

HIGH-RESOLUTION 3D DIGITAL MODELS – CH SURVEYOR

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Abstract. This paper deals with laser scanning developed in Romania in the past 4 years, presented case studies refers to important monuments. Activities were performed under national or international research programs. A short overview of the existing 3D digitations techniques is presented followed by a short presentation of sites where laser scanning was applied. Examples of digital models are presented in different formats, including 3D gallery, may be viewed accessing <http://inoe.inoe.ro/certo>.

Key words: laser scanning, cultural heritage, Romania, restoration, conservation.

1. INTRODUCTION

Less than 15 years needed for first laser application in artworks conservation. It begun in 1972, when in an experiment of feasibility testing to produce large in situ holograms were observed the possibility of ablation with minimum damage. This discovery led to a new domain, laser cleaning [1].

With development of laser technique and studies of laser interaction with matter new and more diverse domains of laser in conservation of artworks were developed, including laser induced breakdown spectroscopy (LIBS), Raman spectroscopy, laser interferometry, laser induced fluorescence, 3D laser scanning and others.

Laser scanners are just apparently a sophisticated alternative to the conventional data collection methods, offering good resolution and accuracy. As a contactless technique, the used radiation doesn't cause any change on the object, by this aspect it can be used in precious or fragile objects with different shapes and sizes. Moreover the 3D model may be further used later and remotely, for study, documentation, demonstration and reproduction and insurance. Due to this validated techniques, and corroborate with the IT instrumentation dynamics in all

domains, 3D models are expected to become soon part of mandatory documentation for entire cultural heritage related to international database.

The first major application of laser used in cultural heritage documentation was made in 1998, which consist in 1 year campaign, in the so called The Digital Michelangelo Project. More than 30 people staff were involved in digitizing artworks by Michelangelo in order to make a 3D archive of artist masterpieces [2].

Benefiting from technique improvements and software developments, several cultural heritage sites were 3D recorded, including location like Royal Tombs at Kasubi, Chichen Itza, Rapa Nui, Angkor [3], Pompei [4], Bamiyan [5], Petra [6] and examples may continue.

This paper presents a selection of significant case studies addressing towards the methods of acquisition and storage information regarding the nature of the material of the artefacts for complex diagnosis, and not only about their shape, but also about the conservation status and risk factors identification.

2. 3D OPTICAL MEASURING TECHNIQUES

The first experiment, as history records, in one of the basic principles used in laser scanning was done in 17th century, when Galileo Galilei tried to measure the speed of light. Were needed more than 200 years to obtain a high accuracy estimation of this constant, which is nowadays used as a common tool for laser scanning.

Volumetric representation using laser coherence proprieties was firstly used in the late 60's, in order to produce holograms that were further on used on public exhibitions.

Depending by the type of recording, 3D measuring optical techniques may be divided in passive (with photogrammetry being the exponential from this category) and active. Following the used principles, active techniques may be further divided in 2 categories: triangulation (the name comes from arrangements: laser head – studied object – photosensor generating a triangle) and time of flight.

As radiation is used coherent light, with wavelength between 0.5 and 1 μm . Also were reported cases of microwave or ultrasonic waves, but their limitation comes from resolution, generated by diffraction limits.

A special case of time of flight technique may be represented by interferometry, since records differences in optical path, between a referential position and a subsequent (different) moment. Limitations of the optical interferometry arrangements are given to $\lambda/2$ (with λ – laser wavelength). Best resolution obtained was compared with $\lambda/100$, in the case of 2 lasers interferometers, in pulsed regime, with beat frequency of several GHz.

As one of the first arrangements used, triangulation is both an active or passive technique. Stereovision is corresponding of the passive one, and consists in geometrical approach of triangles angles. In contrary, the active technique consists

in triangles symmetry studying. The constructive limitation of the active techniques is to several meters and has a strong inconvenient: resolution depends by the distance between the photosensor and laser head, the bigger the distance, the higher resolution, so indifferent to the technical evolution, this arrangements still needs a long base of triangle edge laser-sensor, and so a low possibility of method portability. Furthermore, increasing this distance raises the possibility of object shadowing.

As application, this technique is used to record small to medium size objects, with resolution up to tens of micrometers.

Time of flight technique record the time that electromagnetic radiation travels from laser – reflect on the studied object surface and then recorded by a sensor. Usually the laser and photosensor are incorporated in the same shell and is named forward scanner. This two-way time is used to determine scanner – object distance, with a resolution, depending by the application, less than 1 cm (some systems with accuracy of tens of micrometers). At a distance of 10 m, time of flight is less than 1 ns, and for possibility of recording variation of 1 mm in depth, the sensor needs to be capable to record variation in time of picoseconds.

Depending by application are used pulsed or modulated continuum lasers, and may be used up to distances of several km.

After distance determination between scanner and one point from object's surface, this step is repeated by thousands or even millions times. Scanning repetition may be up to tens of kHz, and a complete scene may be recorded in less than 1 hour.

In the past years several types of 3D scanners were developed, and depending by the maximum field of view may be categorized in: camera scanner (with field of view $40^{\circ} \times 40^{\circ}$), hybrid scanner (field of view $60^{\circ} \times 360^{\circ}$) and panoramic scanner ($270 \times 360^{\circ}$) [7].

This 1 point measurement (example is given for a continuum wave phase modulated scanner), is done by following: laser beam pass thru a beam splitter after that are obtained 2 beams, and one of the beams is kept as reference. The second beam travels to the object, is reflected and a part of the scattered radiation is detected by the scanner's photosensor. Comparing the reference beam with the object beam, from the phase shifting difference is determined radiation time of flight and so the distance between the scanner and studied object is determined. By an optomechanic system the object's beam is deflected. First on vertical, with steps on tenths or hundredths degree, defined prior recording, chosed by several factors: distance scanner – object, final resolution of the 3D model, or application. After this vertical scanning, the scanner rotates, again with values of tenths or hundredths degree, covering the scene on horizontal. This rotation is realized by a rotating stage, on which is the scanner is mounted.

I can be summarized that the scanner observables are range, azimuth and elevation, relative to coordinate system origin. This scanner observables (r, θ, φ) are transformed to objects coordinate, in a Cartesian system (x,y,z) [8].

This point of cloud is exported with formats compatible with several processing tools. Data is noisy filtered, and then, depending by final application, workflow includes meshing (depending by the type of scanner used, where the export format may be directly mesh, the previous listed steps may be omitted), registration, photo coloring and others.

3. RESULTS

European programs supports quite well the application of the research advanced methods within the field of cultural heritage digitalization and a large space in the Communitarian legislation is allotted in this respect. The EC Recommendation (2006/585/EC) includes detailed information about digitalization and online accessibility to the cultural material and digital preservation of cultural materials. Certainly, some of the launched programs in the last years are for the time being referring to the methods and techniques already known to a quite large number of users or cultural agents. Unfortunately, almost the entire approach and the information circulating between the scientific and cultural community has tackled only the digitalization of the cultural resources regarding the shape and only for the large audience “use”, with the purpose of increasing the number of visitors, generally for primary information purpose only.

The photonic techniques has already demonstrated that they can provide extremely rigorous information about the external shape of the object (*e.g.* the 3D laser scanning) and about the morphology of some “hidden” structures (*e.g.* the Doppler Laser Vibrometry, holographic interferometry, G.P.R., etc), about the physical properties of the investigated material (*e.g.* thermo emission, chromatic value, etc) to which implicitly information is digitalized by the method of investigation/ data collecting and processing.

Domains where laser scanning may be used are quite different, from reverse engineering to quality inspection, art reproducing or even entertainment industry (cinematography or computer games). Several application, done by INOE 2000, with high visibility or not, were made in the past years, results that will be presented next [9].

Applications includes archaeological sites, historical monuments, delicate surfaces, where this non-contact technique is ideal, polychrome surfaces, narrowed chambers, different types of materials (wood, clay, bricks, mortar, chalk, etc.) with low or high resolution measurements, and with a goal, not necessary the main one, to produce an internet sharable digital accessible 3D model.

As results from this techniques were quite various, including technical documentation, from the classical section, with resolution of mm, to surface and volume calculation, degradation evaluation, putting in evidence non planar surface deviation for restoration purposes, or just visualization for hard accessible location for restoration strategy planning.

3.1. PAINTED GRAVE FROM CONSTANTA

Discovered in the late of '80, the painted grave is dated from 5th century, with Greeks origin. Laser scanning inside the Hypogeu was difficult because of the small dimensions of the grave. A minimum distance need to be satisfied between the scanner and studied object. Since the length of the grave is approximately 3 meters, were performed 2 recordings. Moreover, the inside recordings were affected by the funeral stones that still exists. In order to have a more complex digital model, 2 recordings were made of the grave's entrance, 1 with the door open, to have details for scans alignments, and a second one with the door close. The goal of the recordings was to make a digital replica – part of a grave's Cyber Museum, replica that it's available at the internet address: <http://inoe.inoe.ro/IMAGIST/> [10]. This monument is the first Romanian site with a complete 3D colored model, realized by laser scanning and photo image mapping. Furthermore 3D stereo movies are available, that requires special color coded 3D glasses for a complete effect of both color and volumetric interpretation. Since is used one wavelength no information about the object's color in recorded. To obtaine a 3D colored model photo images were projected over the object. Except the laser's time of flight it is also stored the intensity of detected radiation. This intensity allows a grey map display that if furthermore used for color image mapping detail identification. 3D color model, as it was in the case of Hypogeu, is obtain by the same detail identification, in photo image and 3D model (displayed as grey map), and after a couple of details picked, photo image is projected on the 3D model, keeping references identified details as constrains.

3.2. ROMAN MOSAIC EDIFICE FROM CONSTANTA

The widest mosaic from south-east of Europe, with a surface of nearly 2,000 m² it is dated during Constantine administration. Scanning of the 45 long paved mosaic was made by 11 recordings, attention also accorded to the structure's walls. One of the measurement aims was putting in evidence dishevelments caused by time exposure.

3.3. BASARABI CAVE ENSEMBLE

Application at the Caves Ensemble from Basarabi – Murfatlar, was maybe the best usage of laser scanning in cultural heritage preservation. Dated between 9-11th century, the ensemble consists in churches, galleries, graves and tombs. A large number of inscriptions, scenes, drawings and others are made on the churches walls, with various origins and languages. Besides recording and digitizing the rich value artifacts [11], computation were performed to measure time erosion, since

the ensemble is carved in a chalk mountain and with a high value of relative humidity [12]. Three-dimensional digital replicas may represent the only solution of a complete documentation of the site. In time erosion was measured by comparing two scans, made at a difference between the measurements at less than 2 years. On some inspected areas this differences may take values up to 0.5 mm, with the mention that some incision's height is less than 1 mm. This irreversible process of the pulverulent surface made the unfortunately event of hardly identifying of some details or, in the worst case, in losing some of the inscription.

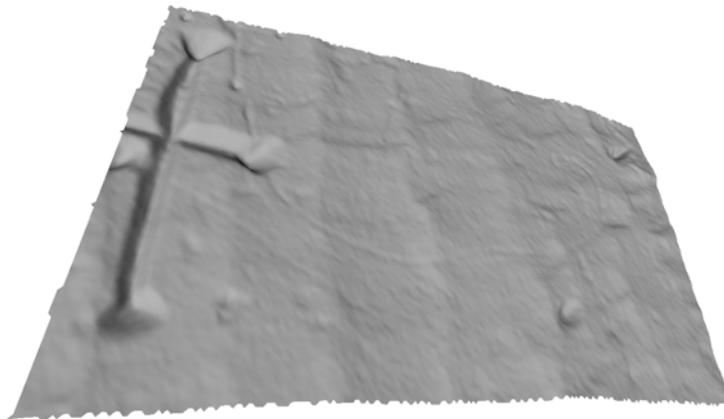


Fig. 1 – 3D digital representation of the ship model.
Model resolution ~ 150 μm , incision height < 200 μm .

3.4. HARSOVA ARCHAEOLOGICAL SITE

Neo-Eneolithic site is placed on Danube's bank, 70 km from Constanta. Laser scanning was applied, for the first time in Romania on a tell, in order to record sit's stratigraphy. For this a total of 5 measurements were made, to scan also the base of the site. Scanning was made in low resolution ones, the general scans, to have a relative positioning of the following high resolution scans that were made.

3.5. HERESTI STONE HOUSE

Placed at 35 km from Bucharest, at Giurgiu and Calarasi County's border, Heresti stone house represent the only civil monument from 17th century from Romania. Activity at this monument were made under a Culture 2000 Program, for status conservation monitoring, and required both high resolution recordings, of writings that mentioned a meeting held at the end of 19th century, and also at a optimized resolution, scan made of the main building façade.

3.6. STAVROPOLEOS CHURCH

Build in 1724, Stavropoleos Church is made in byzantine traditional style. Activity at this church is more complex, for elaboration of an interlinked folder for conservation of the monument, with techniques as laser cleaning and long term microclimate monitoring. Laser scanning was made on church's stoop and the 2 baluster repetitive details. Since the church represent a highly visited monument, and access inside to church had to be restricted during the stop scanning, the measurements were made evening, after the visiting program ended.

3.7. CORBII DE PIATRA

Corbii de piatra (Stone Ravens) Monastery, Arges County, from 14th century is officially attested at the beginning of 16th century. The rupestral church is carved in stone, and laser scanning was applied to obtain high accuracy digital section with precise measurements. One of monument's particularity, is represented by the two altars, raised a problem during scanning, their shape, dimensions and orientation, that required 4 different recordings for a complete scanning.

3.8. BARATIE ENSEMBLE

One of the highly visited objectives from Campulung Muscel, Arges County, is Baratie Ensemble, consisting from parochial house and church, build between 14th – 15th century and Baratie Tower, attested in 1730's. Similar with the case of Corbii de Piatra, a digital documentation was an urgent matter. Besides the height of the tower and vegetation that shadowed one of the towers façade, a problem of tower's laser scanning was represented by the narrowed sidewalk in front of the monument's street façade. For that the measurement was made during night, the scanner placed on the street and with the road traffic partially diverted.

3.9. CATHEDRAL OF CURTEA DE ARGES

One of the most representative monuments from Romania, dated in the 16th century, a digital model, allowing a higher degree of accessibility for shape inspection were needed as part of the towers restoration. Laser scanning was made on the two towers, narthex corresponding, and on the church portal. Furthermore, a digital model of the exterior decoration was also made.

3.10. HUMOR CHURCH

A complete exterior digital model is available of the 16th century on UNESCO monument. Except the nave, which is in restoration, laser scanning was

also made of the stoop, narthex, crypt and altar. Measurements was made not to affect and not to be affected by tourists, interior during evening and night, stoop at the end of October and exterior in late spring.

3.11. SUCEVITA CHURCH

Part of a European Culture 2000 program, laser scanning application was applied on the funeral toms and iconostasis. Placed at the church entrance, on the floor, because of time exposure, the writings were eroded, the height of the letter being less than 1 mm. Since laser scanner could not record the objects corresponding the 90⁰ underneath the scanner (with the field of view of 360⁰*270⁰), scanner head was oriented in order to span the floor with the funeral toms. Sculpted in *yew wood*, the baroque - rococo style iconostas digital model is available at a resolution less than 1 mm, enough to present the fine details and also to perform computation to determine time evolution of observed cracks (by comparing the data from 2006, similar with the Basarabi application) [13].

3.12. BALINESTI CHURCH

One of the most representative Moldavian monuments from 15th century, Saint Nicholas Church, laser preservation was applied in the same European Program. A complete digital representation of the church's stoop, made in gothic style, being one of the most impressive monuments from Romanian's medieval period, is available, that required 5 scans. Additional, laser scanning was made on the church's pisanie. Since the inscription are placed at a high of more than 5 meters, the scanner was placed on a scaffolding, to assure a perpendicularity of recording, to reduce shadowing effects, performing an efficient digitization [13]. Presented activities may be included in establishing of a digital route of Bucovina's churches, in concordance with international trends of digitization and national perspectives for mobile and immobile cultural heritage.

3.13. TISMANA CHURCH

The oldest monachal settlement from Romania, which entered in a mural painting restoration program, laser scanning at the monastery's church is an ongoing project. The aim of the digitization activities is to create a complete interior digital model, accessible on internet and with no costs.

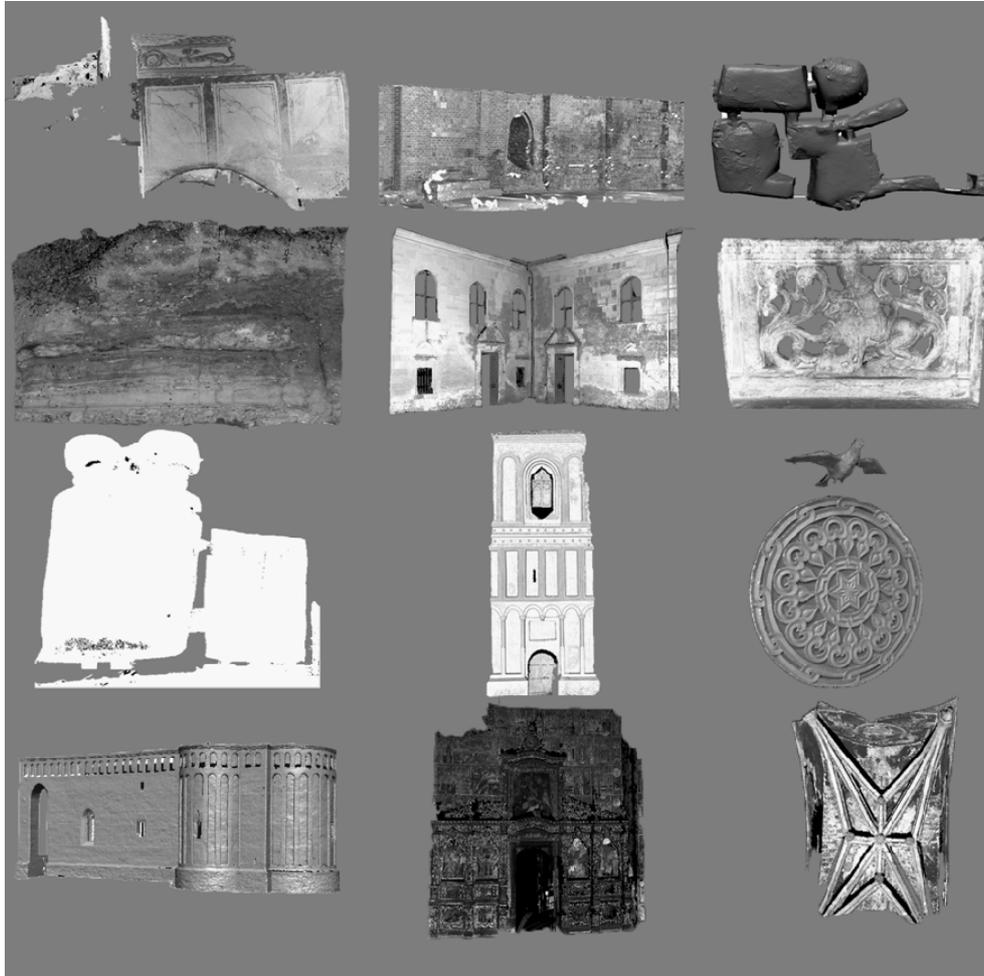


Fig. 2 – 3D Screen captured models: Painted grave, Roman Mosaic, B3 Basarabi, Harsova tell, main facade Heresti Stone House, vertical view of Corbii de piatra's interior, internal facade of Baratie tower, decorative detail of Manole's church, south facade of Humor's church, Sucevita's iconostas, Baliesti stoop cupola (from left to right, top to bottom).

4. CONCLUSIONS

Present paper points out not only the advantages of the 3D laser scanning methods, but also demonstrates their usefulness on certain solved case studies. As non-contact method for complex documentation, 3D laser scanning is also a versatile methods (large range of materials, dimensions, working conditions), fast acquiring data and even unique solution for some special cases (filigree surfaces,

damaged or contaminated surfaces etc.), and not least it is an ecologic methods. Other traditional methods for documentation constructions and replica making are involving external casting of special material. Obviously those have a very limited application range.

The 3D digital model delivered as “digital construction” by only one time moment scanning is not itself important in applied advanced research for Cultural Heritage preservation, but offers a lot of advanced results if multiple scanning data are compared and interpreted.

As it was shown, the current works are focused now on digital investigation results correlation to 3D digital models. However the method claim high professional approach, and some disadvantages have to be mentioned: the high data content of the image records, high capacity and high speed required computers for the image post processing operations. In spite of these, we consider that the 3D digital models will become soon basic data for mathematical models and prediction of conservation status.

By this paper we are no concluding the 3D documentation but present state of the art at a given moment, moment that coincide with a critical point, that can be exploited or not, depending by the assistance offered by the central authorities. The results are presented in different format at the internet address <http://inoe.inoe.ro/certo>, and its ramified links, additional to others laser based techniques that are used in cultural heritage benefits.

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