MODERN CONCEPTS OF 3D MODELING IN GEODETIC WORKS

Georgiana RUSU, Ph.D. Student – "Politehnica" University of Timişoara, georgianarusu85@yahoo.com
Cosmin Constantin MUŞAT, Ş.l. Dr. Ing. – "Politehnica" University of Timişoara, cosmin.musat@ct.upt.ro

***Abstract**: In the context of the evolution and full impact of modern technology, this paper aims to underline the advantages of using Terrestrial Laser Scanner (TLS) and 3D modeling software as an effective surveying technique. The works presented in the last few years about the use of 3D models witness the great interest of surveyors, engineers, architects and archaeologists towards the laser scanning technology as an invaluable mean for different domains. This modern concept stands out through its capacity to collect massive amounts of data within relatively short time periods, with high accuracy and providing 3D modeling applications which may be implemented in areas of major interest.*

***Keywords:** Terrestrial Laser Scanner (TLS), point clouds, 3D model, GIS.*

1. Introduction

Since early '90s terrestrial laser scanners (TLS) have been increasingly spreading out on the market as an efficient alternative method for 3D measurements. The multitude of works presented in last few years about the use of 3D modeling witness the great interest of engineers towards the laser scanning technique as an invaluable mean for different domains. The laser technology can scan any interior or exterior man-made or natural structure or area within its field of view, in a very short time and create a complete raw data set in the form of a 3D image made up of millions of points of data, called "point-cloud". Complete, precise and detailed 3D models of objects can be efficiently and easily created from acquired point clouds. A wide variety of applications demonstrate that 3D models allow the user to process different information contents from a digital representation of the reality.

These features allow laser scanning technology to dominate the market in a variety of applications such as automotive and mechanical engineering, mining industry, archaeology, architecture, geology, historical buildings, medicine, criminalistics, media and film industry, marketing or even virtual reality. The end products are may be represented by movies, complete 3D model of the object, 3D geometry of various objects even phisically located in remote sites, textured DSMs (Digital Surface Models), horizontal and vertical sections, volume calculation, depending on the consumer's demands.

Particularly this paper is focused on the characteristics and the use of laser scanning technique and its aplications in geodetic works.

2. Present stage of measurement techniques

In the context of the evolution and impact of modern technology, angles can now be resolved with single-second accuracy using optical and electronic theodolites and through electromagnetic distance measuring equipment can obtain distances up to several kilometers with millimeter precision. GPS and other satellite systems are used to set three-dimensional position. However, they are unable to solve every positioning problem, so the conventional surveying techniques continue to have a great importance. Although traditional surveying methods have always played a primary role in collecting field data, modern instruments and applications for data capture and processing give the possibility to increase the mass and the variety of achievable information. Nowadays, real-time monitoring systems based on robotic total stations and GPS, digital photogrammetric techniques, high resolution satellite imagery, airborne and terrestrial laser scanners devices are able to provide a set of powerful tools for the geometric surveying and modeling.

3. Basic concepts of surveying

Surveying may be defined as the science of determining the position, in three dimensions, of natural and man-made features on or underneath the surface of the Earth. These features may be represented in analogue form as a map, plan or chart, or in digital form such as a digital ground model (DGM). Either or both of the these formats are necessary and useful for planning, design and construction of works, both on the surface and underground.

A series of methods for measuring spatial points have been developed during the time, from tacheometrical survey techniques where measurement is done point by point and with attributes for each point, up to mass surveying of the points using photogrammetric methods and laser scanning. Tacheometrical surveying time for punctual mesh of objects and inserting of attributes to each point is very high compared to photogrammetric and laser scanning methods which provide rapid acquisition and inserting, but without attributes.

Surveying requires management and decision making in deciding which are the appropriate methods and instrumentation required to complete the task satisfactorily to the specified accuracy and within the time limits available. The surveyor can make a decision only after a careful and detailed reconnaissance of the area. The framework of survey stations is the control network whose coordinates have to be precisely determined and are often considered definitive. Commensurate accuracy is advised in the measuring process, which means that both the angles as the distances should be measured to the same degree of accuracy. All measurements contain errors, but the surveyor has to minimize them using appropriate techniques and methods. Independent checks should be subsequently performed not only in the field work, but also in the processing of field data, preferably using a different method in order to reduce the errors as much as possible.

4. Terrestrial Laser Scanning Principles

Terrestrial Laser Scanning is a new geodetic technique through which the geometry of an object or structure can be measured automatically, without using a reflective enviroment, with high precision and speed. Based on laser technology, laser scanning systems allow to perform dense and accurate measurements of real objects in very short time, producing the well known "point cloud". A terrestrial laser scanner determines the distance between a large number of object points and the scanner by emitting laser pulses in different directions and detecting the echoes from the objects. The Terrestrial Laser Scanning system is based on the principles of the polar method for determining the coordinates. Following elements are measured: spatial distance, spatial direction and the intensity of spatial points.

Three different principles for distance measurement are in use: the "time-of-flight" principle, the "phase comparison" principle and the "triangulation" principle.

The "time-of-flight" scanners or laser pulsed scanners base their measurement determining the time-of-flight of a light pulse by measuring the travelling time between the emitted and received pulse. This method is applied with lasers that continuously emit light. The scanners using time-of-flight principle are able to measure much longer distances, but they are slower than instruments that work by phase or triangulation principle.

The "phase comparison" principle or the "phase difference" principle does not present many differences against the previous one and it is applied at total stations. The distance between the instrument and the object is determined according to the phase difference between the emitted and the received signal. The scanners using phase measurement principle are faster than the others, measuring thousands to hundreds of thousands of points per second, but its accuracy depends on the distance to the object. This is the reason why it is used for the near areas.

"Triangulation" scanning is based on a simple triangulation principle. A light spot or stripe is projected onto an object surface and the position of the spot on the object is recorded by one or more CCD cameras. The angle of the laser beam leaving the scanner is internally recorded and the fixed base length between laser source and camera is known from calibration. The distance from the object to the instrument is geometrically determined from the recorded angle and base length. This is a method for precise measurement of distances using the laser triangulation sensors. The name is suggested by the fact that the laser beam emitted and the laser beam reflected together with the basis form a triangle.

5. Classification of the Laser Scanning Systems

Possible classifications of terrestrial laser scanner systems can be made according to following criteria: the domain of distance measurements, the field of view, the principle used in distance measurement, the density of collected points, the accuracy of data acquisition, the domain of the scan. Laser scanners can also differentiate themselves through their technical properties: combination with devices like digital camera or GPS receiver mounted on the laser scanner or characteristics of the laser beam deflection system.

Current laser scanning technology can be classified into two categories: static and dynamic. Static laser scanning is defined when the scanner is installed in a fixed position during data acquisition. Static laser scanners are encountered under the name of terrestrial laser scanners, but there is no clear distinction between these two terms. The main advantages of this method are: the high accuracy of results, high density of points, easy solving the problems of registering and calculating coordinates X, Y, Z. Dynamic laser scanning is defined when a laser scanner is mounted on a mobile platform. This platform may be aerian, such as a plane or terrestrial, such as a vehicle in motion. These systems are much more complex and expensive because they often work combined with additional positioning systems, such as INS (Inertial Navigation Systems) and GPS (Global Positioning Systems).

Depending on the principles of the distance measurement system: scanning using "time-of-flight" principle which involves measuring distances exceeding a few hundred meters and therefore provides a precision around 1 centimeter; scanning using the "phase comparison" principle involves measuring distances up to 100 m and provides millimeter accuracy; scanning using the "triangulation" principle is most commonly used in industry and provides sub millimeter precision.

Depending on the field of measurement, scanning systems can be classified as follows: large measurement range (150-1000m), medium measurement range or close field domain (1-50m), small measurement range or very close field domain(0,5-2m).

Depending on the field of view, scanning systems can be classified as follows: panoramic scanners, hybrid scanners, digital camera scanners.

Manufacturing companies constantly enter improved tools on the market which have a wide range of applications in different domains. There is no universal scanner that can provide data for any technical application. Depending on the type of application, the field of application and the purpose of the scan, it may be decided the suitable type of scanner to be used.

6. The components of a Laser Scanning System

The laser scanning system has the following main components: the scanner unit, the control unit, power supply, software component, inertial system, position control system and accessories. Scanner unit or the instrument itself is composed of the distance measurement system, the angle measurement system an d the system of deflection. The control unit is usually a laptop, which runs the and supervises the entire scanning process. The link between the control unit and scanner unit is done through cables, dynamic IP, static IP, wireless. The source of energy required in scanning process is different depending on the scanner unit. Component software is usually supplied by the company that manufactures the scanner unit. The software is structured in modules for the main steps: control, processing of data (registering and entering), export of data. The most important accessories of the scanning systems are: the tripod, the mounting platform for dynamic measurement systems or airborne systems, targets, sighting photo cameras, video cameras, transport boxes and cables.

7. Classical survey networks used in Terrestrial Laser Scanning techniques

The same as for the measurements using total stations, GPS technology, photogrammetric cameras or remote sensing sensors, laser scan measurements pursue to define an objects's position, both planimetric and altimetric, to the same reference system, in order to create mathematical reciprocal connections between the object of interest and the other objects around. The make-up and development of control networks using laser scanning technology depends on the type of the laser scanning system, the goal of the works, the required accuracy, the size of the area to be scanned, the density of the details and the scale of the plan to be drawn up based on the measurements.

8. The components of a terrestrial Laser Scanning System

The laser scanning system has the following main components: the scanner unit, the control unit, power supply, software component, inertial system, position control system and accessories. Scanner unit or the instrument itself is composed of the distance measurement system, the angle measurement system an d the system of deflection. The control unit is usually a laptop, which runs the and supervises the entire scanning process. The link between the control unit and scanner unit is done through cables, dynamic IP, static IP, wireless. The source of energy required in scanning process is different depending on the scanner unit. Component software is usually supplied by the company that manufactures the scanner unit. The software is structured in modules for the main steps: control, processing of data (registering and entering), export of data. The most important accessories of the scanning systems are: the tripod, the mounting platform for dynamic measurement systems or airborne systems, targets, sighting photo cameras, video cameras, transport boxes and cables.

9. Classical survey networks using Terrestrial Laser Scanning techniques

The same as for the measurements using total stations, GPS technology, photogrammetric cameras or remote sensing sensors, laser scan measurements pursue to define an objects's position, both planimetric and altimetric, to the same reference system, in order to create mathematical reciprocal connections between the object of interest and the other objects around. The make-up and development of control networks using laser scanning technology depends on the type of the laser scanning system, the goal of the works, the required accuracy, the size of the area to be scanned, the density of the details and the scale of the plan to be drawn up based on the measurements.

10. Sources of errors in Laser Scanning

Concerning applications of topographic or geodetic measurements, the accuracy of determining the spatial position of the point-cloud is an important parameter to be considered and analyzed. The main categories of error sources in terrestrial laser scanning are the instrumental errors, due to the type of the scanner, errors that appear due to the form and nature of the object scanned, errors related to the environment (temperature, atmosphere, radiation interference, disortion fron movement vibration) and methodological errors.

11. Methodology

The methodology developed to acquire complete datasets for precise representation of complex surfaces is divided into two stages: field work and data processing. While the former deals with the equipment setup and data collection, the latter is focused just on data processing.

Field work can be summed up in the following stages: planning, camera calibration, range data acquisition, image data acquisition, control points acquisition.

During the stage of data processing, the information is processed in order to deliver plans and 3D models reproducing the original structure on a certain scale and the different outputs are assessed and evaluated. The sequence of operations in processing registrations: recording, registration referencing, modeling, export, results.

12. Terrestrial Laser Scanning data processing

Processing operations for laser scans require assembling point-clouds obtained in each station point, to transform the coordinates from the local system of the instrument into a common coordinate system. When speaking of a unique coordinate system, registering and entering or georeferencing represents the combination of results from different positions of the laser scanner in order to make the point-cloud usable to defining an object or an area from reality into a unitary system.

Terrestrial laser scanning provides highly accurate, three-dimensional images enabling designers to experience and work directly with real world conditions by viewing and manipulating rich point-clouds in computer-aided design software. These measurements can be imported into CAD or 3D application software and displayed on a computer monitor as a "point-cloud" which has photographic qualities portrayed in one-color, gray-scale, false-color or even true color. system. With additional post-processing and laser scanning services, the raw data can be translated into accurate 2D or 3D AutoCAD drawings to be utilized for 3D visual walk-throughs and 2D or 3D design and can even be rendered further into a full 3D solid model.

Among the successive steps of TLS data processing, the conversion from the 3D point-cloud to one or more 3D surfaces is the essential one. This phase is the modeling of the surface fitting the correct points and yields the so-called “Dense Digital Surface Model” (DDSM) for its general very high resolution, built by means of TIN 3D-meshes, best known as „Delaunay triangulations”, or by means of regular grids.

13. Digital ground model (DGM)

“Best fit” triangles are formed between the points surveyed in the “triangulated irregular networks” (TIN) method. Therefore the ground surface provides a network of triangular planes at various inclinations. Contours, sections and levels may be obtained by linear interpolation through the triangles. The smaller the triangles, the more accurate the final result. It is thus ideal for contour generation and computing highly accurate volumes.

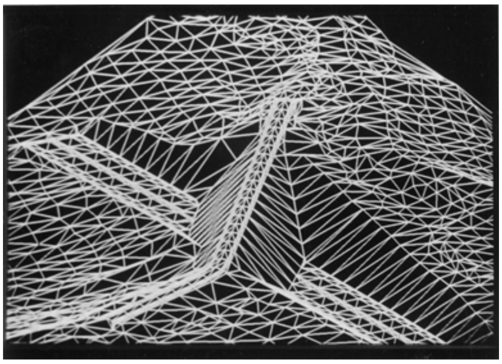

Fig. 1. Example of a triangular grid model

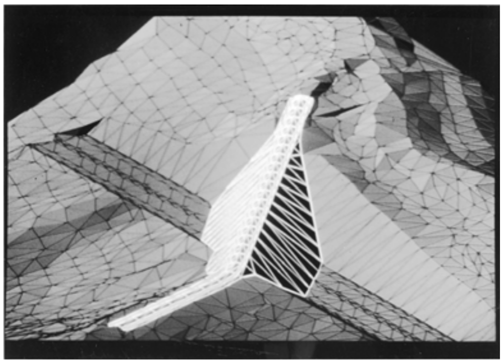

Fig. 2. Example of a triangular grid model with computer shading

14. Computer-aided design (CAD)

In addition to the production of DGMs and contoured plans, a computer-based surveying system permits the finished plan to be easily related to the designed structure. The 3D information held in the database supplies all the ground data necessary to facilitate the finished design. Fig. 3 illustrates its use in road design. The environmental impact of the design can now be more readily assessed by producing perspective views as shown in Fig. 4.

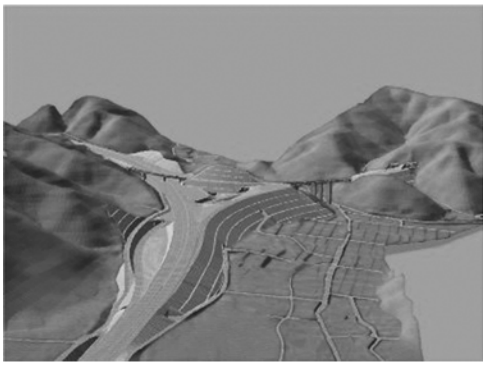

Fig. 3. Example of computer-aided road design

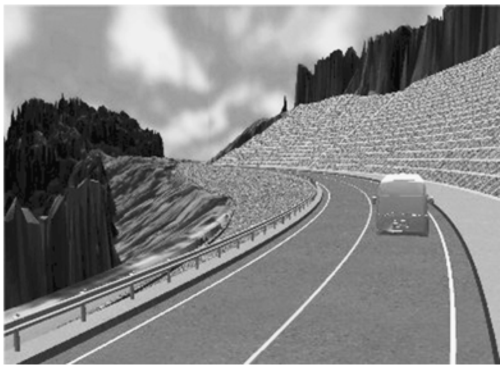

Fig. 4. Example of perspectives with computer shading

15. 3D modeling techniques

The term “model” is a frequently used term in many disciplines. Generally, models are used to make an abstraction of reality with the aim to make reality understandable. Data models consist of classes, attributes, relationships, operations and constraints. Classes are abstractions of phenomena in the real world that can be identified, for example parcels, persons, buildings. Each object has attributes that describe its characteristics. Therefore a complete 3D model restores the characteristics of a real object.

3D modeling is the process of developing the mathematical representation of three-dimensional surface of an object using specialized software, to study its properties and transformations. The 3D model can be displayed as a two-dimensional image, after a process known as 3D rendering or it can be used in computer simulation of physical phenomena.

The main methods for creating 3D models are: polygonal modeling, 3D solid modeling, NURBS modeling and modeling based on spline curves or Patch surfaces.3D surfaces made of a large number of polygons grouped in a network are designed using polygonal modeling method. These models are very flexible and they can be rapidly rendered by computer. It does not offer the possibility to create very smooth surfaces. Parameters are used to specify the properties of the object in parametric modeling method. Elementary geometrical objects such as cubes, cylinders, cones and spheres are used in 3D solid modeling method in order to build more complex models. The latter method is similar to NURBS method, except that the surfaces are created using curved lines which become their edges.

Parametric modeling enables to control the 3D model according to a set of changes, working with parameters such as height, depth, thickness and other attributes. Using realistic model renderings gives the opportunity to view a project before it is finished. Rendering functions can be adjusted to suit the ambient conditions (transparency, refractions, reflections, textures) in order to obtain a framework that seems detached from reality. Furthermore, horizontal and vertical sections can be generated automatically.

Fig. 5. Scanning of Timişoara City Hall building

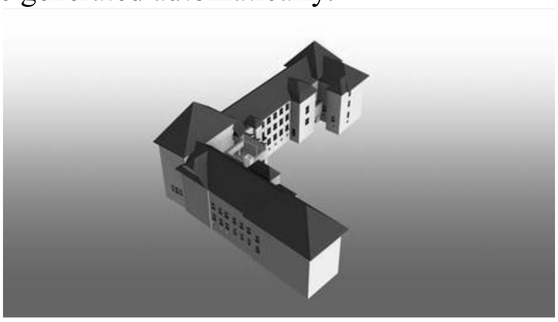

Fig. 6. Parametric Model of Timişoara City Hall building

Fig. 7. Vertical sections of Timişoara City Hall building

16. Terrestrial Laser Scanning and 3D modeling applications

Laser scanning is used in architecture, engineering, construction, heritage preservation, archaeology, facilities, manufacturing plants, airports, hospitals, roads and bridges, offshore platforms, forensics, virtual reality, media and film. All these domains require accurate, detailed, 3D spatial information for their projects and rigorous design review. A wide variety of applications demonstrate that 3D models allow the user to process different information contents from a unique digital representation of the reality.

3D laser scanning survey system has extensive applications in various fields and activities such as 3D topographic surveys, surveying of busy street intersections, highway design surveys, bridge and tunnel design surveys, construction volume calculations, monitoring structure deformation, surveys for hazardous site areas, building information modeling, historic building preservation and renovation, façade laser scanning for historic restoration, as-built surveys for exterior or interior building renovation, retrofit, remodel, forensic surveys (accident or crime scene reconstruction), as-built surveys of complex facilities such as processing plant, piping and ductwork retrofits and marketing.

Civil engineering and surveying companies use laser scanning technology to develop TIN meshes of roadway surfaces, volume calculations of quantities of rock, soil or other material, safer and quicker measurement of bridges and where safety is a concern, such as accurately measuring the surface of a highway active with traffic or scanning the underside of a damaged bridge. This technology is a valuable tool for reduction of construction costs by eliminating 3D design errors that may lead to project delay and to determine whether designs are definitely ready for construction by eliminating design problems that may appear. Volumetric calculations become easier to be done and more precise by using 3D terrain models.

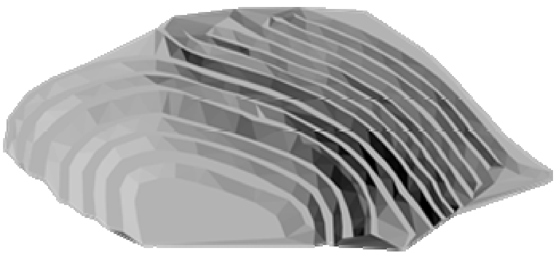

Fig. 8. Digital terrain model of a career

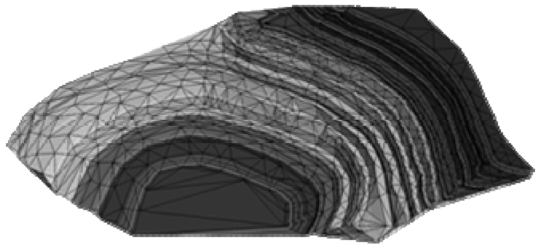

Fig. 9. The analysis of terrain elevation of a career

Laser scanning is able to model and analyse forensic information from real-world scenes. Detailed 3D data is easily modeled and exported to other specialized software for visual examining scenes to determine causes and sequence of events. Contouring and surface modeling make it easy to build surfaces and to improve scene visualization.

Due to Terrestrial Laser Scanning technology, several inaccessible galleries have been recorded. In this way, detailed surface models and contour maps that show the complete shapes and profiles of the caves with high accuracy can be obtained automatically. 3D data model obtained through laser scanning technology allows the quantitative assessment of surface erosion and deterioration of the rock, engravings and paintings with enough high accuracy.

Virtual reality refers to artificial ambient created on a computer that offers a simulation of reality so successful that the user may get the impression of almost real physical presence, both in some real places and imaginary places. Information provided by 3D scanning and modeling helps very much in realistic simulation of the required ambience.

17. 3D modeling for Geographic Information System (GIS)

3D modeling is interrelated to GIS through its aplications towards 3D visualization of combined terrain data with vector graphics, businesses thematic map, weather map, in one interactive 3D screen. A 3D modeling aplicability consists of the 3D interactive tools such as markers, intersection planes, volume, distance measurement, using transparancy to highlight more important data or even visualize Digital Elevation Model (DEM), land map, roads, satellite image, LIDAR data in the same screen.

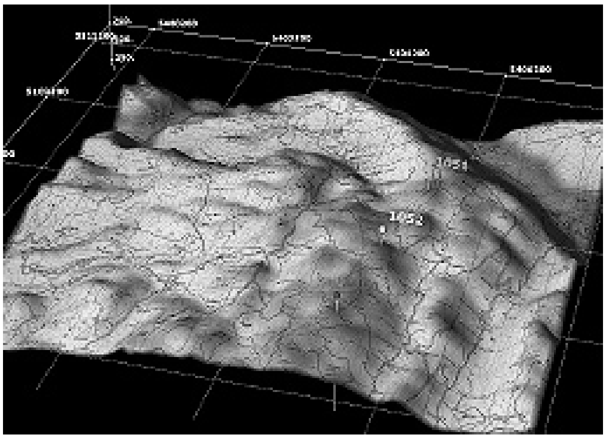

Fig. 10. The visualization of a thematic map

18. Advantages and benefits of laser scanning

Laser scanning is a new versatile technology that offers ultra fast, high density and remotely captured 3D digital images of objects and surfaces. From a practical and overall economic standpoint, this feature set has proven beneficial in comparison with traditional surveying.

- Speed of data capture - reduces time and costs;
- High point density data ensures a complete topographic survey;
- High-density, accurate data using direct measurements;
- Remote acquisition and measurement - increases efficiency and safety of surveys;
- Abundance of data captured in laser scanning ensure accuracy and that all objects and structures are captured;
- Imagery and 3D visualization provides added confidence that mapped objects correspond to reality.

19. Drawbacks of laser scanning:

- Price. Currently, the instrument costs about 200.000$;
- The complex processing of the dense datasets;
- Instrument size. Difficult to get shots in tight areas or from very close range.

20. Conclusions

Today's surveyors, civil engineers and contractors face tight timelines and even tighter budgets, especially in today's challenging economy. To finish projects on time, within budget and to specification, they need to work accurately, efficiently and too often around the clock. Fortunately, by combining the strengths of the new technologies engineers, contractors and surveyors can improve significantly the productivity and accuracy and can complete projects faster and more profitably. It is said that the quality of decisions is related to the quality of information.

In the past few years, the measurement technology was "revolutioned" by the Terrestrial Laser Scanning (TLS) systems, sophisticated equipment appeard on the market and new applications of dedicated software. Terrestrial Laser Scanning system provides the user a dense set of threedimensional vectors to unknown points relative to the scanner location. Given the volume of points aguired in very short time and high sampling frequency, laser scanning systems offer surveyors an unprecedented density of geospatial information coverage. The involvement of other scientific domains in solving fundamental problems of geodesy and terrestrial measurements, have led to new areas of application of measurements, to which we had no access so far. This paper presents the advantages of using the terrestrial laser scanning systems and 3D modeling as well as the wide variety of fields in which they have applications.

21. References

1. *Guarnieri, A., Pirotti, F., Pontin, M., Vettore, A. – 3D surveying for structural analysis application, 3rd IAG/ 12th FIG Symposium, Baden, Austria, May 22-24, 2006;*
2. *Diego González-Aguilera, Angel Muñoz-Nieto, Javier Gómez-Lahoz, Jesus Herrero-Pascual 1and Gabriel Gutierrez-Alonso – 3D Digital Surveying and Modelling of Cave Geometry:Application to Paleolithic Rock Art, Sensors 2009, 9, 1108-1127; doi:10.3390/s90201108*
3. *Coşarcă, C. – Sisteme de măsurare în industrie, Editura Conpress, 2009*
4. *SAVU, A. – Perfecționări ale lucrărilor topografice şi geodezice în domeniul căilor de comunicații. Doctor's degree paper. Technical Constructions University of Bucharest, 2010;*
5. *www.leica-geosystems.com*
6. *www.calvada.com*
7. *www.3dreshaper.com*
8. *www.gim-international.com*
9. *www.blacklight.ro*