3D HIGH RESOLUTION PHOTO REALISTIC MODELS FROM A PROTOHISTORIC BURIAL SITE (OLMO DI NOGARA, ITALY)

G. Salemi*, A. Canci^, L. Salzani+, M. Cupitò^,
G. Concheri*, R. Meneghello*, G. Savio*, E. Faresin⁕

giuseppe.salemi@unipd.it

* Engineering Faculty, University of Padua, Italy
\+ Superintendency of Veneto, Italy
^ Archeology Dept., University of Padua, Italy
⁕ Science and Technology for Cultural Heritage, University of Padua, Italy

Keywords: laser scanner, multisensory systems, 3D models

Abstract: The cemetery at Olmo di Nogara (Verona, northeast Italy) is one of the most important protohistoric burial sites in Italy. From the paleopathological point of view, eleven cases of perimortal lesions, which may be interpreted as the results of injuries inflicted during life by weapons, were found on the males. To acquire three different archeological finds (a femur, a vertebra and a skull) without using traditional instruments like calipers, two different laser scanners, the Konica-Minolta Vivid 910 and the Faro laser ScanArm V3, are used to produce 3D high resolution models. On these models metric surveys are possible with an high level of accuracy and submillimiter resolution. Konica-Minolta is a non-contact 3D digitizer and it employs laser-beam sectioning technology to scan samples using a slit beam. Light reflected is acquired by a CCD camera and 3D data is then created by triangulation. This laser can measure 640 × 480 individual points per scan, complete measurements are acquired in 2.5 seconds by three different scans. An important aspect is that color image data are acquired using a rotating filter separating the light and creating image data for the scan window. The Faro Cam2 laser ScanArm is a contact/non contact measurement system. The precision is up to 0.0006”. Textured 3D models (photorealistic 3D models) are presented in a proprietary format in order to be measured and analyzed, especially from a metrical point of view, in specialized software environments.

1. INTRODUCTION

The cultural heritage of the necropolis of Olmo di Nogara (Verona, Italy) for its historical and aesthetic value is an asset that represents the identify of the man who has lived with it. Its preservation and development require an extensive documentation both in art history and in terms of physical characteristics such as location, shape, color and geometry. The major expectations in the field of cultural heritage documentation shall be directed to three-dimensional laser scanning techniques: a system capable of operating in a quasi-standard way in terms of acquisition speed and resolution and with the ability to directly access data in real time. The applications are numerous: documentation and archiving of the actual state of a monument are essential in case there is a need for reconstruction or conservative. The ability to detect features/anomalies with high accuracy allows the analysis of complex geometries and details which would be difficult to detect with traditional techniques. A goal of this work is to use the same methods and systems coming from reverse engineering in the field of Cultural Heritage in order to make micrometrics measurements, in particular in stab injuries. Currently these types of measurements are performed with common instruments, such as micrometers, that provide approximate results and not entirely correct in terms of geometrical aspects.
Through the 3D scanning, however, it is possible to map the depth of the perimortale fracture along the entire length. The main stage of work were:

- Acquisition of geometry objects;
- Data processing;
- Creating a 3D model;
- Isolation of the fracture;
- Processing of the mesh;
- Mapping depth.

2. THE ARCHEOLOGICAL SITE OF OLMO DI NOGARA

The archeological site of Olmo di Nogara (Figure 1), dated between the middle and recent Bronze Age, is located a few hundred meters West of the town of Nogara, about 30 miles south of Verona.

The necropolis is located on the right bank of the riverbed of Tartaro, on a sandy hill with NW-SE direction. The cemetery, consisting of more than 500 tombs, is mixed with very clear prevalence of ritual burials on incineration (86% vs 11%) and it is characterized by internal articulation in at least three distinct cores aligned along a major road, probably structured for ceremonial.

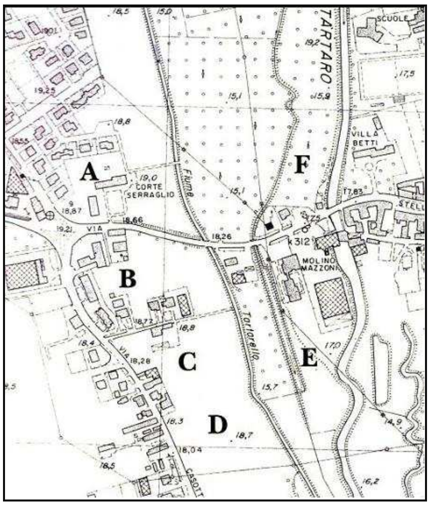


Figure 1: The archeological site of Olmo di Nogara

The complex was dug in a systematic manner by the Superintendence for Cultural Heritage of the Veneto region under the direction of Dr. Luciano Salzani between 1987 and 1997; smaller but very significant investigation were performed in 2002 and 2009.

Olmo di Nogara is one of the most important necropolis of the Bronze Age: it is a key element for the reconstruction of socio-political dynamics that characterize Verona, and the active throughout the Bronze Age, between continental Europe, Italian Peninsula and the Mediterranean world.

The centrality of the complex of Olmo di Nogara depends on four factors:

- The necropolis was investigated in a systematic manner and the information field is of high quality;
- The overall chronological range of the cemetery encompasses the entire development of civilization;
- There are codes that distinguish explicitly funerary distinctions of age, sex and rank of the deceased;
- The anthropological sample of the burial ground is one of the largest and most complete of all the Italian Bronze Age. The skeletal material is the most anatomically complete and shows excellent storage conditions.

The samples were fully investigated by Prof. Cleto Corradin (University of Padua), and the results were published (monograph, 2005). From 2006 through the cooperation of Prof. Alessandro Canci, professor of Human Paleontology at University of Padua and Dr. Luciano Salzani (Superintendence for Archeological Heritage of Veneto) a project of systematic review of the osteological material of the cemetery started.

Area A comprises 36 tombs which can be dated to the Late Bronze Age burial; in area B 123 tombs, 15 inhumation and 108 cremation burial dated to the Middle Bronze Age have been excavated; in area C, divided into two groups, North and South, 367 graves were found, 46 of which inhumation and 321 cremation burials, dated to the Middle and Late Bronze Age.

The burials are all in simple hole and easily identifiable by the presence of red-brown or light brown silt-sand fills that distinguish them from the surrounding lands. Carbonaceous traces were found on some skeletons, and were interpreted as remains of wood fiber, so that the presence of boxes or coffins is than assumable.

The deceased, for the most part, are placed in the supine position with arms straight at the sides or bent over the basin. There also evidences of on the side or prone placements.

The burials are often accompanied by a set: generally weapons for males and an ornamental parure, bronze pendants and combs made of bone/horn for females.

3. MATERIALS

Grave 475: A mature adult male about 40 years old. The diaphysis of the left femur (Figure 2) of this individual, exhibits in the most distal quarter a lateral injury perpendicular to the long axis of the bone made by a straight metal blade; it measures 28 mm in width by 0.5 – 2 mm in width. At the upper edge of this cut a small amount of bone has been removed, whereas in correspondence to the lower edge there is a fracture line which encloses a semicircular chip of bone. Both of these features are doubtless the result of the violent impact of the weapon. The injury was presumably caused by a blow inflicted with considerable force just above the knee.

Figure 2: left male femur with a lateral injury

Grave 38: A young man between 25 and 35 years old. He has two distinct lesions stab located respectively on the skull (Figure 3) and on a lumbar vertebra (Figure 4). The head injury extends obliquely across the coronal suture on the frontal bone. It is 24.5 mm long and between 1 and 2 mm wide. Given its morphological characteristics, it is the outcome of a blow inflicted with a sword, from top to bottom and from right to left. It can be assumed that the stroke was led by a right-handed person placed in an elevated position than the victim.

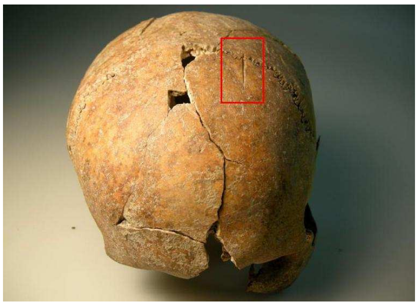


Figure 3: male skull with injury across the coronal suture

The spinal lesion is located on the right side of the third lumbar vertebra. It crosses obliquely the whole vertebral body from the attack of superior articular facet of the vertebra at the base of the body and it is 44 mm long, while the width ranges from 2 mm of the central part, very deep, to 0.27 mm of the upper edge. Given its morphological characteristics, the lesion may be interpreted as the result of the blow tip led to the lower abdomen, botton_up, which struck the vertebra to slip. Regarded the location of the wound is likely that the shot had severed the inferior vena cava and affected the right kindney.

Figure 4: male third vertebra with an injury

4. METHODS AND INSTRUMENTS

Being able to have three-dimensional digital models that faithfully represents shape and characteristics of color and texture of real art is proving to be of great importance in an increasing number of applications: study and cataloging iconography, restoration planning and creation of virtual museum or tours, assistance for reconstruction of archeological findings and production of copies for preservation or popular purposes.
In addition, there is no methodology that can be applied to different problems in the same way: the characteristics of the object that must to be analysed, such as geometrical complexity of the object shape and surface features such as reflectivity and transparency, strongly influence the choice.
The specific applications that is expected for the model such as accuracy required of the digital model, complexity of the description of the digital model for optimal benchmark application, compatibility of tinime and cost of acquisition within the budget project are also considered.
There are different types of scanners classified according to their scanning system: scanners that have a scanning system in contact and scanners that have a non-contact scanning system. The first type is the most established and widespread in companies, while the latter is now beginning to ensure the performance of dimensional tolerance required for more sophisticated applications of Reverse Engineering and is suitable in cultural heritage where contact with the scanning device is absolutely a non-destructive investigation and therefore it has to be considered a non-invasive investigation technique.
The systems on which the attention are placed is the optical triangulation systems: they are suitable for capturing objects in small or medium scale, providing accuracies of the order of few tens of microns and allowing the creation of very dense sampling of the order of 4-10 per mm² sample surface.
They normally have very low scanning times of the order of few seconds for each shot.
In the optical triangulation system the ray of a laser light transmitter is refracted through a lens system forming a beam that is projected on the object; the reflected light is captured by a CCD sensor. The position of the light recorded by the camera provides the location of the space.
The geometry of the acquisition (emitter, object, sensor) is shown (Figure 5).

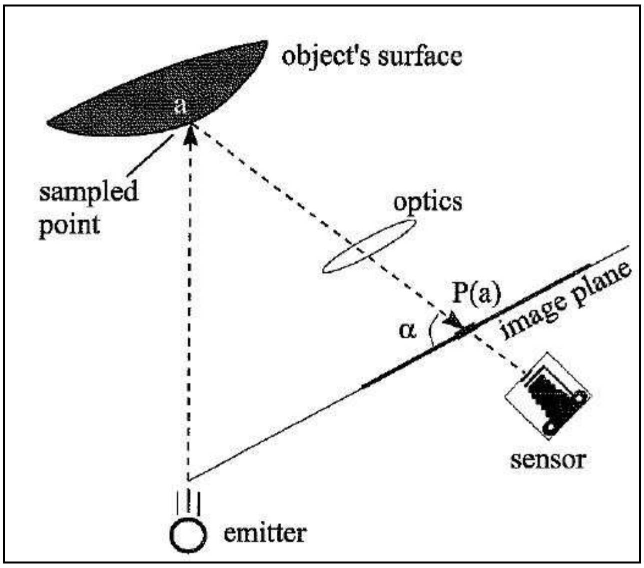


Figure 5: diagram of the method of triangulation from [6]

This type of laser, by definition, allows to capture only the properties of the object surface and the quality is highly dependent on the reflectivity characteristics of the object.
The bones are opaque objects and the acquisition is excellent; the problem emerges on the inside: the bone tissue is porous and therefore in case of fractures, the laser ray may not always capture all the points and may leaves some gaps.
Two different laser scanner are used to produce 3D high resolution models:

Laser ScanArm V3 (http://www.faro.com): The Laser ScanArm V3 allows contact and contactless measurements. This instrument is perfect for comparison piece/CAD, rapid prototyping, reverse engineering and dimensional modeling (Table 1).

CAM2 Laser ScanArm combines portable measuring arm CAM2 7-axis with a probe laser. It is very easy to use and provides maximum freedom of movement with no annoying external cables.

This laser, compatible with the arm CAM Platinum offers several advantages: it has accuracy of 35 microns; it works with wireless Bluetooth: users can inspect and scan objects up to a distance of 10 m, even through walls.

Introduced in 2003, CAM2 Laser ScanArm was the first measurement device in contact/non contact laser scanner with a seven axes integrated system. It allows users to collect simple point variations with the solid probe, while the laser scans sections requiring larger volumes of data.

This type of system can make measurements without interruption thanks to articulation that enables 360° rotation; it has got also a built-in sensor for automatic compensation of ambient temperature measurements.

CAM2 Laser ScanArm is compatible with Geomagic, Polyworks, RapidForm and the data interoperability is guaranted through standard format like STL.

Table 1: characteristics of the laser ScanArm V3

Model	Laser ScanArm V3 2.4 m Platinum
Accuracy	35 µm
Repeatability	± 35 µm, 2δ
Depth of field	85mm
Effective scan width	Near field 34mm, Far field 60mm
Points per line	640 points/line
Scan rate	19200 points/sec

Konica Minolta VI-910 (http://www.konicaminolta.eu): The VI-910 employs laser-beam light sectioning technology to scan workpieces using a slit beam. Light reflected from the workpiece is acquired by a CCD camera, and 3D data is then created by triangulation to determine distance information.

The laser beam is scanned using a high-precision galvanometric mirror, and 640 × 480 individual points can be measured per scan (Table 2).

Konica Minolta's unique high-speed image processing chips have been integrated in order to ensure rapid measurement, and this has made it possible to complete measurements in 2.5 seconds (or in as little as 0.3 seconds in FAST mode). In addition to distance data, furthermore, this 3D digitizer can also be used to acquire color image data. Employing a rotating filter to separate the acquired light, the VI-910 can create color image data for 640 × 480 points with the same CCD as used for distance data.

Table 2: characteristics of Konica Minolta VI-910

Model	Non-contact 3d digitizer VI-910
Measurement method	Triangulation light block method
Light-receiving lenses (exchangeable)	TELE: focal distance f=25mm MIDDLE: focal distance f=14mm WIDE: focal distance f=8mm
Depth of field	0.6 to 2.5m
Optimal 3D measurement range	0.6 to 1.2m
Accuracy	X: ± 0.22mm; Y: ± 0.16mm; Z: ± 0.10mm to the Z reference plane

5. RESULTS

SKULL

From multiple acquisitions a three-dimensional model was obtained, requiring further pre- and post-processing by the operator. The processing steps are the same for all three acquired items.

Mosaicking single acquisitions a model of 29 shells, 565108 vertices and 1062944 faces was obtained (Figure 6). First of all, it is necessary to delete the parts and the points that do not belong to the object.

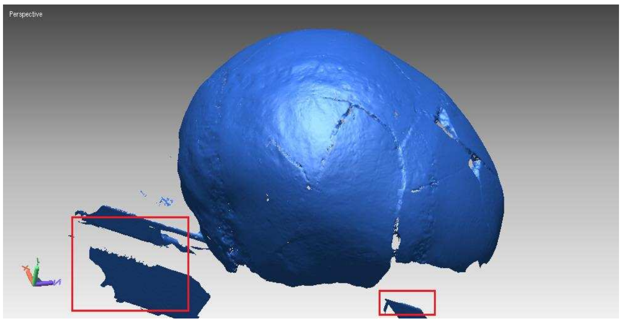


Figure 6: model of the skull after the acquisition

A model of 545259 vertices and 1025970 faces was so obtained. The merge procedure/command that combines 29 shells in a single shell was started. A model of one single shell, 228336 vertices and 449223 faces was obtained. Then the lacunas were closed with fill holes command, getting the final three-dimensional model (Figure 7). The gaps due to lack of acquisition point by the laser are marked in red. The holes belong to the surface of the skull.

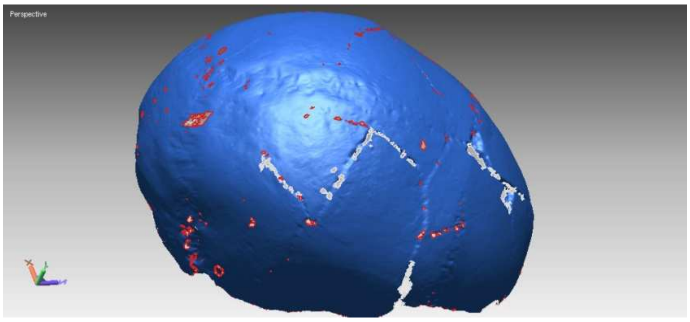


Figure 5: model of the skull with lacunas in evidence

In Figure 8 the main axes of inertia are highlighted. These are the axes of symmetry: if the body rotates around this axis, the angular momentum is parallel to the axis of rotation.

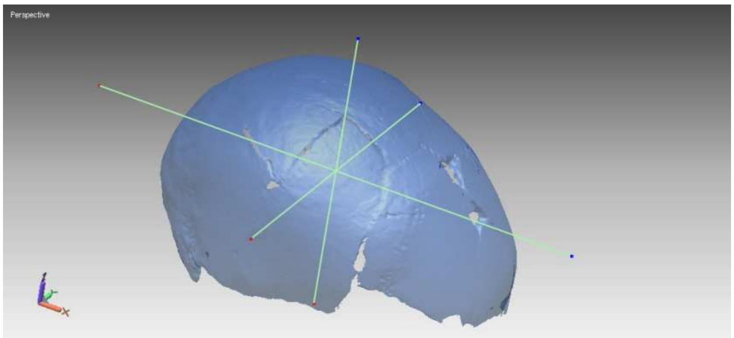


Figure 8: three-dimensional model of the skull with the axes of inertia

The textured model of the skull was obtained using the Konica Minolta VI-910. In this case scans were done every 45 degrees to 360 degrees (Figure 9). Then the model was cleaned from the scanned point that did not belong to the skull. In this case the merge command must not be given, otherwise the texture will be lost.

Figure 9: photorealistc 3D model: the three-dimensional model of the skull with the texture

FEMUR
The starting model of the femur, after the acquisition, has got 10 shells, 346393 vertices and 669082 faces. The three-dimensional model is obtained by processing shells (cleaning and closing holes), alignment and merge (Figure 6).

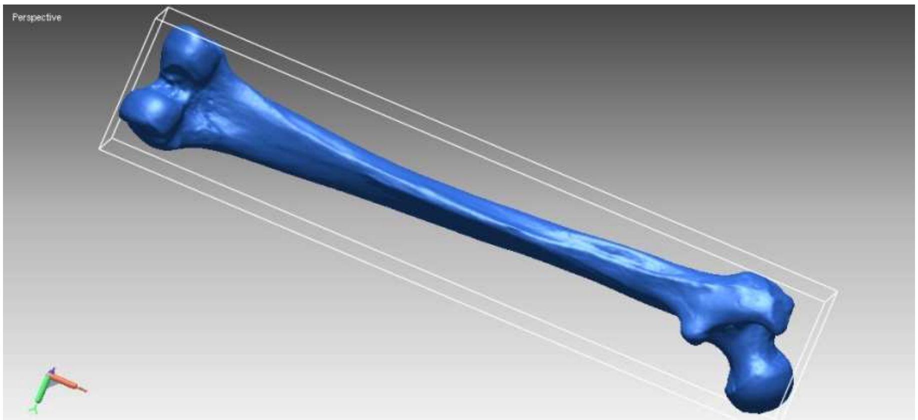


Figure 6: three-dimensional model of the femur with the bounding box

VERTEBRA
The starting model of the vertebra has got 6 shells, 85669 vertices and 16361 faces. The three-dimensional model is obtained by processing shells (cleaning, closing holes) and merge (Figure 7).

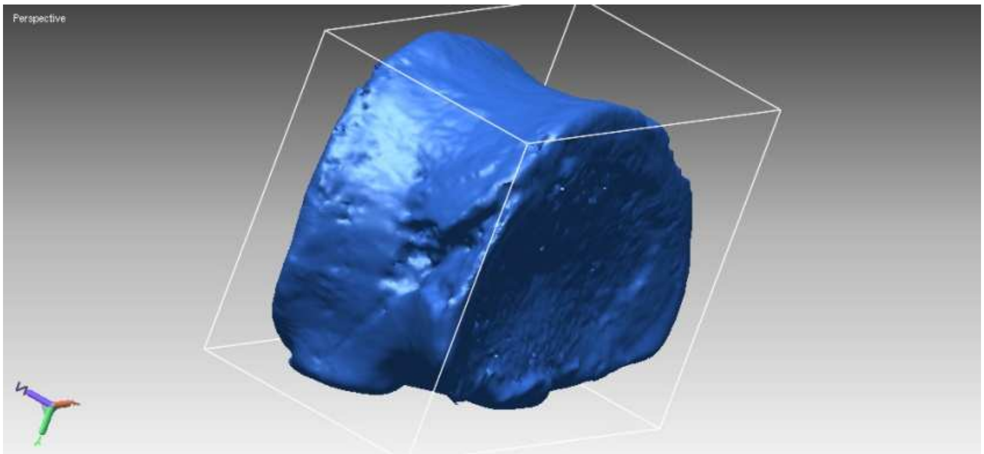
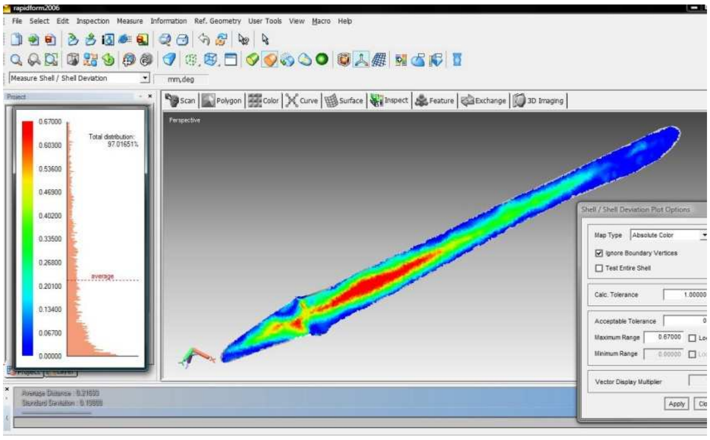


Figure 7: three-dimensional model of the vertebra with the bounding box

6. CONCLUSIONS

The primary objective of the research concerning the three-dimensional models, is to develope and testing tools that make available a new instrument of knowledge in the "industry" of cultural heritage: a very high resolution 3D photorealistc model of an object. A greater spread of three-dimensional techniques will be induced by the simplification and automation of procedures for the creation of three-dimensional models and by the T.C.O (Total Cost of Ownership) of the acquisition system. The creation of a digital model of an historic and artistic object is still a complex process that involves the use of an appropriate hardware instrumentation and software environment and it is not free of manual intervention of experienced operators yet. The correct application of existing methodologies to measure, properly designed, has achieved the objectives proposed by the production of detailed, both in quality and quantity, elaborate to satisfy the needs of different disciplines involved in the conservation process, where the potential of global three-dimensional model, ranging from 3D visualization to the calculation of metric and topological characteristics of complex surfaces. In particular, the acquisitions have provided essential metrics information for the knowledge of superficial parts that are not directly perceptible, such as fractures (Figure 8). A reading and a reasoned elaboration of the metrics, may lead to the knowledge of the shape of the weapon that inflicted the mortal blow, maybe an ax in the case of the skull.



Total distribution: 97.01651%

Map Type: Absolute Color
☑ Ignore Boundary Vertices
☐ Test Entire Shell
Calc. Tolerance: 1.00000
Acceptable Tolerance: 0
Maximum Range: 0.67000
Minimum Range: 0.00000
Vector Display Multiplier

Figure 8: map of the depth of the skull fracture

7. REFERENCES

[1] Andreetto M., Brusco N., Cortellazzo G.M.: *Automatic 3D modeling of textured cultural heritage objects*, Image Processing, 2004, 354-369.
[2] Bitelli G.: *Moderne tecniche e strumentazione per il rilievo dei beni culturali*, Geomatica per l'ambiente, il territorio e il patrimonio culturale, 2002.
[3] Cantoni R., Vassena G., Lanzi C.: *Integrazione tra laser scanning e metodologie di rilievo tradizionali nella ricostruzione 3D*, ASITA Federazione delle Associazioni Scientifiche per le Informazioni Territoriali e Ambientali, 2002.
[4] Cupitò M., Leonardi G.:*La necropoli dell'età del Bronzo all'olmo di Nogara*, Memorie del Museo Civico di Storia Naturale di Verona, 2005, 488-491.
[5] Mays S.: *The archaeology of human bones*, London, 1998.
[6] Montani C., Rocchini C., Scopigno R.: *Tecnologie 3D scanning. Introduzione e valutazione comparativa*, C.N.R., Pisa 2001.
[7] Ortner D.J., Putschar W.G.J.: *Identification of pathological conditions in human skeletal remains*, Washington, 1981.
[8] Pavlidis G., Kautsondis A., Arnaoutoglou F., Tsioukas V., Chanzas C.: *Methods for 3D digitization of Cultural Heritage*, Journal of Cultural Heritage, 2007, 93-98.
[9] Pieraccini M., Guidi G., Atzeni C.: *3D digitizing of cultural heritage*, Journal of Cultural Heritage, 2007, 63-76.
[10] Pollefeys M., Van Gool L.: *From images to 3d models*, Communications of the ACM, 2002.
[11] Yastikli N.: *Documentation of cultural heritage using digital photogrammetry and laser scanning*, Journal of Cultural Heritage, 2007, 423-427.