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# **Use of Terrestrial 3D Laser Scanner in Cartographing and Monitoring Relief Dynamics and Habitation Space from Various Historical Periods**

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Additional information is available at the end of the chapter

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## **1. Introduction**

Nowadays, modern cartography employs various techniques and methods, which were deemed inconceivable just two decades ago. The GIS technology is particularly important among these, a technology that advanced cartography to the highest standards of graphical (visual) representation. 3D laser scanning is one of the most notable new cartography techniques that is part of this "new wave". This instrument, specifically a Leica LIDAR scanner, capable of monitoring land dynamics with an accuracy of 1 mm/1 mm from a distance of 300 m, as well as its use, are the subject of the present paper. In the field of physical geography and geo-archaeology, the 3D laser scanner can be used to map and monitor soil degradation processes (ravine-creation, surface erosion, landslides, etc.), the erosion and aggradation of a river's channel and valley, shore and slope processes, beaches and escarpments, dunes, caves and man-made excavations (including salt mines), iceberg dynamics, archaeological sites and the spatial position of the archaeological finds, heritage buildings and structures, works of art (sculptures, reliefs, etc.) etc.

Even though the 3D laser scanning technique is relatively old, i.e. from the '90s, it has enjoyed increased use in physical geography and in geo-archaeology only during the last few years. Most of the cartography projects employing the 3D laser scanner focus on the morphology and dynamics of the slope geomorphological processes, as well as on river bed and shoreline dynamics. Up until the advances in technology allowed the 3D scanners to become widely available and practical enough for cartographic use, countless attempts to use "modern" cartographic methods were made, but, in most cases, they proved to be inexact and cumbersome. Therefore, most of the studies employed the

classical, rudimentary, methods which rely on wooden or metal markers and analog data collecting.

This study will present several examples from eastern Romania: the Moldavian Plateau, the Bend Subcarpathians, the Danube floodplain, etc. (Figure 1). The geomorphological processes that are active throughout the Moldavian Plateau are carefully watched by specialised institutions but, unfortunately, the necessary equipment is lacking or is unsuitable, and the results are therefore unsatisfactory. By using a 3D scanner, many of the results expected from dynamic geomorphology and geo-archaeology will be accurate and the database much enriched.

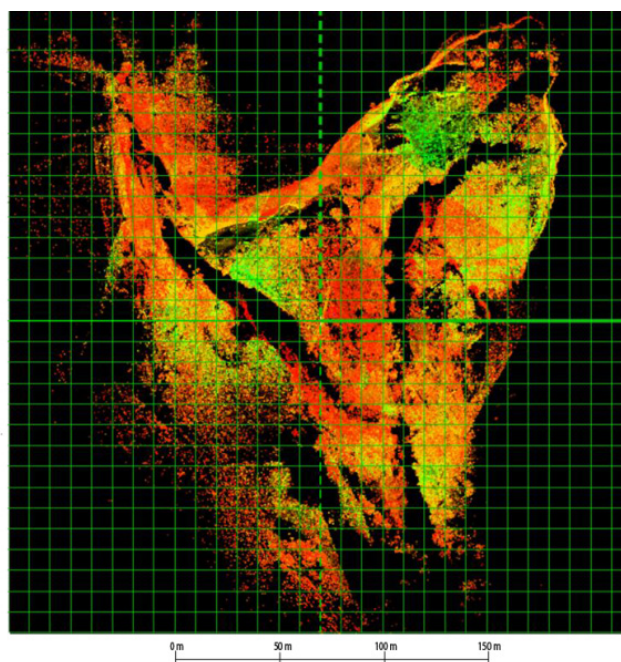


**Figure 1.** The location of the main sites on Romanian territory scanned with a 3D scanner

The eastern part of Romania is extremely rich in Neolithic, Chalcolithic, Ancient and Medieval remains, and it is strongly affected by surface geomorphological processes and, which is critical, by powerful floods. Elaborating a study on the dynamics of the relief from Eastern Romania implies the development of a specific methodology for the 3D scanner, as well as the acquisition of correct data, on a millimetre or centimetre scale, on the changes that can occur in very short time intervals.

The correlation between the data acquired via 3D scanning and that obtained through classical methods will certainly lead to improvements in the manner in which

geomorphologic risk phenomena are prevented and combated, and how the historical conditions of the evolution of human habitation can be better interpreted (Figure 2). Concurrently, the aim is to make the technique versatile enough as to be employed in various domains: geomorphology (land degradation), agronomy (landscaping, irrigations), environmental protection, land management, architecture, civil engineering, etc.

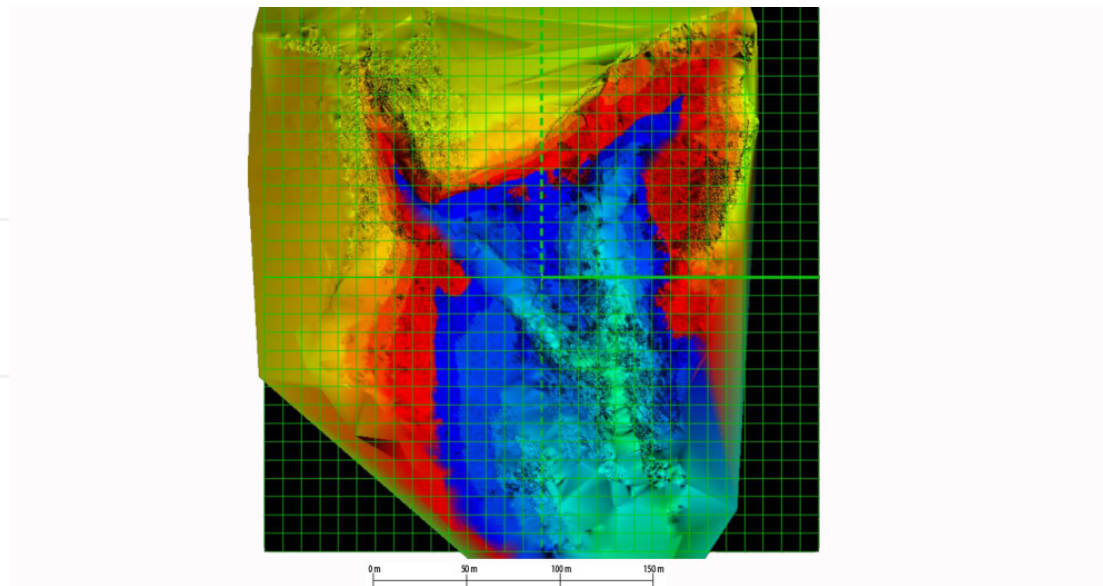


**Figure 2.** The point-cloud obtained from the measurements conducted in the gully impacting a Chalcolithic archaeological site from Cucuteni culture

Since 2000, the international literature in the field of laser-based 3D technologies grew continuously. At the present, certain fields of research, such as geo-archaeology, geomorphology, photogrammetry etc. created their own methodologies and the papers published in these fields are greatly sought after. From this point of view, it is important to mention the use of the 3D scanner in geomorphology [1-25], hydrology [26-29], architecture [30-32], archaeology [33-35], cartography and topography [36-37], methodology [38-54], etc.

The relief dynamic from Eastern Romania is extremely active and most of the major archaeological sites are affected by gullying or landslide processes [55-67] (Figure 3). The ultimate objective of the present undertaking is to elaborate cartographic material (approximately 25 colour and B&W illustrations) representative and suggestive enough to demonstrate the dynamic nature of the environment and its impact on relevant and significative locations. To this purpose, a series of cartographical representations will be produced, depicting the dynamics of a gully and the effects of several landslides which affected some Chalcolithic sites belonging to the Cucuteni culture (specifically, Cucuteni-Baiceni and Habasesti-Holm, Iasi County, Romania), and a river (the Danube) which affected the morphology of a Chalcolithic tell (an archaeological mound created by successive human occupation and abandonment of a location over several centuries), belonging to the Gumelnita culture, from Harsova (Constanta County).





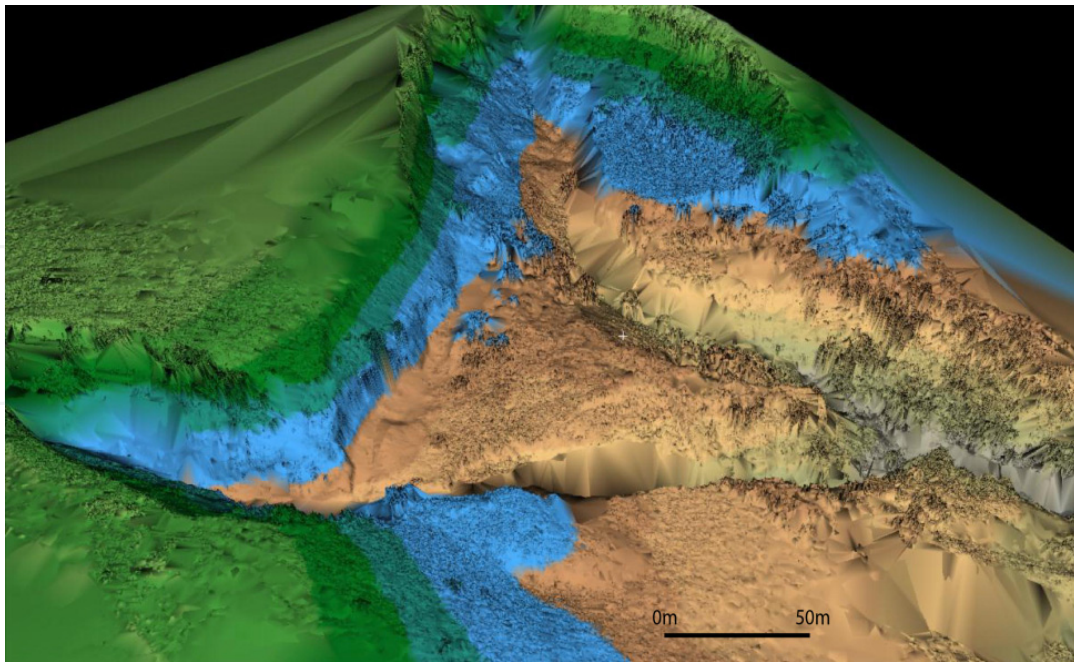
**Figure 3.** The final cartographic product for the investigated gully

For a better monitoring of relief dynamics, the use of the GPS is imperiously necessary. This tool can delimit with accuracy the spatial limits of the phenomenon. These coordinates constitute the backbone of the morphological analysis of a dynamic land form. Unfortunately, the 3D scanner cannot precisely identify by itself the border between one area and another. By using the 3D scanner we are able to move to the next step of the analysis of the dynamics of the relief and man-made forms. The accuracy of the obtained data and the exceptional cartographical representation means that the 3D has a long use-life and a greatly-diverse usability (Figure 4, 5).

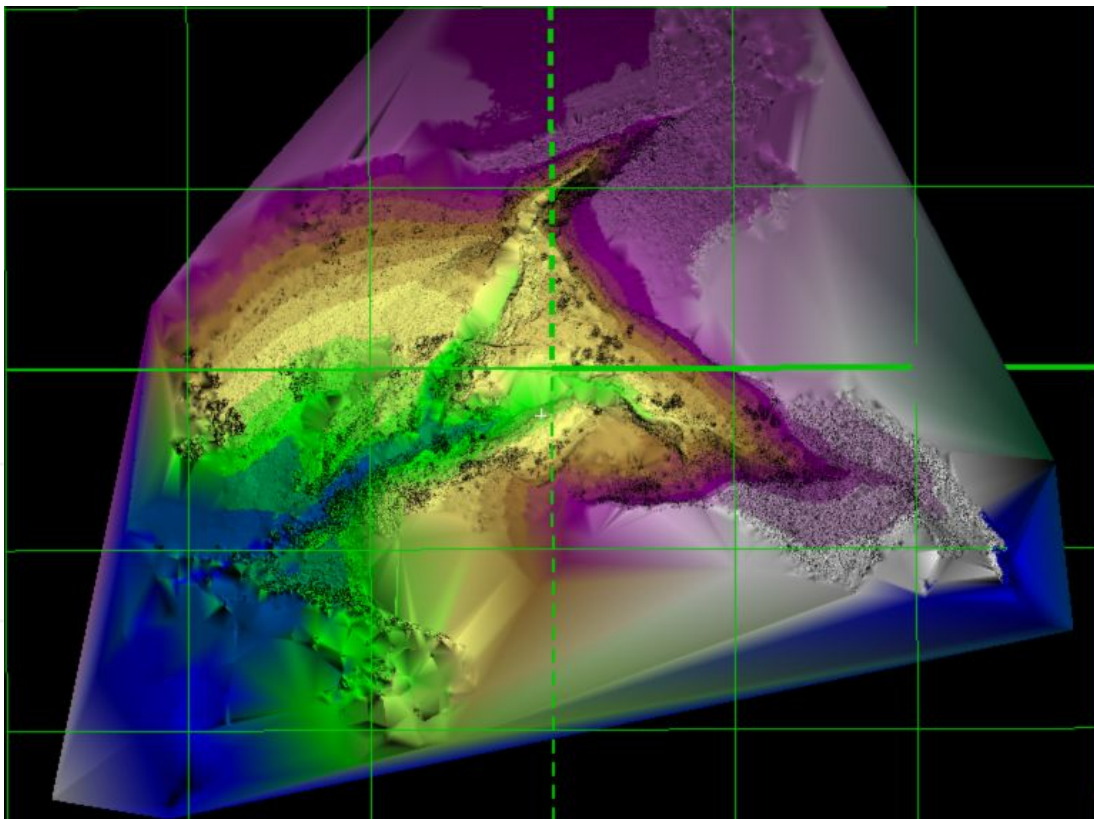
For the study of the geomorphological processes we selected an area in the Moldavian Plateau that is affected by intense gullying. The complex analysis of the Cucuteni Ravine aims also at the impact it has on the Chalcolithic site. For all the other examples we presented only the fields of research they pertain to, while the results will be included in several future papers.

## 2. Materials and methods

The phenomena of gullying are affecting, on a global scale, large areas in the tropical and temperate regions [68-76]. In Romania, these are specific to the Moldavian Plateau, the Transylvanian Depression and the Getic Plateau [60-61, 65-66, 16, 77]. Apart from the archaeology and architecture applications, which are more visible to the public, the 3D ground laser scanning is successfully used in monitoring the processes of ravine-creation in eastern Romania. This technology was also used with promising results in monitoring the riverine valleys and the landslides [78, 5, 79, 38, 80-83]. As a result of its performance, it can be used successfully to assess the state of the environment, especially in land mapping and with limited extension in measuring the rate of erosion in certain land surfaces [33, 84-85].



**Figure 4.** The detailed cartographic representation of the upper sector or the gully



**Figure 5.** The final cartographic representation of the gully (100 m grid)

In terms of definition, the 3D laser scanning is one of the new technologies, by which the geometry of an object or surface can be automatically measured, without the aid of a reflector, with speed and precision well above the ones of the classic solutions. The ground-

based laser scanner records the tridimensional points by measuring the vertical and horizontal angles, as well as the distance to each point. Even though there are largely different technologies, the field-use of the 3D scanner uses elements of the work methodology of the total station. In case the morphology of the scanned object is complex, more than one station points will be used. Thus, all its surfaces will be scanned. In case the shadowed surfaces are not reached by the laser beam, the software captures such areas automatically then integrates them to the scanned object. The process relies on registering distances and angles, and the data thus produced is used to compute the points' coordinates. The ability to register a massive amount of 3-D information in a relatively short time is the main advantage of this instrument, in contrast with classical equipment such as the total station [24, 10].

The methodology used for the analysis of Cucuteni Ravine is strongly influenced by its impressive size and the local topography, which required, in the end, the use of 17 station points. To merge the 17 positions, 6 reflective tie-points (Figure 6) were used for each of them, except for the last one. Nevertheless, for the entire model we used 24 tie-points, since some of the scanning positions were referenced to tie-points also used by other station points, where the physical distance allowed. Terrestrial laser scanning (TLS) generates several point clouds, with local coordinates and additional info (the light intensity in the reflected beam, and the RGB values obtained from an external or internal photographic camera). The point clouds, after having been registered from different positions, must be merged as to obtain a complete model of the scanned target. This procedure is called "registration" and involves merging the point clouds through the use of reflective tie-points, specially built and delivered by the manufacturer, which are automatically recognized by the scanner when a very fine scan is performed.



**Figure 6.** The round target used as tie-point

For the current project, in all of the three scanning sessions, we employed a Leica ScanStation HDS 3600 3D scanner. It is a time-of-flight active scanner, which works by timing the round-trip time of a pulse of light. The operation range is 270° horizontally and 360° vertically (Figure 7), and the active distance is 300 m. With a resolution of 6 mm at a distance of 50 m, and due to its ability to register approximately 2000 points per second, the ScanStation HDS scanner is among the most effective equipment of its type. The average resolution for all of the scans was of approximately 6 mm, and the registered points numbered millions, despite the fact that the majority of positions overlapped. Although an



external photographic camera can be attached to the scanner, we thought it to be no better suited for the task than the internal camera [86].



**Figure 7.** The visual field of the scanner

A particularly important phase of the fieldwork facet of the project was the geo-referencing of the point clouds. Using a reference station positioned on fixed known spot and a Leica 1200 GPS receiver, we referenced the point cloud established as the basis for the 3D model to the national coordinates system (Stereographic 1970). In fact, our methodology was based, for all of the three sessions, on computing the differences between the obtained geo-referenced models using CAD and GIS. In respect to the raw data processing, it was carried out by filtering the data using the Cyclone dedicated software program, registering the data (see above), reducing the point cloud, creating a mesh by triangulation, and texturing the model. The final results of the analysis were produced by exporting sections, transverse and longitudinal, of the three tridimensional models obtained in each session.

As a case study, the selection of the Cucuteni-Baiceni Ravine for the present paper was based on its high level of activity and its lack of arboreal vegetation, which could have partially impeded the measuring of the volumetric parameters. The undergrowth vegetation had then to be erased using the technical methods allowed by the software. Furthermore, for increased accuracy, the edge of the gully was outlined during each session by using the two "traditional" instruments mentioned above (the reference station and the 1200 GPS receiver, both produced by Leica). The operation was somewhat cumbersome, because in such cases the data must be collected from extremely numerous positions, as to take into account all of the inflexions [44, 10]. All of the positions were geo-referenced and corroborated with older measurements. In this way, we were able to estimate the rate of soil erosion in the gully, for each of the measurements taken. The conjoint use of these two types of measurements (GPS and 3D scanner) means that the risk of error was much diminished.

Another stage worth mentioning is, in the lab phase of the project, the filtering and modeling of data, to the aim of producing results compatible with the complementary software we used (CAD, GIS). Data filtering is a compulsory stage of the analysis, as the vegetation present at the scanning site, together with the very large amount of data, could result in errors in the Digital Terrain Model export-for-GIS process, as well as during the



volume calculation of the whole resulting model. In the first step, the tridimensional model was trimmed by removing the points lying outside the analyzed area, in order to reduce its originally large size. Concurrently, the model was scaled down in order to be more easily handled by the software. All these steps were carried out within the Cyclon platform, the proprietary software of the scanner, which was specially designed to handle the point-clouds in a 3D environment. The large number of axial and cross-sections of the model were produced at the same time, together with the various graphic, image and video exports.

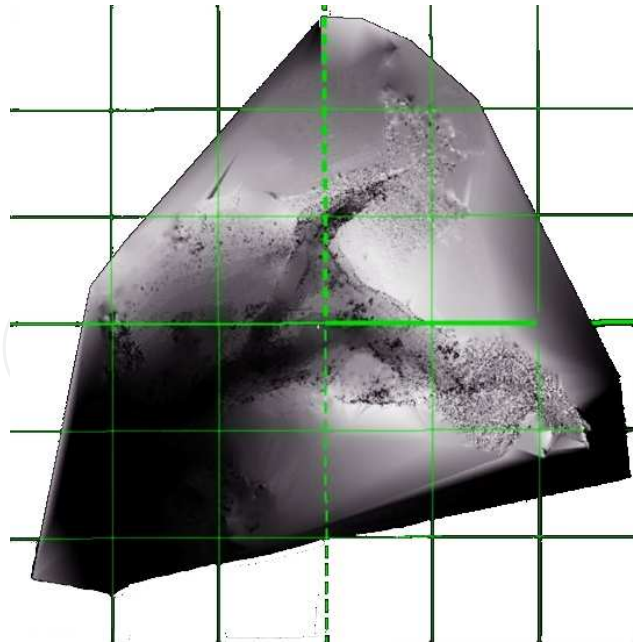
The stage of interpolating the scanner-produced points, to the aim of achieving a Digital Elevation Model, was carried out within the GIS platform (using the ArcGIS suite). Based on the resulting DEM, several derivatives were produced (contour lines, volume calculations, various graphs and diagrams etc.) The proprietary software of Leica is also providing export functionality, but the options are more oriented toward GIS and CAD formats. In order to reduce to minimum the error margin of the volume calculations for the three models (of three successive years), which is the definitive element for outlining the timeline of change between the three scans, we used the Cyclon software. Following this procedure, there were no major, visible differences between the employed calculation methods.

The Cucuteni gully was selected for the present research because it is extremely active. The area occupied by the gully is very sparsely covered by vegetation, and the trees are virtually absent; therefore, nothing prevented volumetric measuring. The very sparse shrub vegetation was removed using the techniques made available by the dedicated software. The reason behind the selection of the gully for our investigation was due to the fact that the gullying process is affecting a very important archaeological site dating back to circa 5000 B.P. This made it easier to assess the rate of erosion over a period of great lengths.

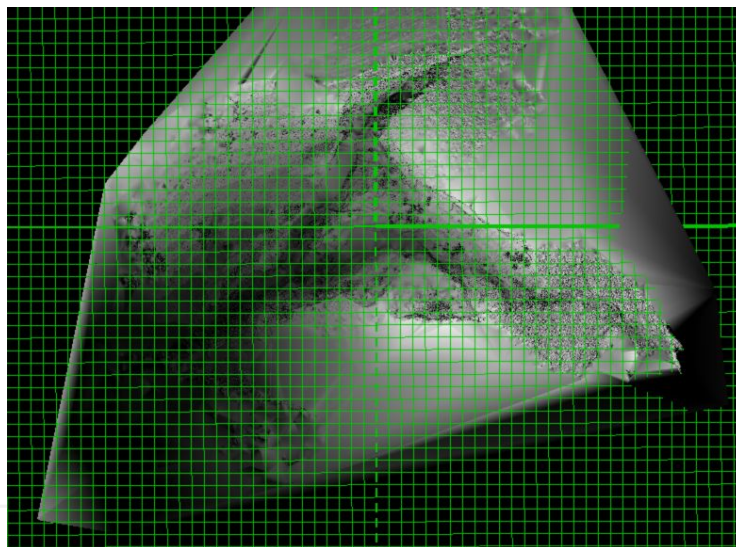
Three consecutive measurements were performed at relatively equal intervals in 2008, 2009 and 2010 (Figure 8, 9, 10, 11). The last measurement was made in spring 2010 after a solid



**Figure 8.** The 3D scanner in action on the Cucuteni-Baiceni Ravine



**Figure 9.** The 3D model and the map of the Cucuteni Ravine in 2008 (100 m grid)

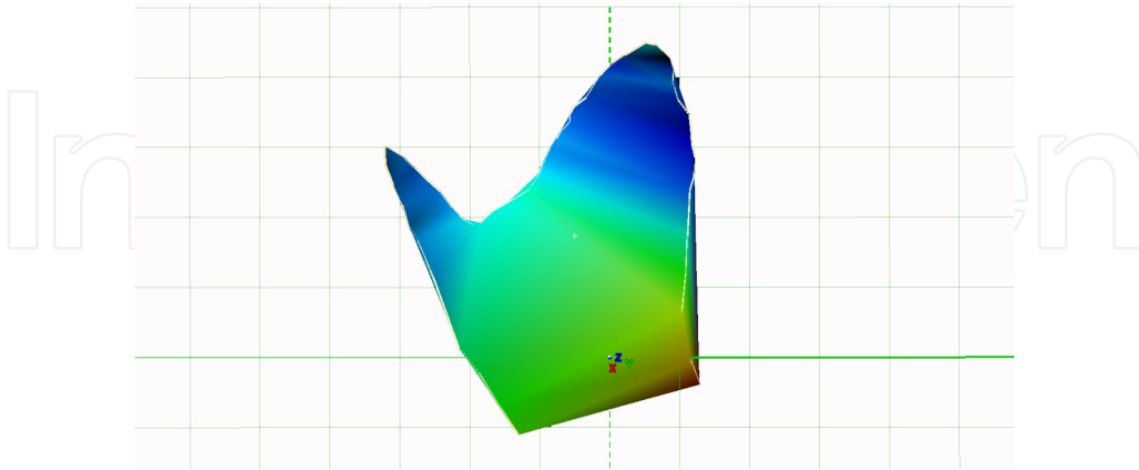


**Figure 10.** The 3D model and the map of the Cucuteni Ravine in 2008 (10 m grid)

winter precipitation and high rainfall in spring. For the historical evolution of gullies, topographic maps and military plans of the Romanian Army were consulted. During the Second World War the Army had placed a battery of guns in the area of the unit studied. Unfortunately, it has only been possible to make use of zoning maps from after 1950. The maps drawn earlier are not accurate and they are often for orientation only, with a high degree of generalization.

Meteorological data on precipitation, daily and monthly, were provided by the Meteorological Centre, Iasi, Moldavia. They were focused on Cotnari Meteorological Station, located near the Cucuteni-Baiceni ravines. The most important stations were rather uniformly distributed on Moldavian territory (Eastern Romania) [87]. Certain old

cartographic material was provided by the Military Topography Directorate in Bucharest. The orthophoto maps and the military maps dating from WW II were supplied by the ANCPI (The National Agency for Surveying and Real Estate Publicity) in.



**Figure 11.** The model used for volume calculation for the eroded and transported material (50 m grid)

### 3. Results

There were several thematic maps elaborated for the Cucuteni-Baiceni Ravine, emphasizing its dynamics. The morpho-graphic and morpho-metric maps were built on the basis of the 3D scans (Figure 12), which were further used as basis for the spatial yearly analysis of the ravine. In this case the erosion and accumulation sectors were outlined on the walls of the ravine or on the bottom of the cut (Figure 13, 14). The measurements included three consecutive years: 2008, 2009 and 2010.

The Cucuteni Ravine was extremely active during the years 2008-2010, due to the high frequency of torrential rainfall. The selected site can be regarded as representative for the whole Moldavian Plateau, as its relief energy is high and the loess deposits of its subbasement are very friable [16, 58].

Along the gulying processes, the monitoring could include also the gravitational processes, such as landslides (Figure 15). Due to the loess subbasement and the general deforestation in the Moldavian Plateau, large tracts of farmlands are subject to large-area landslides [62, 64]. As in the case of gulying, the landslides can be scanned successively, monitoring the reference points in order to assess the dynamics of the phenomenon. In the present paper, the case of Holm Hill, near the village of Habasesti (Iasi County), presents a complex situation due to the presence of an archaeological site (Cucuteni culture). The application of the 3D scan-based analysis proved to be salutary, as the combined derivatives produced using the point-cloud enabled a successful monitoring of the interest area. The use of 3D graphic modeling software (3D Studio Max) resulted in the creation of models useful for studying the topography and planimetry of the prehistoric settlement. All the modeling processes were based on the available archaeological data and the tridimensional model produced by scanning (Figure 16).



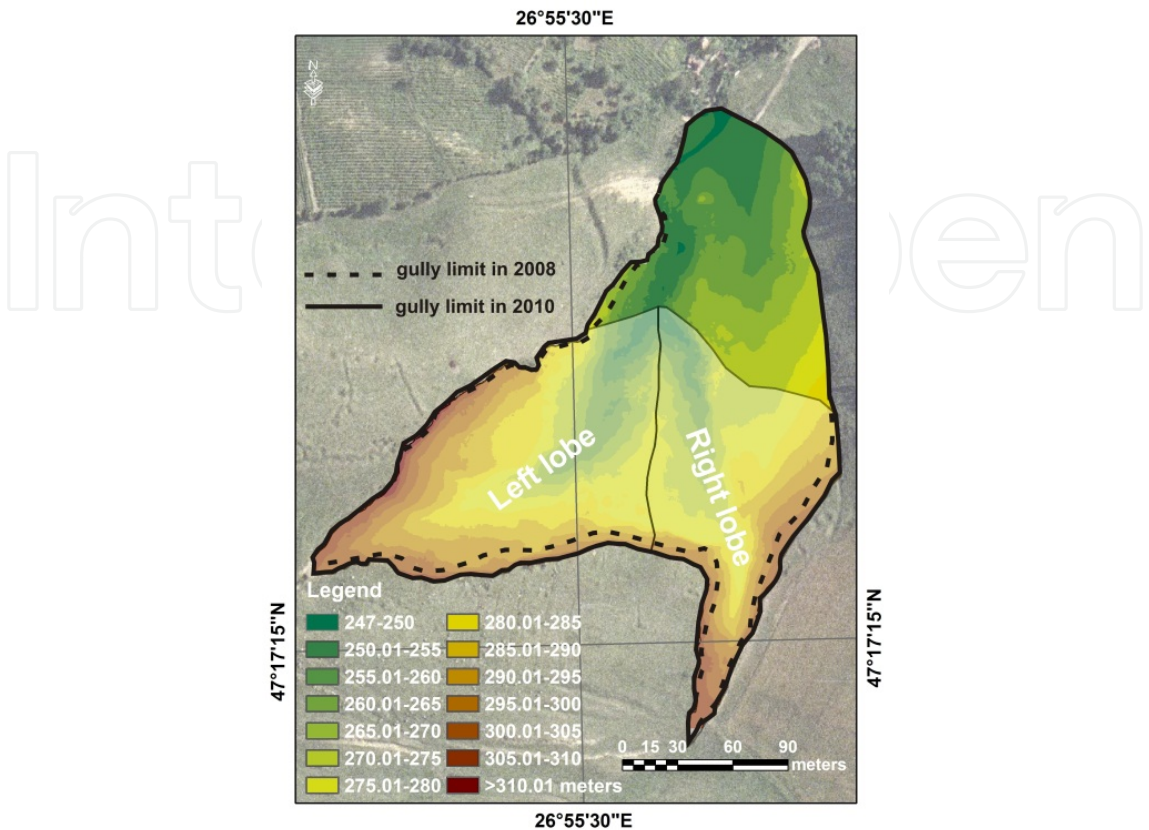


Figure 12. Making the morphologic map of the Cucuteni-Baiceni Ravine

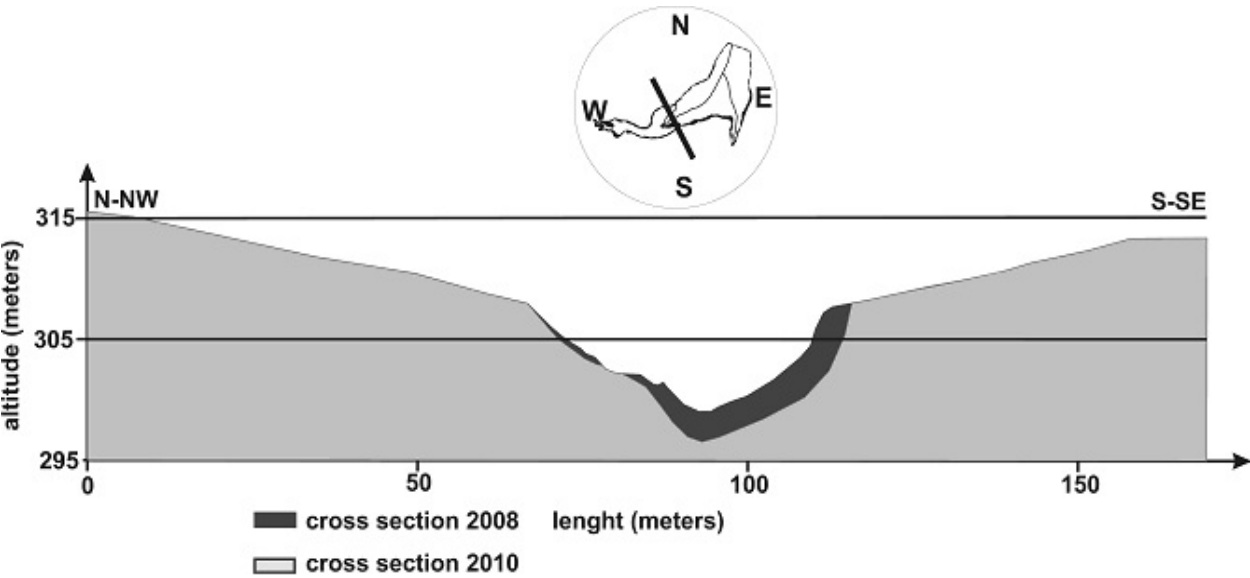
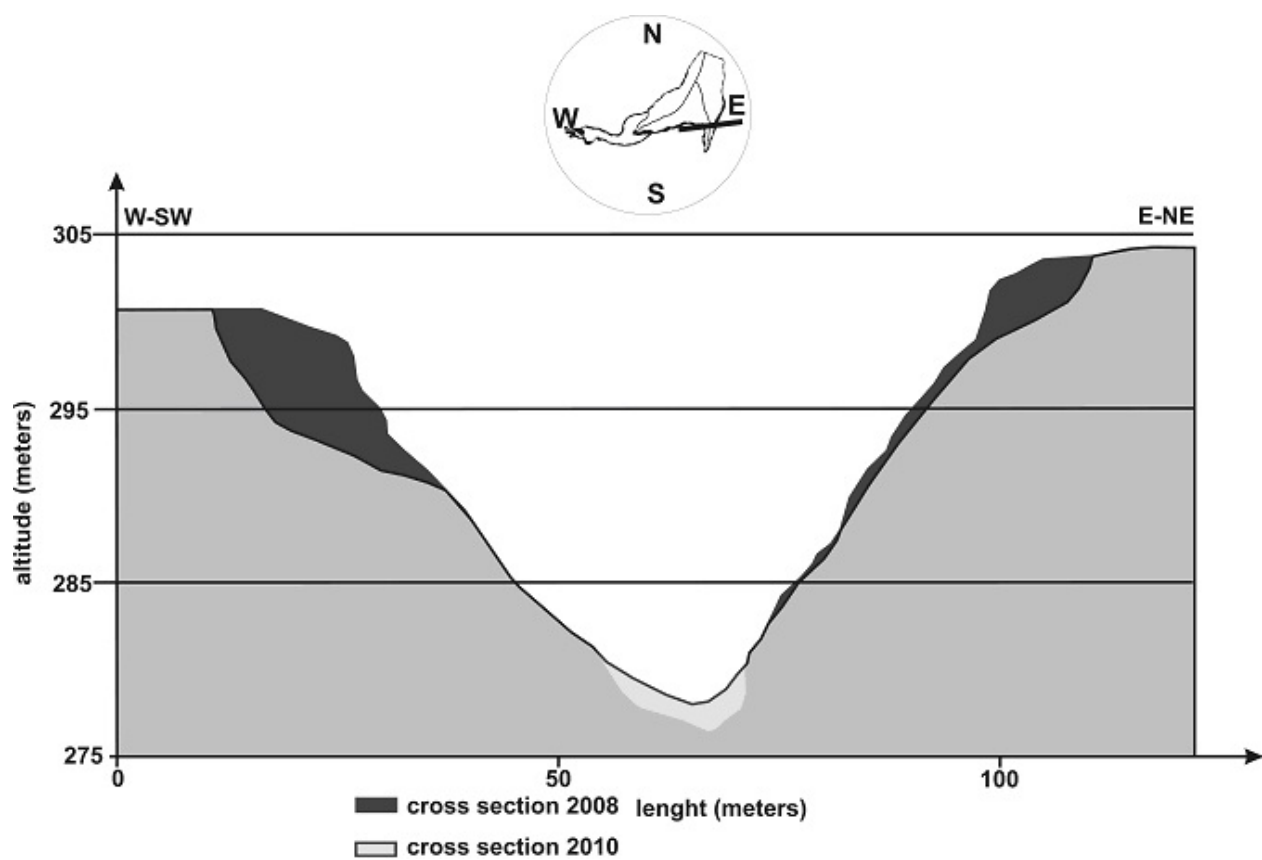
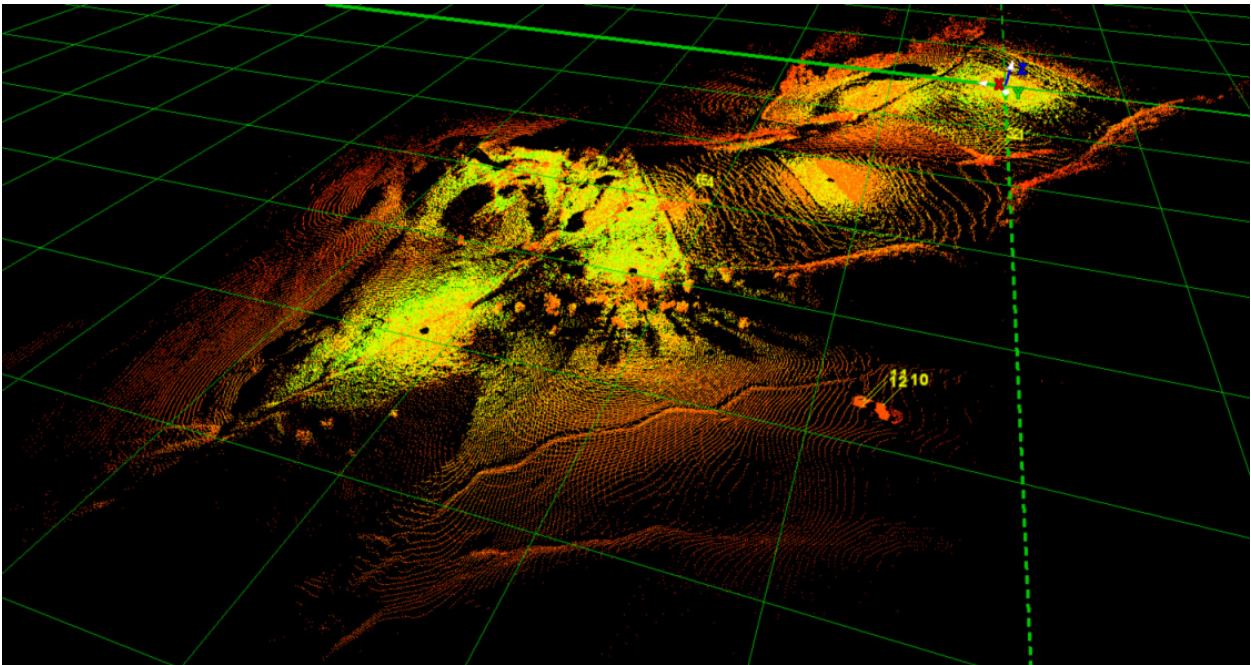


Figure 13. Cross-section through the Cucuteni-Baiceni Ravine, with the indication of the 2008 and 2010 measuring sessions (erosion only)

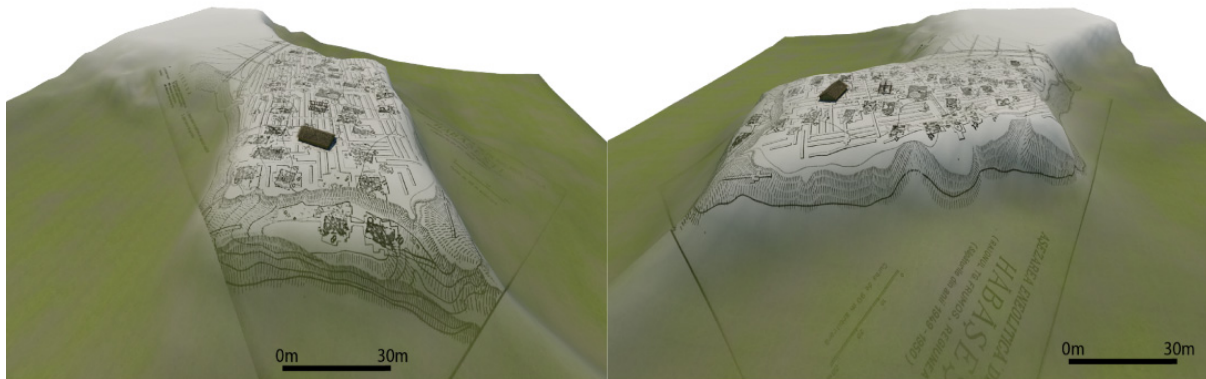




**Figure 14.** Cross-section through the Cucuteni-Baiceni Ravine, with the indication of the 2008 and 2010 measuring sessions (erosion and accumulation)

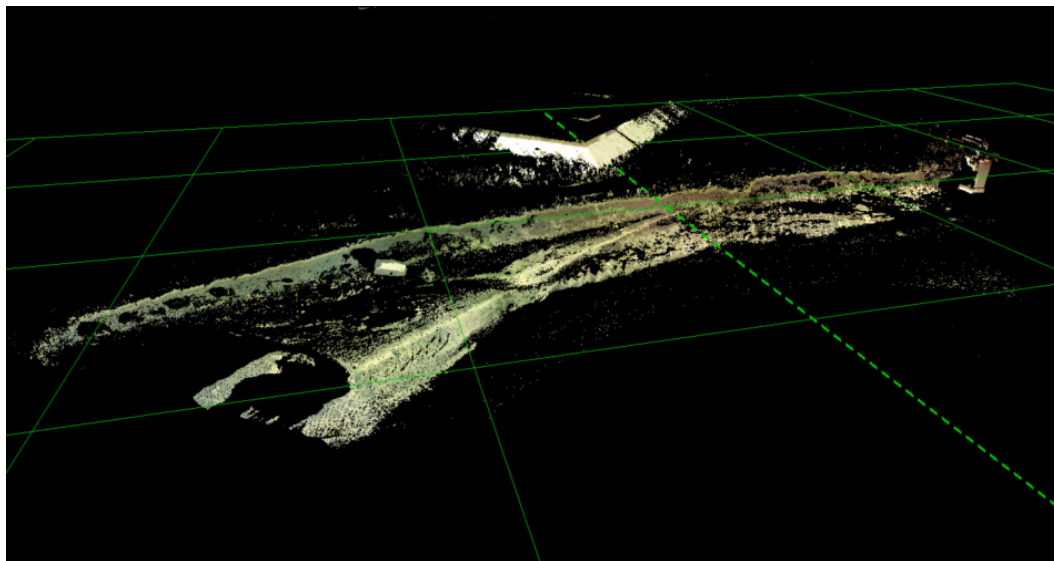


**Figure 15.** Landslide on the Habasesti-Holm (50 m grid)



**Figure 16.** The prehistoric site of Habasesti following point-cloud processing

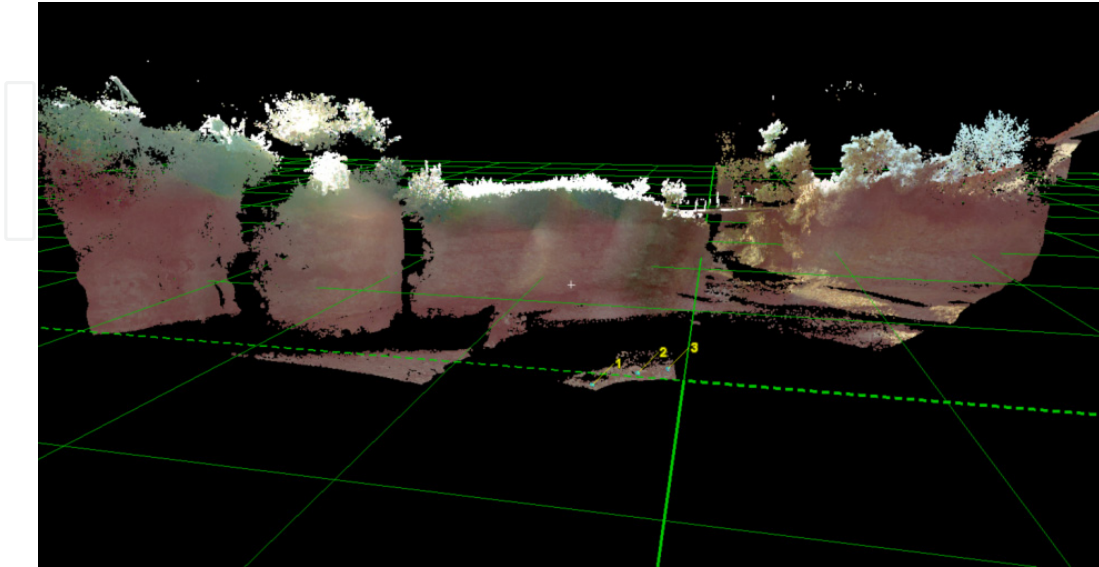
The 3D scans are also instrumental in monitoring the riverbanks and in analyzing the dynamics of the riverine valleys and channels (Figure 17). The most useful measurements include the lateral erosion, especially at flood times, as well as the accumulation processes along the riverbed and at river-mouths. In the latter case, the measurements should be taken at much shorter intervals, as the accumulation and erosion processes can affect the navigation. It is recommended that the measurements be carried out after each flash-flood. In this case, the riverbank and riverbed processes can be successfully monitored, especially the thalveg ones.



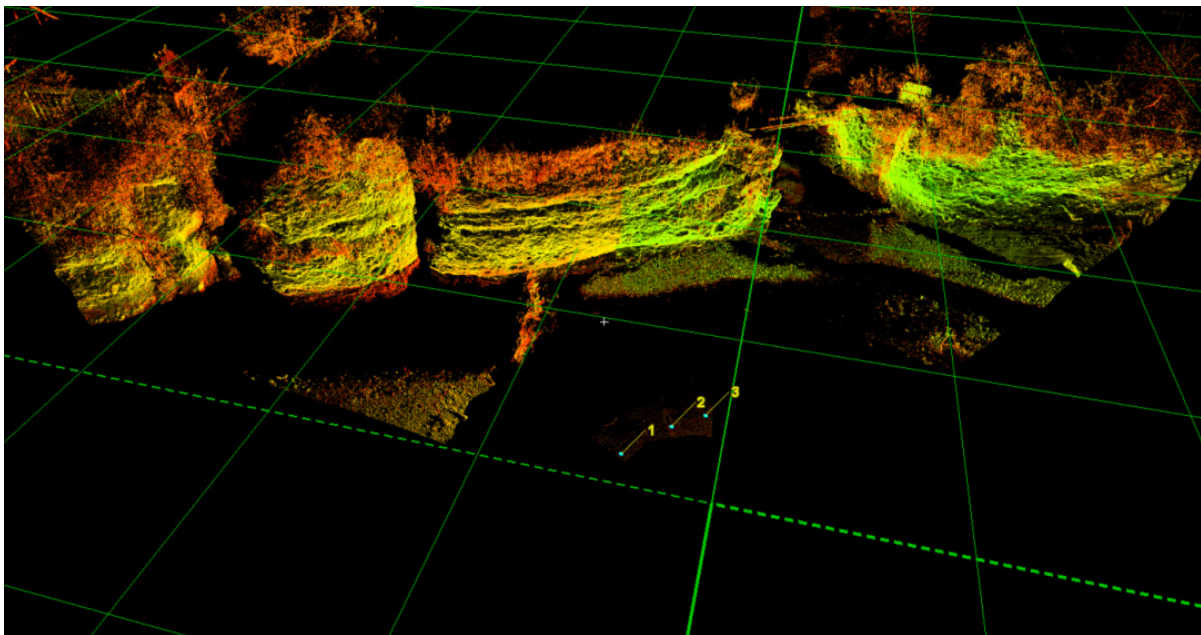
**Figure 17.** The channel of Trotus river at Onesti (30 m grid)

The steep riverbanks are easier to monitor, particularly in the case of highly friable subbasements (Figure 18, 19). The spasmodic character of rivers in the Moldavian Plateau bestows a high level of dynamicity to their channels. The solid alluvia of the eastern Romanian rivers are volumetrically high, while the geomorphologic processes result in bank-collapse and large accumulations. The use of a large palette of colours in process-

modeling may increase the accuracy of interpretation of the hydro-geomorphologic phenomena, as it outlines the erosion and accumulation areas, the wetter or drier layers, the finer or coarser grained strata, etc.



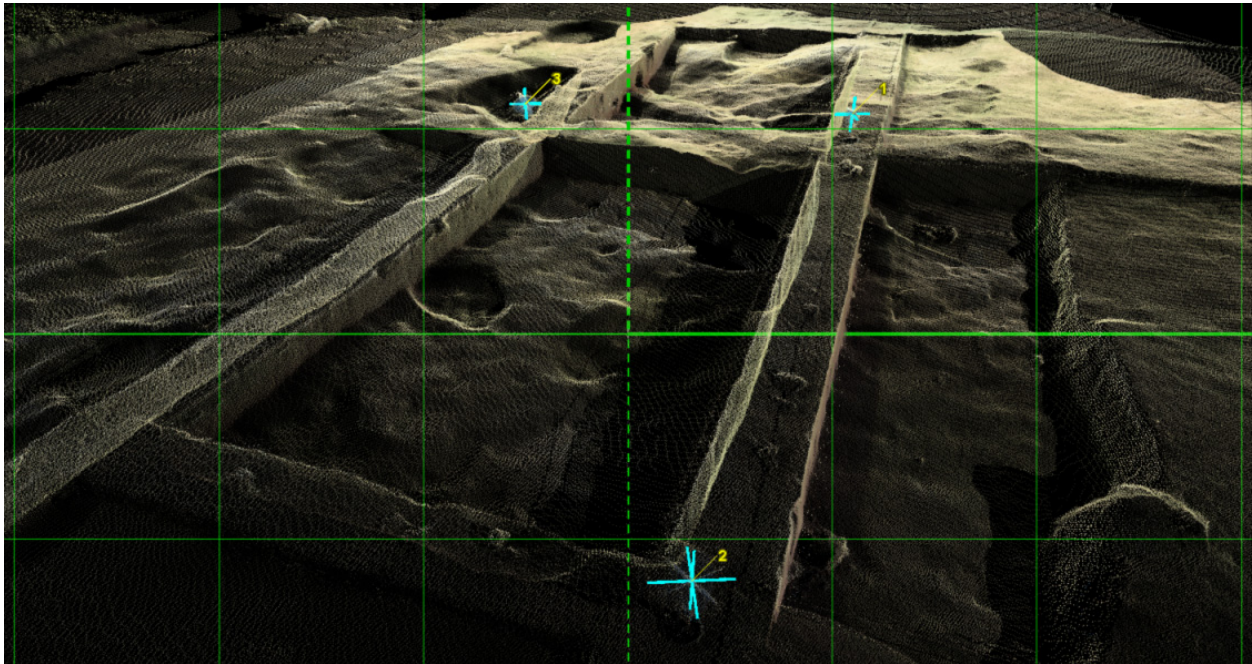
**Figure 18.** Detail of Dofteana river banks – 1 (10 m grid)



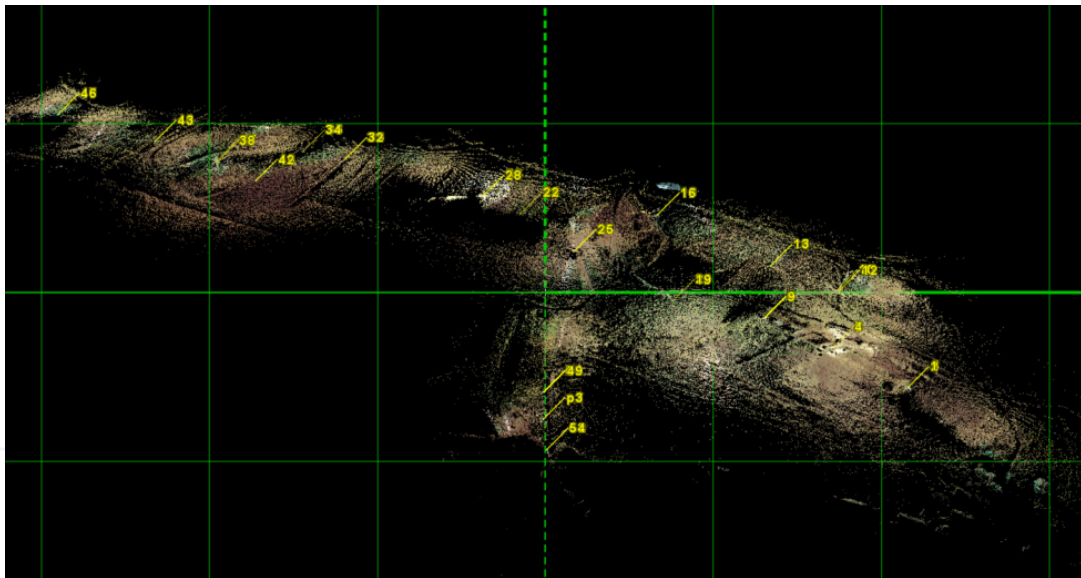
**Figure 19.** Detail of Dofteana river banks – 2 (10 m grid)

One of the first uses given to the 3D scanner was the study of archaeological sites. As such, the excavations and the tracking of the finds were recorded accurately in time and space (Figure 20, 21). The archaeological use of the 3D scanner included the sites of Bucsani, Ibida, the tells of Harsova, and Tangaru, the walled town of Ulpia Traiana and the defensive ditch of Silistea, Neamt County. For the future, we plan to monitor in this way all the archaeological excavations in Moldova and Dobruja.





**Figure 20.** Bucsan archaeological site – during the archaeological excavations (1 m grid)



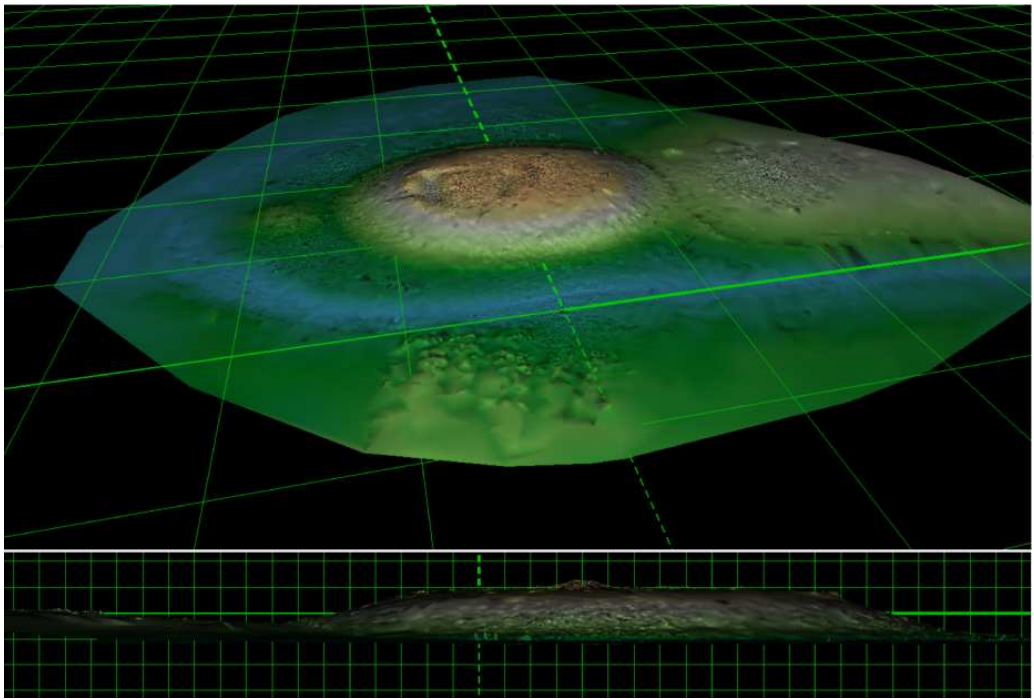
**Figure 21.** The walled town of Ibida – the archaeological excavations (200 m grid)

The 3D scanning on archaeological sites applies not only to the excavation area but to the location and tracking of finds as well. The most remarkable results were achieved in the field of architectural reconstruction of the built space. The Romanian territory conceals a veritable archaeological treasure, with several hundreds of major sites. In spite of this richness, most of the excavation projects are still at the level of intention or slow startup.

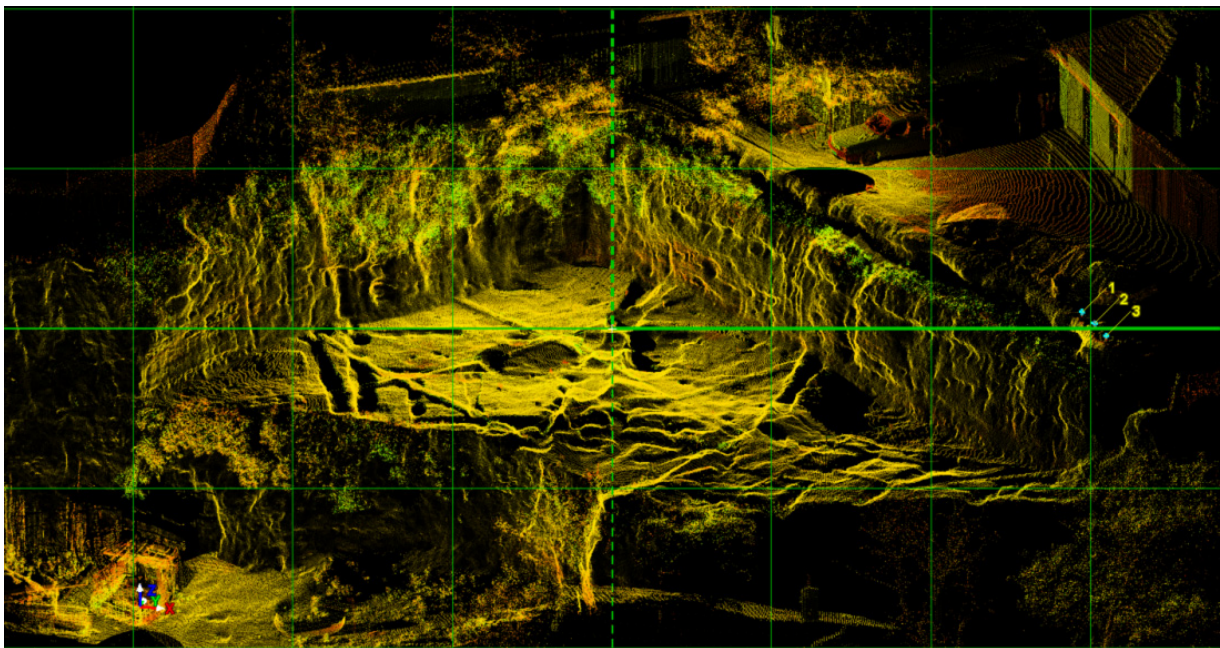
In a first phase, we carried out the measurements required to outline the features of a tell (ex: Tangaru) (Figure 22). To delineate the excavation stages and to accurately locate the finds, several successive scans are carried out on the site, as is the case of the sample



research stage at the tell of Harsova, on the right bank of the lower course of Danube (Figure 23). The outstanding importance of the Harsova tell resulted in its close and adequate monitoring, as well in its promotion on the international heritage scene.



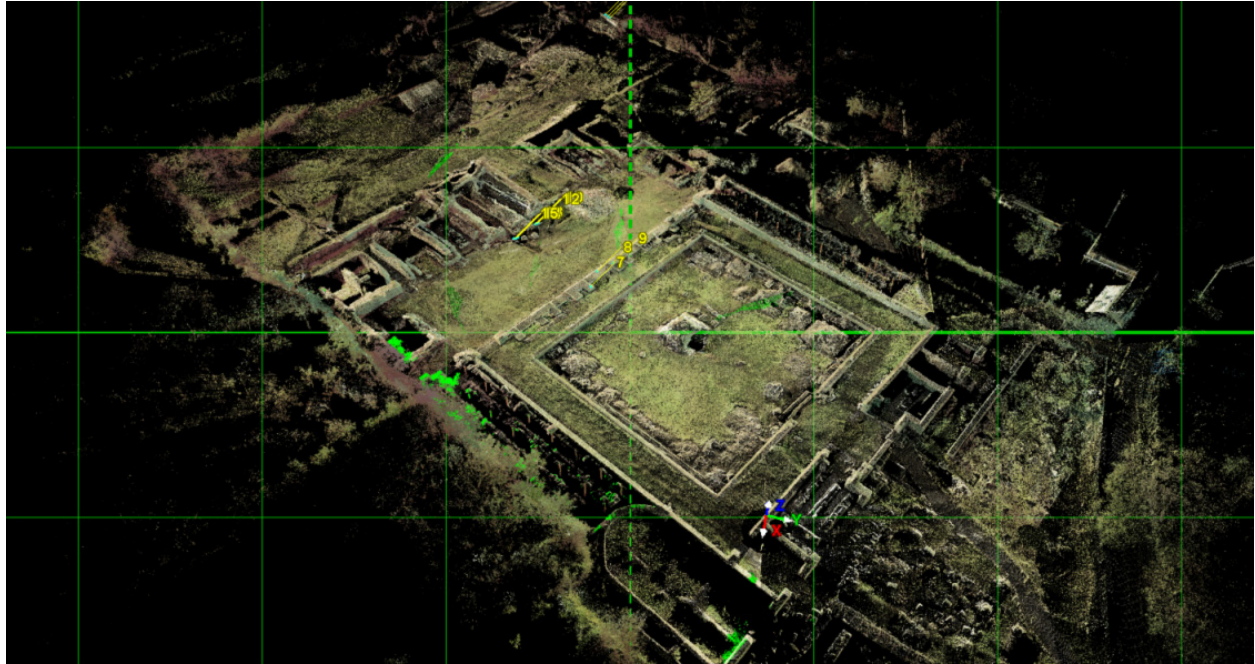
**Figure 22.** The morphologic features of the tell of Tangaru (during the data-modeling) (50 m grid up, 5 m grid bottom)



**Figure 23.** The tell of Harsova, on the right bank of the Danube (5 m grid)

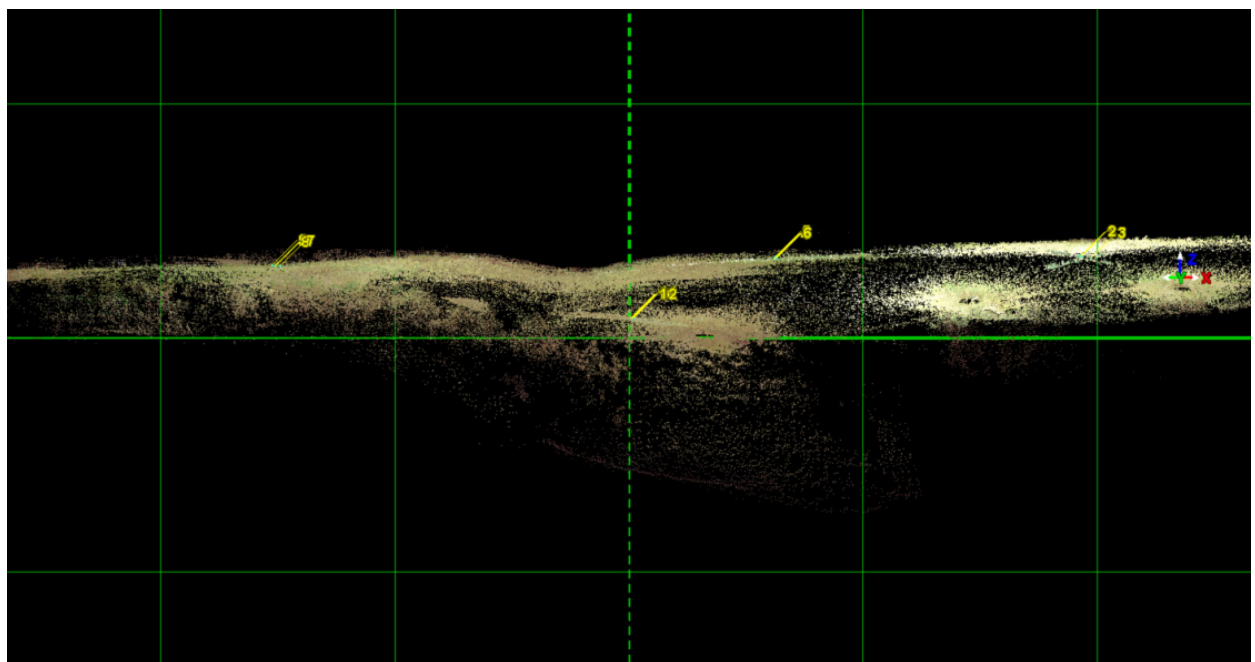
The 3D scans carried out at the site of the ancient walled town of Ulpia Traiana in the Orastie Mountains unveiled a large and well-provisioned urban settlement, au par with the better

known contemporary Roman towns. The tridimensional image can help in filling the unknown areas and in the clarification of certain issues of urban zoning (Figure 24). The complete image of a settlement is useful in carrying out a succesfull synchronic comparative study.



**Figure 24.** The walled town of Ulpia Traiana in Orastie Mountains (30 m grid)

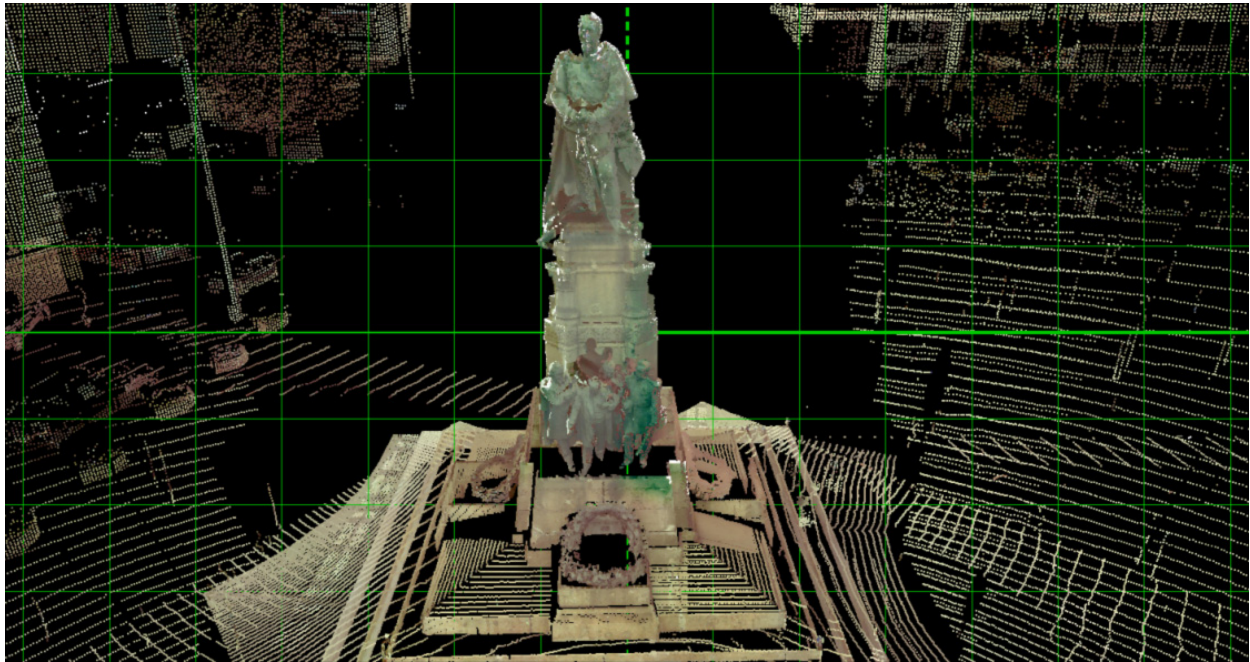
On the archaeological site of Silistea (Neamt County), the 3D scanning was directed on the defensive ditch of the settlement (Figure 25), making important contributions to the monitoring of the cultural landscape.



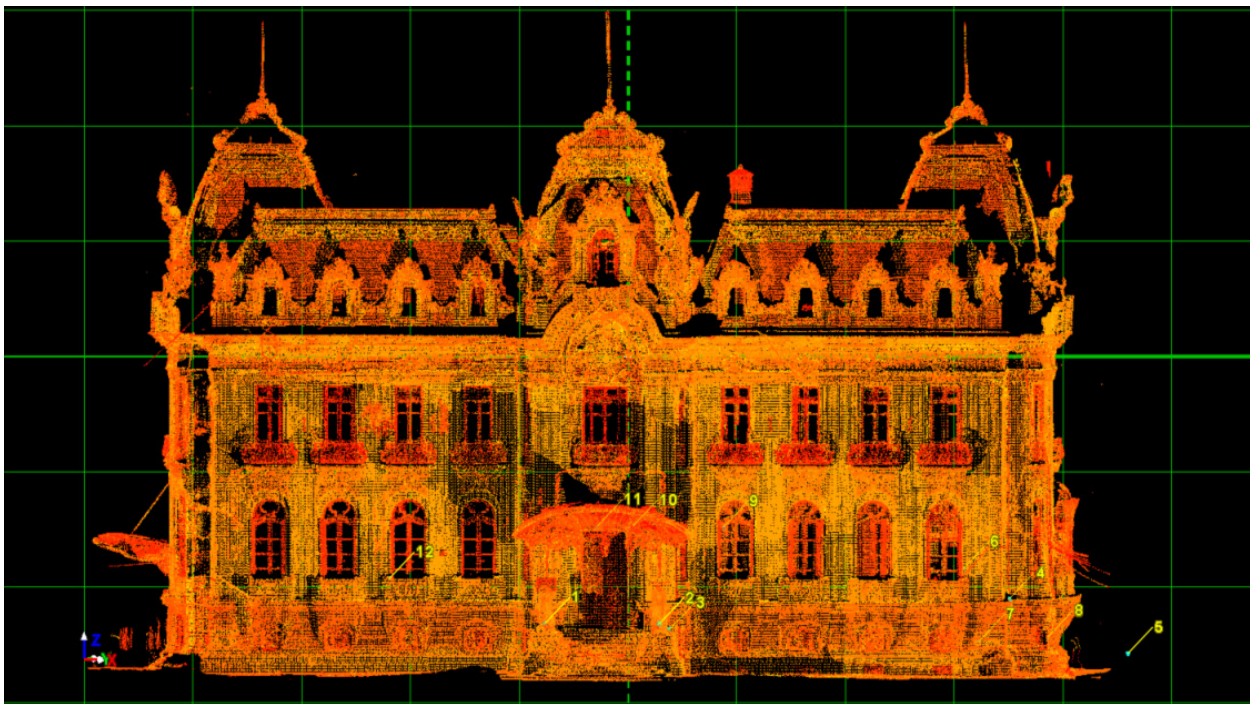
**Figure 25.** Silistea, Neamt County – the defensive ditch (30 m grid)



The architecture and art history benefit also from the 3D scanning, which opens new directions of research for them. In this regard, the scans are useful for studying the relation between a statue and its environment (Figure 26) or the makings of a building (Figure 27, 28) (on the small scale), or for analyzing the center of a city (on the large scale) (Figure 29).

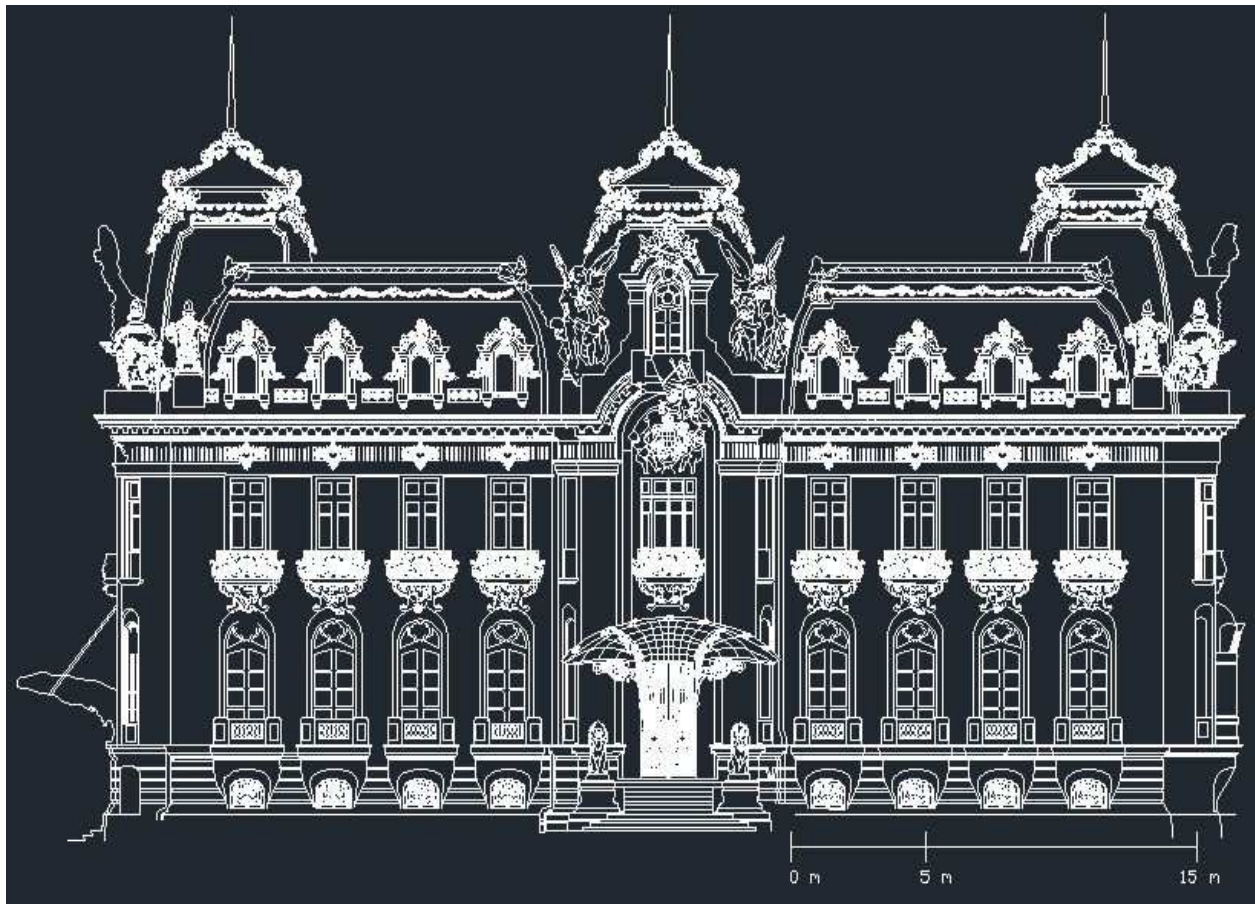


**Figure 26.** Prince Alexandru Ioan Cuza statue, in Union Square, Iasi (2 m grid)

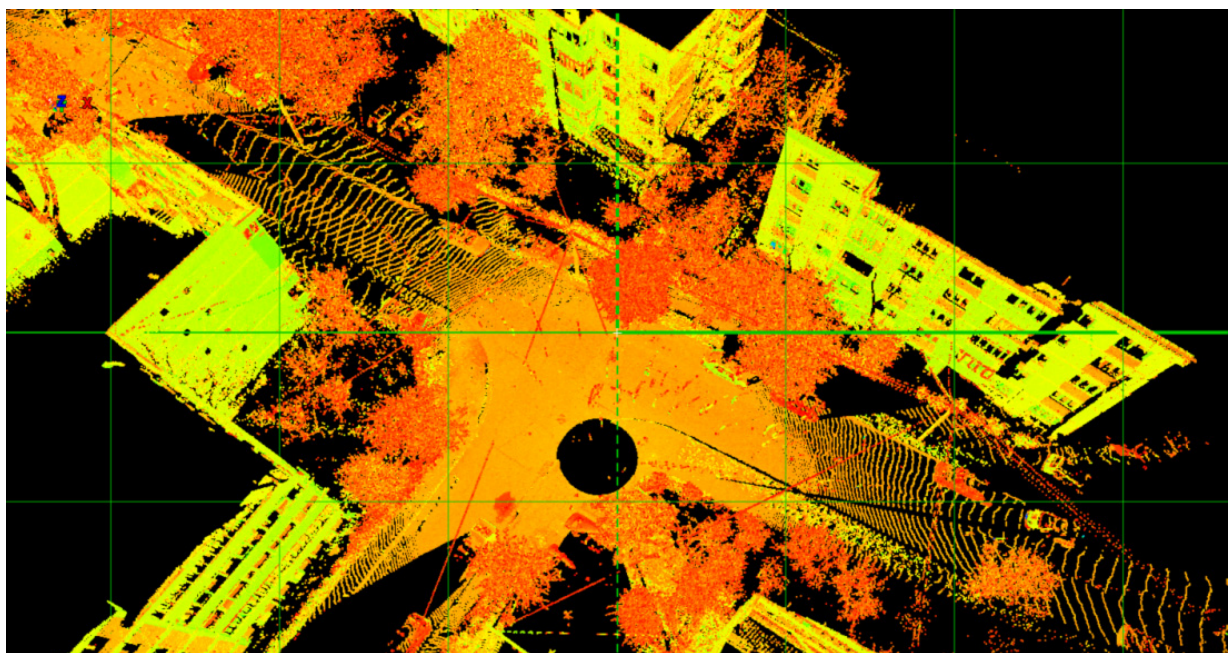


**Figure 27.** The Cantacuzino Palace, in Bucharest (5 m grid)





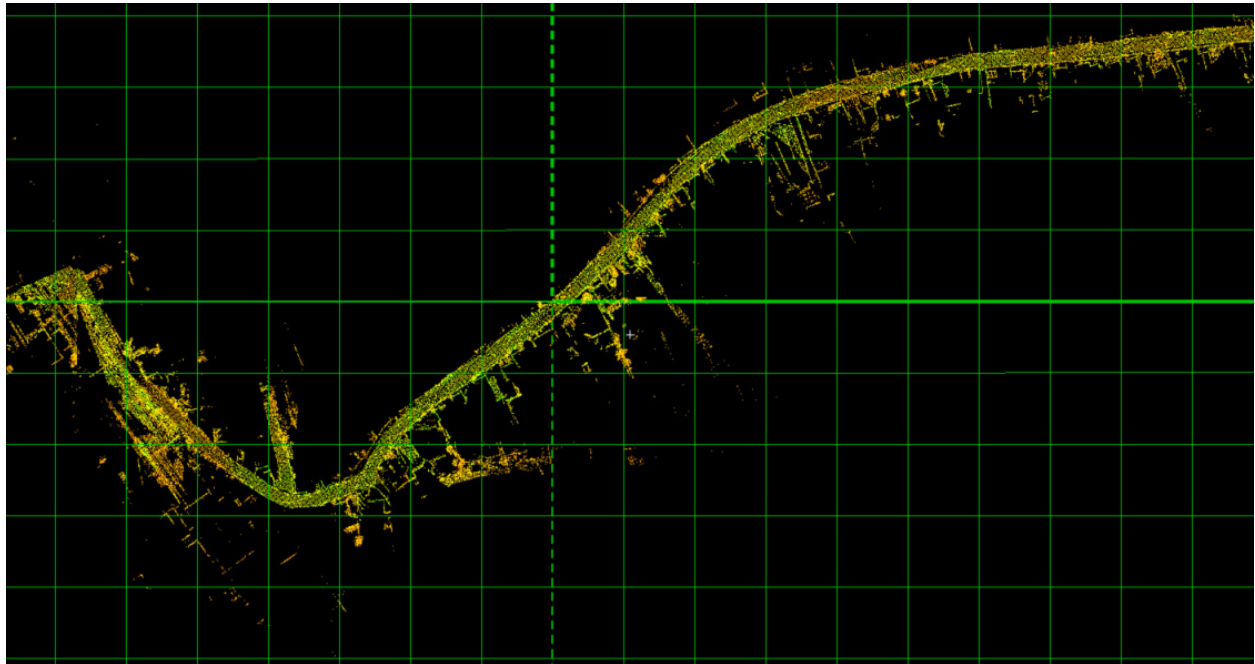
**Figure 28.** The Cantacuzino Palace, in Bucharest – the final product



**Figure 29.** Iasi city-center (10 m grid)



The 3D scanner is also an instrumental aid in designing the land networks (Figure 30): forestry roads, county and national roads and motorways, or other land-based facilities: ski tracks, bobsleigh courses, golf fields, power, gas and oil transport networks, etc.



**Figure 30.** Road-building in Rarau Mountains (Suceava County) (50 m grid)

## 4. Conclusions

The 3D scanner is the most powerful and versatile instrument used in monitoring the natural and man-related processes on short term scale. The processing/production times are short and the mapping products are flawless.

On a large scale, it can be useful for a wide range of activities. Up to the present, it was used for dynamicity analyses in geomorphology (gullying, landsliding, bank- and slope- collapsing, riverine dynamics etc.), archaeology, architecture, civil and military engineering etc.

The first practical application on the Romanian territory was carried out on the Cucuteni Ravine (Iasi County), in the Moldavian Plateau.

For small items, with minute change over time, the most recommended resolution is 1mm/1mm. For large areas, with active dynamics over time, the most recommended resolutions are 5-6mm/5-6 mm (reducing significantly the scanning time – two or three times faster).

The mapping products resulted following the interpretations of the 3D scanning results are much more accurate than the ones produced using classic methods.

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