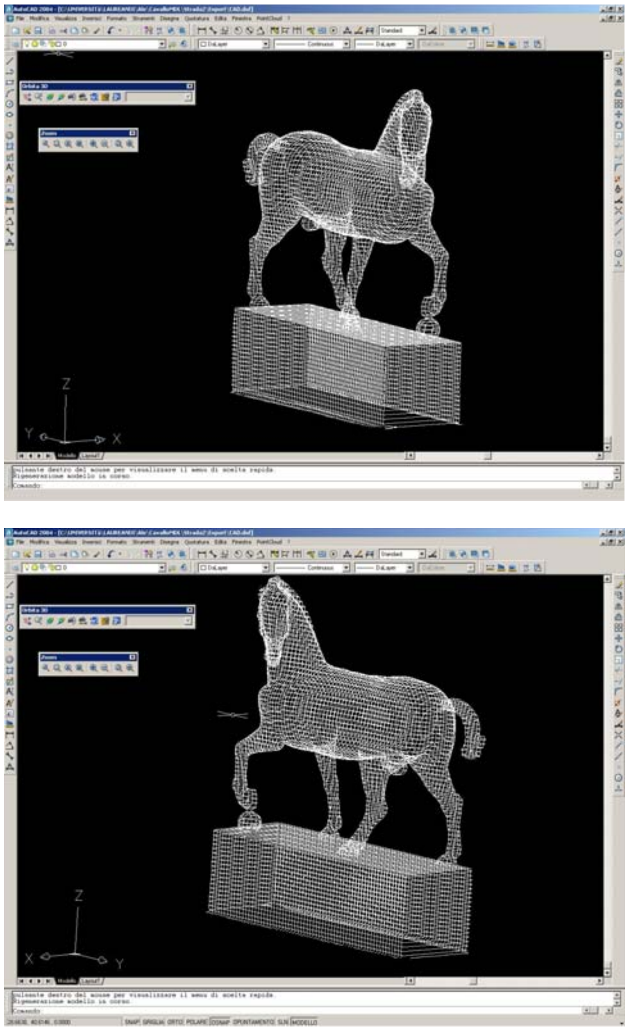


Figure 11. The 3D model of the wooden horse obtained by the cross sections generates with RapidForm2004 software managed with the AutoCAD software

7. CONCLUSIONS

The application of the laser scanning methodology and its integration with the classical topographic procedures has allowed to generate a 3D model of the “Cavallo ligneo” of the “Palazzo della Ragione” in Padua; the wooden horse, built in 1466, characterized by relevant dimensions and morphological complexity, has a very degraded wood and restoration work has been planned.

The laser scanner HDS 2500 have been used and the specific reflective targets were acquired in a local reference system and used as control points.

Due to the limited available space around the object, some lacunas were located; the allignment has been obtained using the Cyclone software and a specific analysis has been performed to evaluate the performance of some interpolation algorithms. Some of these methods have allowed to filling lacunas with precision comparable with the laser scanner accuracy (the improment results were obtained considering some points of the surveyed data inside the lacuna). However, the application of the kriging algorithm to reconstruct the back and the top of the horse in this case not provide good results. These methods can be used with small lacunas taking advantage by the automatic procedures.

Using the RapidForm2004 software the lacuna on the back of the wooden horse was filled by means of a semi-automatic procedure: at first, has been create by the operator an carrying skeleton in respect to the curving and subsequently the holes, has been filled automatically.

On the final 3D model a decimated polygonal mesh has been generated guaranteing the laser scanner accuracy: subsequently nurbs surfaces, profiles and cross sections have been extracted as input data for further analysis in AutoCAD environment for the restoration of the wooden horse.

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