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Research Paper

The Use of Technology Opportunities with Terrestrial Laser Scanning Image for 3D Bridge Modelling and Monitoring

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Abstract: 3D modelling and monitoring of engineering objects, based on the use of Terrestrial Laser Scanning image, provides ideal opportunities for the study, design and monitoring of these infrastructure works. The object of the study is the Bridge on Shkumbini River, an integral part of the existing railway infrastructure Rrogozhinë-Lushnje. This study reflects the necessity of using this technology due to the very high rates of development of instrumental measuring geodetic technologies, the need to increase monitoring rates, guaranteeing maximum operational safety in all projects where these facilities are applied. This method, due to its application in geodetic motorization technology, distance receiving information technology, without being required to provide the facility, digital photography technology through the digital cameras installed in them and due to advanced processing programs with photogrammetric graphics, results efficient, fast and incredibly accurate. As a result, the product offered entirely based on cloud-point pixels with a resolution of the millimetre order is a 3D format drawing rendered with maximum and complete dynamic accuracy needed for studies, monitoring, and rehabilitation projections of these very important infrastructural engineering works.

Keywords: *Modelling, Plotting, Monitoring, Digital Photo, Laser Image Scanner, Resolution, Points' cloud,*

Introduction

3D Laser scanning of existing bridge structures provide to civil engineering and contractors with very high accurate situations of bridges, it helps them for inspection, to determine exact measurements of bridge components and creating inspection models to planning, testing etc or of proposed building sites. The maintenance and reconstruction of these infrastructural engineering objects, of particular importance and directly related to the lives of their users, in order to keep under control, the functionality and the revitalization of these objects through the relevant specialists, had as a request to provide geodetic a finite graphic model as exact and real as possible. This requirement has been linked not only to the particular constructive elements in itself, of which these engineering objects are composed, but also to the geometry of their mutual positioning of these constructive elements in relation to one another. Often, this information becomes more important if offered in the dynamics of their changes in time. As a consequence of these high demands, the previous detection methods were not able to provide such information, important for the reconstruction or monitoring of existing bridges.

Also, given the long-time of their construction, around 70 years, these objects are of particular importance because they are directly related to the safety and quality of rail transport and not only that. The modernization of plotting methods through such numerical surveys creates a good basis for proper analysis, interpretation and action in the proper time with the ultimate goal to preserve the lives of users of these infrastructural engineering facilities. The instrumental technology used to accomplish these plotting processes ensures not only high precision, but also short plotting or monitoring time. These techniques guarantee the obtaining of complete dynamic information even in areas inaccessible to the operator as a result of applying them to laser rays technology (Remondino, 2011).

Compared to the classical modelling and monitoring method, which maximally provides a 3D model based on a number of reduced points and for a long-time realization, the modelling and monitoring method with the Terrestrial Laser Scanning image through specialized software provides

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extra visual information with a resolution of millimetre order in a very short time. So we can say that the final graphical material is a "3D metric digital photography" in full dynamic. In this article we intend to look at how these techniques and technologies are applied.

Materials and Methods

The engineering object we have taken in the study belongs to the group of long-term facilities since it was built in the 1960s at the time of the railway line Rrogozhinë-Lushnje. It is a dual rail and motorway bridge about 270m long, 9.5m wide and 16m high, its beams are supported on two support walls and 7 piles. This object was constructed as an engineering solution for the passage of this Railway Line over the Shkumbin River, one of the country's largest rivers, which is distinguished for immediate changes in its hydropower regime. These changes give impacts to its bed, increasing erosion, increasing or decreasing the amount of alluviums and consequently increasing its destructive potential to engineering works built beside it. Added here and the impact of the factor on the inexcusable use of this bed for the production of construction inertia and climate changes which constitute an unforeseen destructive potential for these engineering works.

Probably the low level of maintenance necessarily requires the advancement of modelling and monitoring methods, programmed on the scientific basis of these objects, allowing for the control of the work and intervention to revitalize it within the technical design parameters. The cause for the monitoring and assessment of the sustainability of this bridge has been the collapse of 2008 in the motorway that was 70m in the eastern part of the bridge in the study (Fig.1, a, b, c), its seniority and not a very good current state of the structural formation of the river bed in which two of its main feet are incinerated.

This article we are introducing is an integral part of a geodetic monitoring project being implemented on this engineering work from the moment of the fall of the above-mentioned motorway bridge until now.

Figure 1. a) Position of the fallen bridge, **b**) Position of the bridge in the study, **c)** Incision of the feet at the riverbed

Data Base Admission

For the realization of this part of this geodetic project, we have been obliged to gather concisely existing graphic and engineering data from the archives of the respective institutions, old photos and drawings related to the realized and implemented project, topographic plans and maps, geological and tectonic information of the area in which this engineering object is built and continues to function.

From a geological point of view, the foundations of the bridge are located in Quaternary QH formations, which are represented by gravel deposits ranging from 3 to 20m in space. Deposits of the "Rrogozhina" formation are normal sequences with the "Helmesi" formation and have a sparse character. They are represented by sandblast, conglomerate and gravel thick and middle layer with silty clays and clay layers. The sandy areas are layered, mostly semi-sloping to compact. Conglomerates are an important element of this pack and meet in pockets, lenses of various sizes and mainly layers, from friable to poor cemented. The clays are silty clays type. The sandy areas are massive, mainly small grains, large grains, often sandy-gravels mixtures. Thickness in some sectors goes up to 1500m. Gravel is large from some mm to 5-6 cm of sedimentary and magmatic composition. Sandy areas are mostly compact to half compact. Clays, several times silty clays type,

compact with many carbonates, are beige in white colour. Conglomerates are massive with thick grain matrix. Within the conglomerates we find clay - silty clays type and sandstone layers. Thickness is up to 500 - 900 m (usually about 300 m). All this information has served us to build a full engineering and visual chronology, in order to better understand the situations that this object has been through for years. The process of acquiring the database for geodetic purposes has been carried out in two main phases:
A-Build a geodetic support base for the purpose of plotting and monitoring the object.
B-Numerical plotting of the object.
A- Construction of a geodetic supporting basement for the purpose of detecting and monitoring the object.
The ground geodetic support network is materialized as the main network, such as scanning stations and as a monitoring and plan marker. The network points are materialized on the ground steadily with concrete and the observations for the determination of their coordinates have been performed with post-position method with observation point ST-50 at not less than 3 hours observation (Figure 2).

Figure 2. Presentation of the geodetic supportive points used in the object.

Measurements for obtaining geodetic network coordinates (Fig.4) have been realized using the GNSS satellite system, through measurements with the TopCon GR-3 Satellite Receiver. This instrument, which uses DSP technology and a new UHF radio system, is designed to build strong geodetic bases using two satellite systems, GPS and GLONASS. The accuracy of the point coordinate designation (static method) is of the order:

3mm ± 5ppm in plan,   5mm ± 5ppm in height.

Below is an overview of the coordinates of the main geodetic network in the UTM Zone 34N system (Table 1).

Table 1. The coordinates of the main geodetic network in the UTM Zone 34N system.

Nr.	COORDINATES X(N)	COORDINATES Y(E)	QUOTA H
ST_10	4 546696.7010	386861.2260	22.5150
ST_50	4546860.1184	386944.5209	15.3354
ST_60	4546719.6199	386838.0197	15.9413
ST_70	4546736.7914	386926.3432	17.5180
ST_80	4547007.7102	386956.0703	22.8464
ST_90	4546904.0353	386883.8306	14.7719
ST_100	4546944.6994	386989.8299	14.0095

B- Numerical object plotting.
In 2008, when the first measurements were carried out at this object for plotting of the area and the bridge, as well as for its monitoring, were used classical measurement and geodetic monitoring methods based on the TopCon IS 203 instrument with the following parameters:

2mm + 2ppm distance designation accuracy, Angle measurement accuracy 3”

together with the GNSS satellite system TopCon GR-3, the data of which is given below in Figure 3.

Figure 3. Presentation of the geodetic support network used.

The classical measurement technology used in this period, in this engineering object, provided an enough precision because the information received on the terrain does not have the required density of plotted points. The classical plotting method has a nearly zero chance of getting the necessary information on the characteristic points of the object or requires a lot of engagement in the staff and tools to make it possible to get this information. The cause is the necessity of physical presence at the desired point without which the method cannot function.

The necessity of a greater frequency of information on the points plotted in this type of object in order to obtain a more accurate form and metric relationship in the object, has conditioned us on the use of Terrestrial Laser Scanning image. With this instrument it is realized plotting through (point cloud), with a very high accuracy (Topcon, 2008). The frequency of the points is determined in function of the element and purpose of the survey. In our case, it has reached several million scanned points directly into the object. TopCon IS owns an excellent robotic technology; it has 2 integrated digital cameras that provide colour images in real time in two different positions (Fig. 6). Until now the data for obtaining a more fully model was reached with passive techniques based on images obtained through the photogrammetric method (Remondino & El. Hakim, 2006). The photogrammetric materials obtained offer realistic low cost, but the high quality of the 3Dato model requires well-known distances between points or some checkpoints on the terrain. (Barsanti et al, 2014) Active Techniques Using Classical Scanners (Vosselman, & Maas, 2010) somewhat meets some of the observed deficiencies in the first method since it provides accurate metric relationships between the plotted 3D points, but remains behind the inconvenience of receiving the visual information. As a result, in order to obtain a complete finishing material that can extract a lot of important engineering information; we thought the application of 3D modelling of the object based on the Laser Scanning Image technology. The result we obtain is a data matrix in space where the laser point coordinates reflected in the object can be calculated from this matrix equation:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} x0 \\ y0 \\ z0 \end{pmatrix} + d * \begin{pmatrix} vx \\ vy \\ vz \end{pmatrix}$$

Where:

X, Y and Z are the coordinates of the point where the laser is reflected.

x0, y0 and z0 are the center coordinates of the instrument from which the laser measurement is performed.

vx, vy, and vz are the components of the vectors of the laser's directions.

d is the distance measured by the instrument at the point reflected in the object.

Exactly the systematic provision of this matrix makes this method effective (Boquera *et al* 2012) Thanks to this technique also based on the accuracy of angular measurements which is of the order of 3 "this instrument realizes the acquisition of information through a large and frequent number of points in the object with a resolution of up to millimetre order even for its specific constructive and damaged parts(Figure 5).

Figure 5. Scan times from a scanning temporary station.

Figure 7. Damaged structure

In this way, through scanned points cloud in the object with 4-dimensional coordinates (X, Y, H, Color), the problems previously displayed as a result of the application of the classical method were rebuilt as the object was plotted with a frequency of order points 3 -10cm for the whole object and up to 1mm for special elements such as the support of the beams on the bridge feet and supportive walls, in the vicinity of each other's beams on the same foot, as well as in the space between the beams .
There were 7 basic scanning stations and about 6 temporary scanning stations, with average plotting distance from object 5-50m. As a result of the intelligent measurement technology "iSCAN Feature Plotting", which creates the ability of the instrument to identify the characteristic points by means of previously taken pictures and then scan them. Also, Grid Scan technology provides an ideal opportunity to plot the object according to a cloud of distance points between the points previously set by us. Each pixel plotted in this way, based on the colour photos realized by the cameras that owns the instrument itself or from the external camera, you attach the fourth attribute that is related to the colour of the point. A summary overview of the main parameters of the realized scanning (Table 2).

Table 2. The main parameters of the realized scanning

Nr. of scans	Nr. Of scanned points	Scanning resolution	Scanning distance
7+6	24 861 214	1mm-3cm	5-50m

Elaboration of DATA-Acquisition of the 3D model

Numerical material obtained from terrain measurements is necessary to be filtered and purified from unnecessarily recorded information. The obtained file is the database that through the program TopCon Image Master Pro, a program specializing in photogrammetric processing and scanning, are used to describe desirable drawings up to the final 3D object model. Through this program, measurements are performed on the numerical photograph, ortho-picture is generated and 3D models are created using the images taken from the numerical cameras installed on the instrument. The program also performs 3D measurements from stereo images (Figure 6).

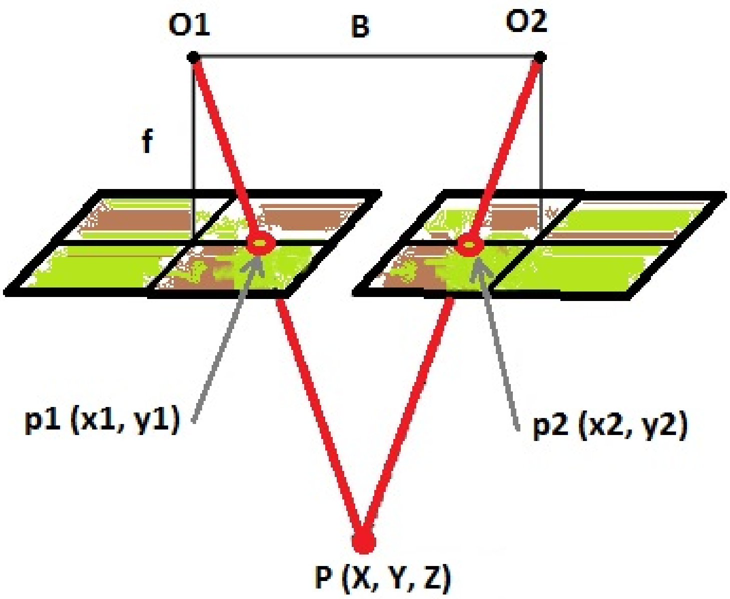


Figure 6. The basic concept for measuring 3D from the images is based on the stereo image.

The terrain resolution from 3D measurements on the image is given according to these formulas:

$$\Delta\ \mathrm{XY} = \frac{\mathrm{H}}{\mathrm{f}}\mathrm{x}\ \delta p$$
$$\Delta\ \mathrm{Z} = \frac{\mathrm{H}}{\mathrm{B}}\mathrm{x}\ \Delta\ \mathrm{XY}$$

Where: Δ XY: planar resolution, Δ Z: height resolution, f: focal distance, δp: image resolution, H: photograph distance, B: photo base.

We can also create 3D panoramas. Image Master Pro has an important function that allows the creation of a unique object model from the image control point coordinates, calculated from terrain instrumentation points. Then it is also obtained the contour line, profiles, sections, triangular network and finally the 3D model of the plotted object. The material obtained along with ortho-photos can be stored in various graphics formats that can be edited by drawing programs like AutoCad or MicroStation, while the 3D model can be exported to VRML format. Registered and acquired files from the Master Pro Image Program also provide an excellent opportunity for use by GIS applications (ImageMaster 2008).

Final Numerical Product in 3D

We can say that what we have gained from the use of this method and technology is not compared with the previous classical methods of surveying and obtaining the final numerical material. The following figures show the 3D model of the object obtained with the classical modelling method, a bridge photo, and the 3D model obtained with the plotting earth scanning image method (Figures 7-9).

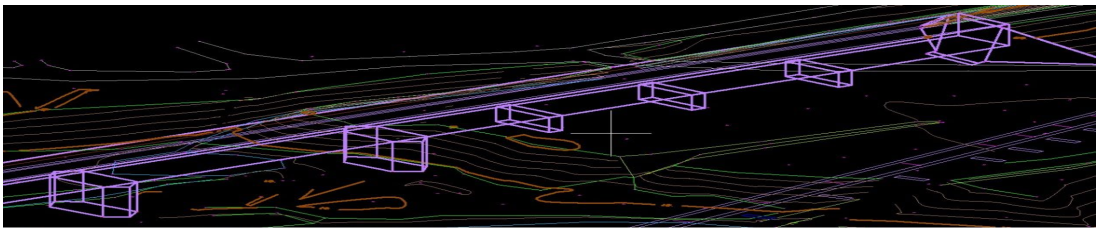


Figure 7. Isometric view of the bridge obtained according to the classical plotting method with Total Station and GNSS System.

Figure 8. Photo of the bridge.

Figure 9. Isometric view of the bridge obtained from the cloud of colored points with terrestrial laser scanner image.

Isometric view of the bridge obtained from the cloud of colored points with *terrestrial laser scanner*. The numerical products that we took from the 3D model obtained through the scanning program are different. Among them, we can mention the plan and longitudinal or cross-section of any kind of desirable position in the object (Figure 10).

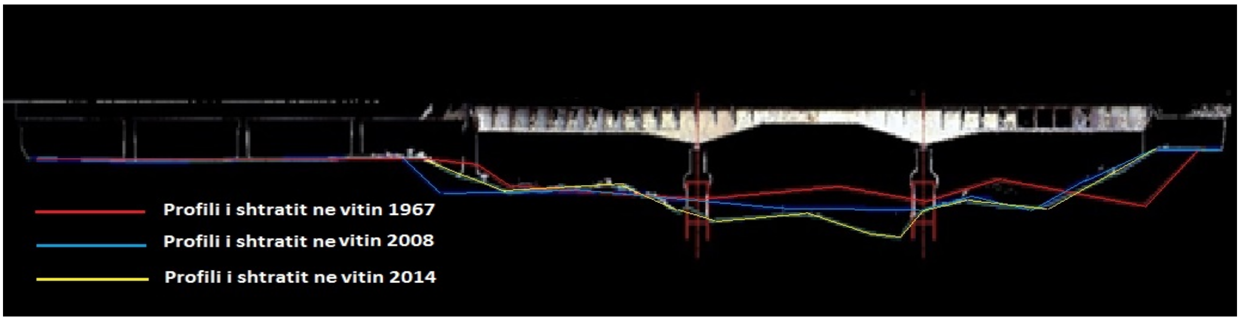
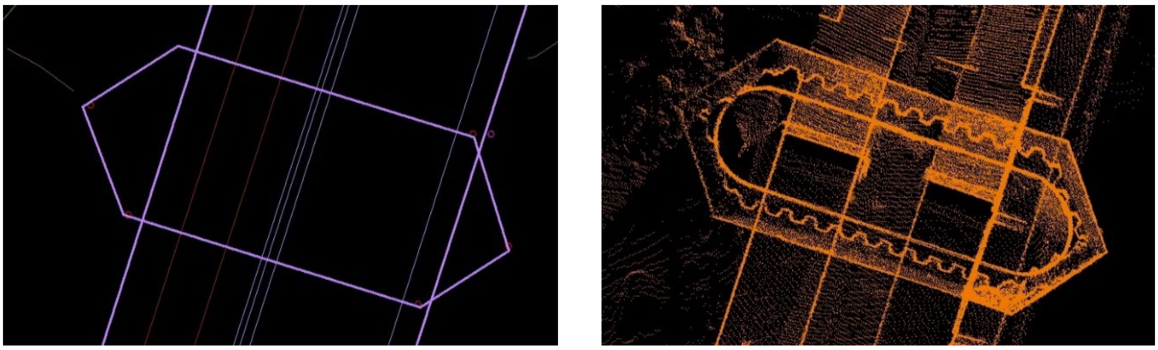


Figure 10. Longitudinal cut of the bridge.

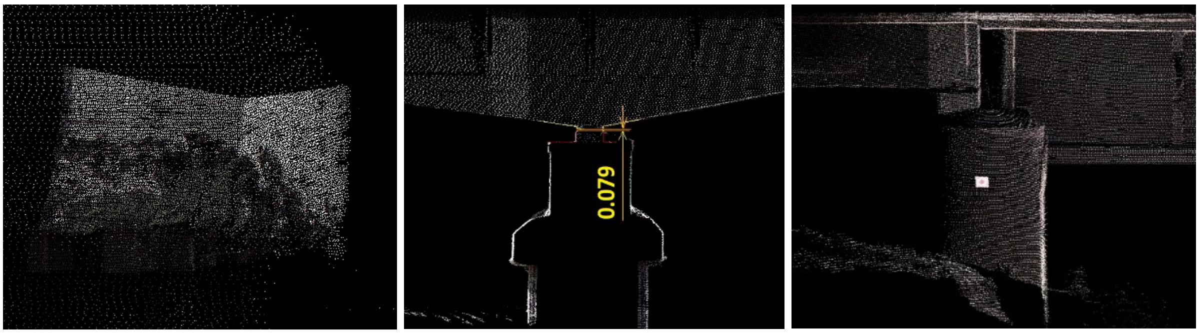
Also accurate 3D and 2D models of important constructive engineering details were obtained with great value for analyzing the actual situation of the object, designing reconstruction projects or monitoring it with the aim of maintaining the engineering parameters of functioning, of vital importance (Figure 10).



A. Top-view classic method of modelling b. Top-view.laser scanner of modelling method

Figure 11.a, b. top-view presentation of the bridge's foot according to the classic method and ILST.

Due to the large number of points plotted in the object and the 3D modelling of the obtained surface, we can deduce up to the details in relation to the various constructive elements of the important object as for the design phase for its reconstruction as well and for the monitoring phase in order to keep within the engineering parameters of its functioning (Figure 12, 13).



a. ***b.*** ***c.***

Figure 12. Important monitoring elements (a. Constructive damaged parts, b. Vertical monitoring brand, c. monitoring between the constructive elements).

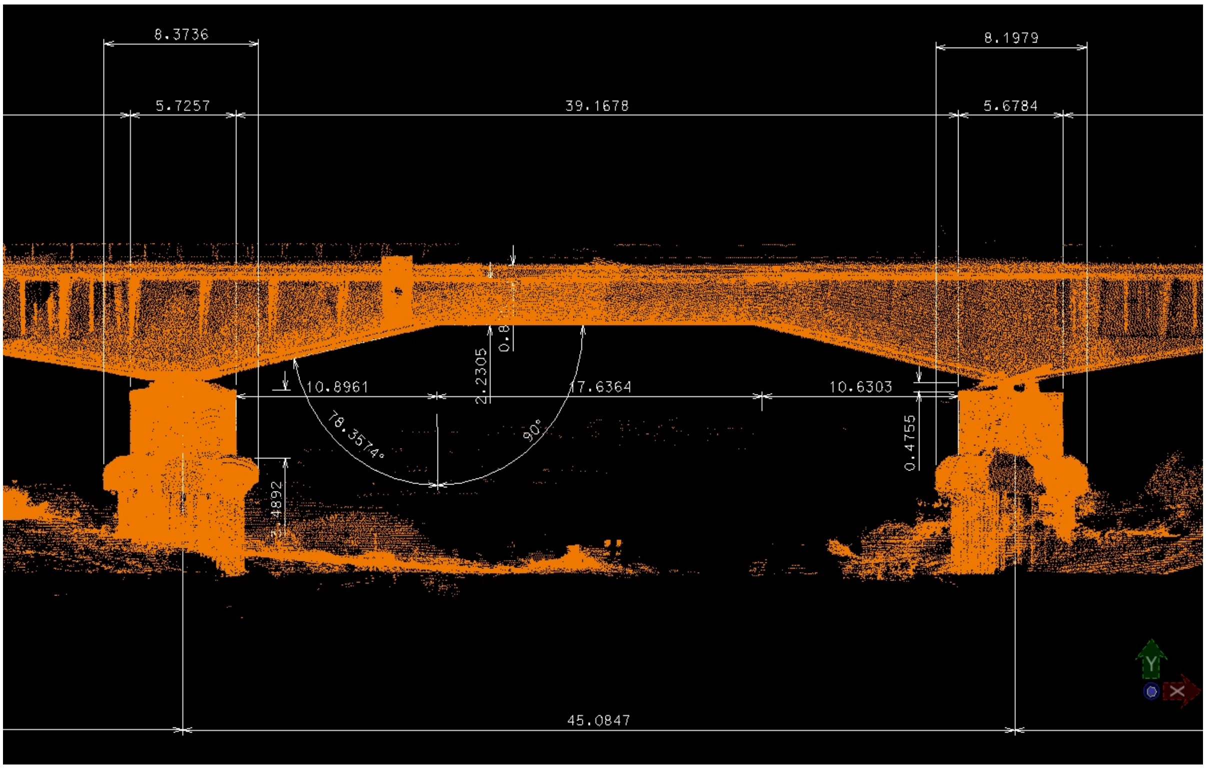


Figure 13. Presentation of some of the dimensions realized...

But the main product we have achieved to realize from this type of survey is to outline the 3D graphic model of the entire object, in which are clearly and accurate defined reciprocal metric relations between the constructive elements of the object itself, as in the developments in the plan and the altitude, also enriched with an accurate information of the object in terms of its visual state, i.e. the colour of each point (Figures 14, 15).

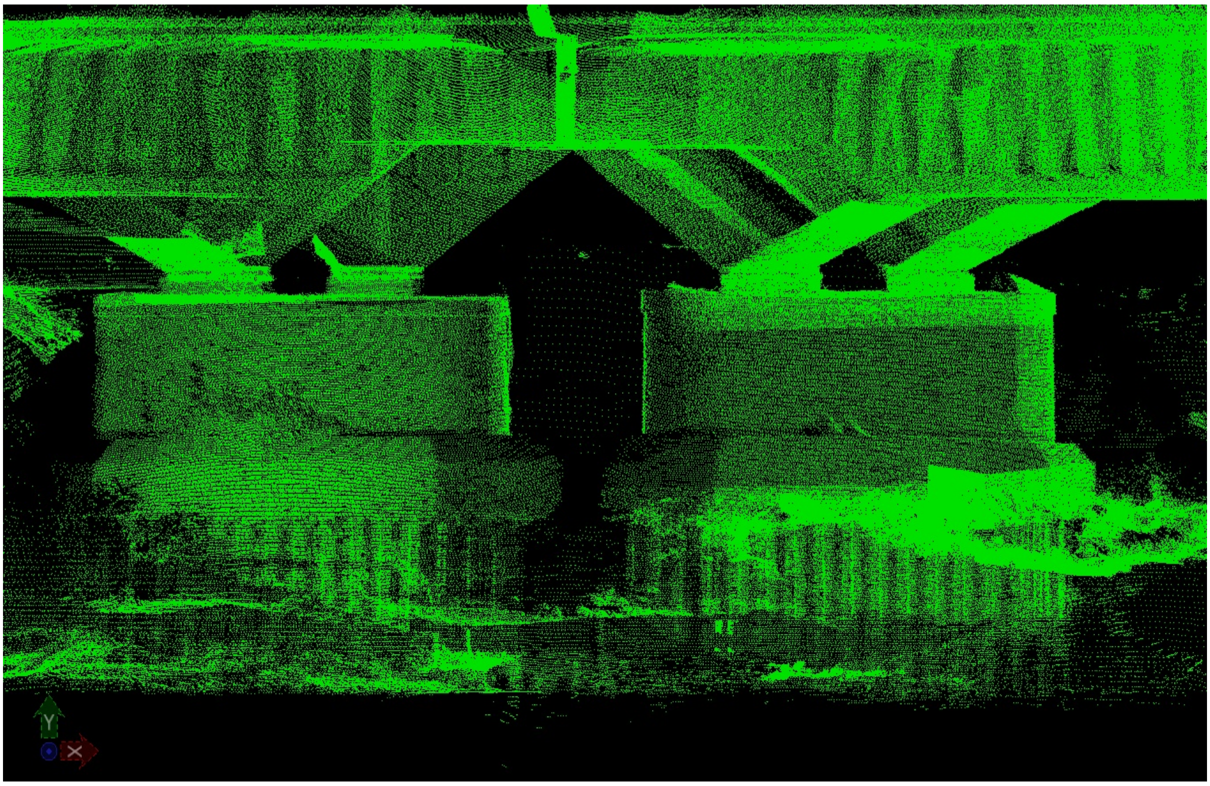


Figure 14. Right-view Presentation of the scanned object.

Figure 15. On the left, Object's Photographic Model, on the right Object's Scanned Model.

Conclusion

Using technology relevant engineering objects with Terrestrial Laser Scanning Image enables creation of a perfect object model as the metric point of view, both in terms of positioning and visualization. Thus, in a very short time and in large numbers, accurate graphics can be obtained with respect to any engineering details such as: different profiles, different horizontal cut-outs, and dimensions in each important part of the object as well as Real-time, detailed visual information in the same graphical model. This information is accurately provided up to 1mm resolution. Plotting this object with Terrestrial Laser Scanning Technology showed that this technology is a powerful tool for reducing the time of receiving terrain information while providing high resolution. This technology generates massive numerical data and therefore requires no programming and computer accessories with maximum parameters. The data obtained also serves to archive the current state of the object as well as to create the possibility of realization with high precision of reconstruction projects in order to maintain the quality and safety of the operation of these types of objects. The use of this plotting method also provides ideal, not applied before opportunities for monitoring these engineering objects.

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