

# **Application, specifics and technical implementation of the 3D terrestrial laser scanning for measurement and analysis of the spatial geometry of a steel construction**

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**Key words:** 3D terrestrial laser scanning, steel construction, measurements

## **SUMMARY**

The technology of the 3D terrestrial laser scanning offers the geodesists and other professionals many new possibilities. 3D laser scanning could be applied in a number of engineering tasks and one of them is our specific case - measurement and detailed analysis of the spatial geometry of a steel construction.

This paper studies the technical details from the practical implementation of: 3D terrestrial laser scanning, data processing and analysis of a steel construction. The last consisted of two rows with ten columns in each one. Two under-crane beams, mounted over each row of the columns were also subject of detailed analysis. The sequence of the geodetic activities, also the specifics (including the scanner settings, processing and the interpretation of the information in the point cloud) are discussed in details in the paper. The final results from the 3D laser scanning (the spatial coordinates of each point) were used later on for thorough analysis of the steel construction, using specialized geodetic software.

The respective discrepancies of the elements of the steel construction from their theoretical values were analysed in details in the paper. The axes of both: rows of the columns and the under-crane beams were also studied and the results were presented in the respective geometrical and analytical way.

Recommendations and proposals for future work are also given.

## **АБСТРАКТ**

Технологията на 3D наземното лазерно сканиране предлага на геодезистите, както и на други специалисти много нови възможности. 3D лазерното сканиране може да бъде приложено в много инженерни задачи и една от тях е нашия специфичен случай – измерване и детайлен анализ на пространствената геометрия на стоманена конструкция.

Този материал изучава техническите детайли от практическата реализация на: 3D наземното лазерно сканиране, обработката на данните, както и анализа на пространствената геометрия на стоманена конструкция. Последната се състои от два реда с десет колони във всеки от тях. Две подкранови греди, закрепени над всеки от

редовете от колоните бяха също предмет на обстоен анализ. Последователността на геодезическите дейности, също така и спецификата (вкл. настройките на скенера, обработката и интерпретацията на информацията от облака от точки) са дискутирани детайлно в статията. Крайните резултати от 3D лазерното сканиране (пространствените координати на всяка точка) бяха използвани по-късно за цялостен анализ на стоманената конструкция, чрез използване на специализиран геодезически софтуер.

Съответните отклонения на частите на стоманената конструкция от техните теоретични стойности бяха анализирани в представения материал. Осите на колоните, както и на подкрановия път бяха също изследвани и резултатите представени в съответния подходящ за интерпретация вид.

Препоръки и предложения за бъдеща работа също така бяха дадени.

# **Application, specifics and technical implementation of the 3D terrestrial laser scanning for measurement and analysis of the spatial geometry of a steel construction**

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## **1. INTRODUCTION**

3D terrestrial laser scanning is one contemporary way for fast and accurate gathering of spatial information – the coordinates of each measured point along with the intensity of the returned laser signal in the scanner, see [Milev, 2012]. Information about the process of laser scanning could be found in many sources on the Internet, see [[http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/15\\_Surveys.pdf](http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/15_Surveys.pdf)] and [<http://www.aftopo.org/download.php?matricule=412807>]. There are various types and brands of laser scanners and their usage in the practice depends for instance on the size of the object, accuracy requirements, etc.

The type of the object in this paper – steel construction, which was approximately 9 m. high required usage of 3D terrestrial laser scanning, due to the following reasons:

- absence of any surveying documentation;
- dangerous and practically impossible to access the upper parts of the construction;
- the conventional surveying instruments were not able to provide the required spatial data with the necessary amount and completeness;
- it was necessary to determine very fast and accurately the current spatial geometry of the steel construction in order the relevant maintenance activities to be performed;

The tasks of this paper are:

- to perform a study of the technical requirements, which should be followed in the process of scanning a steel construction;
- to analyse the various sources of data, derived from the point cloud;
- to propose recommendations, based on the derived results.

The focus in this paper is concentrated especially on the outdoor scanning of a steel construction.

## **2. SOME OF THE APPLICATIONS OF 3D TERRESTRIAL LASER SCANNING IN GEODESY**

There are a number of applications of the terrestrial laser scanning in the area of geodesy. Some examples are given below:

- in deformation measurements [Bu et al., 2008], [Zogg et al., 2008] and [Zhang et al., 2008];
- for tunnels surveying [Wang et al., 2013];
- for health assessment of concrete structures [Yang et al., 2014];

-for analysis of steel structures [Cabaleiro et al., 2014], [Park et al., 2007], [[http://www.gim-international.com/issues/articles/id21113-D\\_Modelling\\_of\\_Shukhov\\_Tower.html](http://www.gim-international.com/issues/articles/id21113-D_Modelling_of_Shukhov_Tower.html)] and [Křemen et al., 2008].

One other possible application, involving also specialized Bulgarian geodetic software will be given here in this study. The last focuses on the following key moments:

- the conducted survey field procedures in order all required spatial information to be captured;
- applying the necessary settings in the laser scanner for outdoor scan of the steel construction;
- the way of processing of the raw data and extraction of the necessary information from the point cloud;
- usage of the point cloud to perform spatial interpretation of the object;
- analysis of the derived data;
- usage of a specialised external geodetic software to determine the discrepancies in the 2D space;

### **3. TECHNOLOGY REQUIREMENTS. ADVANTAGES OF THE USAGE OF TERRESTRIAL LASER SCANNING FOR THIS PROJECT**

In this chapter are listed some of the requirements, which must be followed when conducting laser scanning. It should be noted that the accuracy, quality and reliability were essential for this project. In order to be produced data with the required good quality, several environmental conditions should be carefully observed before start of the process of laser scanning (for complete list, see the user manual [<http://mep.trimble.com/sites/mep.trimble.com/files/Trimble%20TX5%20User%20Guide.pdf> ]):

- Surveying should not be conducted if the ambient temperature falls below 5 degrees Celsius;
- Measurements should not be conducted in dust, snow or rain;
- Scanning against direct sunlight should be also avoided;
- Highly reflective or absorbing objects' surfaces will increase the inaccuracy of the measurements.

The above listed requirements of the terrestrial laser scanning required choosing of appropriate time period of the day for conducting of the measurements in order to be produced reliable and quality results, according to the specifics of the assigned task.

Here could be listed some of the major advantages of applying the terrestrial laser scanning for this project:

- the usage of laser scanning facilitates the analysis of the spatial geometry of the steel construction, i.e. it gives the possibility to obtain thorough spatial data for the object in a short time period at the field;
- the object was “sealed” at the moment of measurements, which eliminated the need for performing additional field measurements in order to obtain more information, if required;
- significant part of the steel construction, subject of measurements and analysis was at a high, dangerous and very difficult for human access place. Those circumstances required the usage of contactless technology for conducting of the geodetic measurements;

#### **4. PERFORMED GEODETIC ACTIVITIES BEFORE CONDUCTING THE SCAN**

The object under assessment – the steel construction (consisted of total 20 columns) was carefully recognised before the start of the geodetic measurements. It was concluded, that 3 stations of the laser scanner should be used in order to be assured the following requirements:

- the necessary (short) distances between the various parts of the object and the scanner;
- the required angle of incidence between the scanner and the targets [<http://mep.trimble.com/sites/mep.trimble.com/files/Trimble%20TX5%20User%20Guide.pdf>];
- the safety of the scanner and its accessories;
- the necessary visibility between the scanner and the artificial targets;
- the visibility of the spheres between each two stations;
- the required spatial geometry between the spheres;
- the distances between the scanner and the spheres (in this case were used both two types of spheres);

The places for the stations of the scanner were carefully chosen as to be assured the direct visibility of:

- the bottom and upper parts of each column;
- the under-crane beams;

According to the current environmental conditions, the proper settings were applied (described in details in the next chapter) in order to be produced scans with high quality.

#### **5. TECHNICAL PARTICULARITIES OF THE 3D TERRESTRIAL LASER SCANNING OF THE STEEL CONSTRUCTION. PARAMETERS OF THE SYSTEM. PROCESSING OF THE RAW DATA**

The procedure of the laser scanning was started after assuring, that all of the mentioned in the previous chapter requirements were met. For conducting of the scan, Trimble TX5 was chosen amongst all other possibilities, due to its technology and technical possibility to achieve the required accuracy, needed for the study of the steel construction. In Trimble TX5, as it is known, there are colour settings - options for the exposure metering mode. In order to produce quality data from the laser scanning, the correct mode was chosen, according to the current environmental conditions. The usage of a certain scanner should be carefully considered, see [Alkan et al., 2012].

Due to the very fast changes in the weather (sunshine and clouds) during the time of performing of the measurements it was difficult to choose the right setting for colour metering for the outdoor scan of the steel. The absence of warning messages, also the chosen resolution and quality of the scan guaranteed high quality of the raw scan data.

The mentioned above settings in the laser scanner assured, that the accuracy requirements of the project will be met and the quality of the panoramic photos will be enough for the extraction of the necessary spatial information. A balance between the accuracy, quality of the scanning

and productivity in the field work was assured for this project.

The raw data was input in Trimble RealWorks and the necessary processing was done, using “spatial sampling” instead of sampling by step and adaptive sample. The used method produced a homogeneous point cloud, which was essential for the spatial analysis of the steel construction.

In order to create highly accurate and reliable 3D digital model from several scans, the requirements listed in chapter 3 and 4 should be followed. For this case – analysis of a steel construction each technical detail was of high importance, due to the accuracy requirements.

## **6. APPLICATION AND USAGE OF THE POINT CLOUD FOR VIRTUAL INTERPRETATION AND SPATIAL STUDY OF THE STEEL CONSTRUCTION**

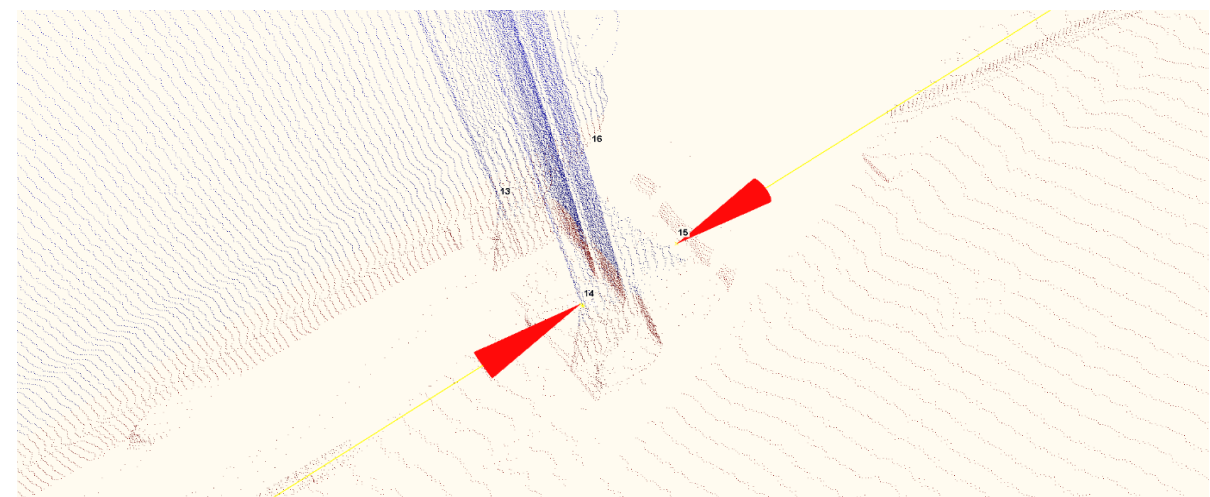
The point cloud was used for several purposes, including but not limited to: 3D visualization, creation of dimension lines for the respective objects and extraction of the necessary 3D coordinates. Trimble RealWorks was used not only for processing of the raw data, but also to export the required information from the point cloud, in the relevant format to external software products for further interpretation and analysis.

The following data, listed below was required for the analysis of the spatial geometry of the steel construction:

- the coordinates of control points from the point cloud of the steel construction, see fig. 3;
- the deviation between the lower and upper part of each column, i.e. the deflection of the vertical of each column;
- the distance between the columns, see fig. NN: 1 and 2;
- the distance between each north and south column, measured at the inner edges of the under-crane beams, see fig. NN: 4, 5, 6 and 7;
- the deviation between the theoretical axis of the under-crane beams and their actual position in the plane, see fig. 8;
- determination of the heights of the inner edges of the under-crane beams, see fig. 9;

### **6.1 Graphical representation of the data, necessary for the spatial study of the columns**

- the coordinates of the contour points of the lowest and upper parts of each column, see fig. 1;



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Gintcho Kostov

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6/14

FIG Working week 2015

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Fig. 1 The control points and the dimension lines at the lowest part of a column

-the distances between each one of the columns, measured at the lowest places, see fig. 2;

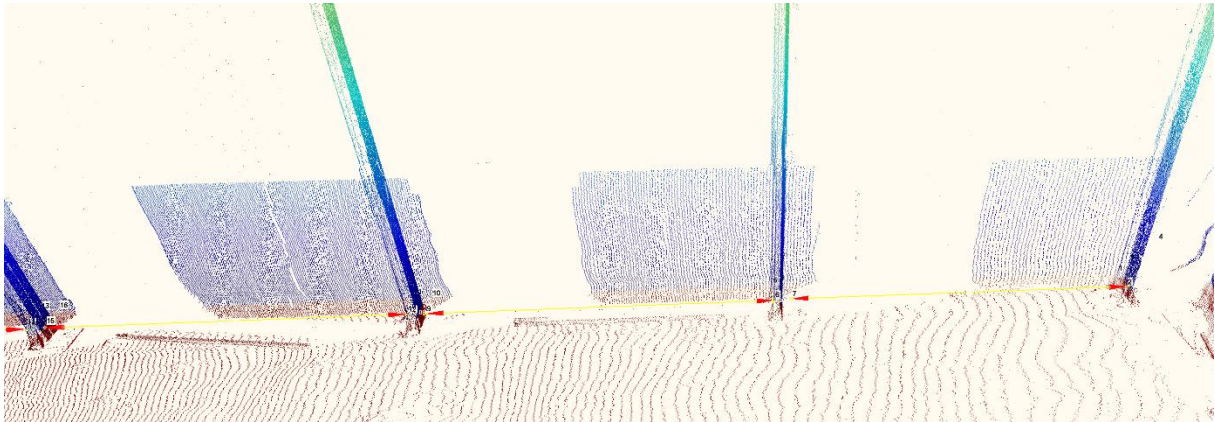


Fig. 2 Created dimension lines in the 3D space between each one of the columns

## 6.2 Graphical representation of the information, necessary for the spatial study of the under-crane beams

-the coordinates of the inner edges of the beams, at each two opposite columns, see fig. 3;

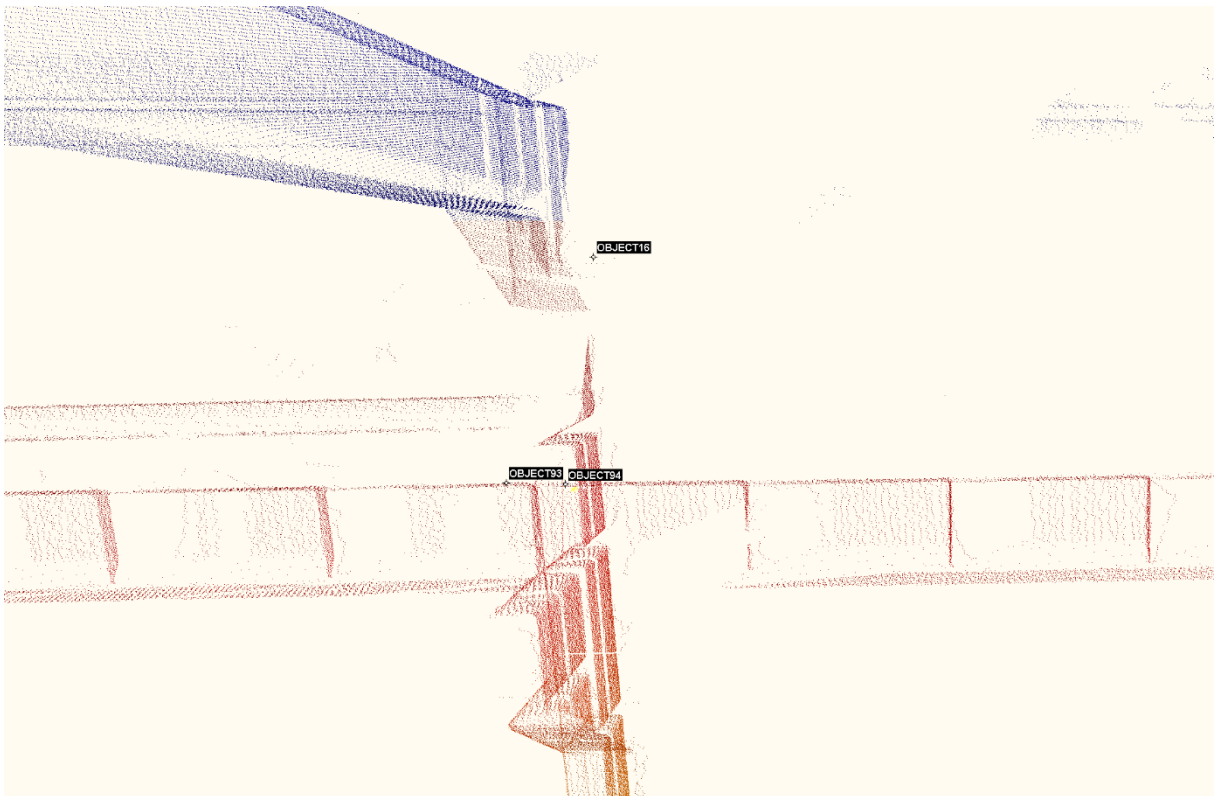


Fig. 3 Control points on the inner edges of the beams



-the dimension lines in Trimble RealWorks between the inner edges of the beams, see fig. 4;

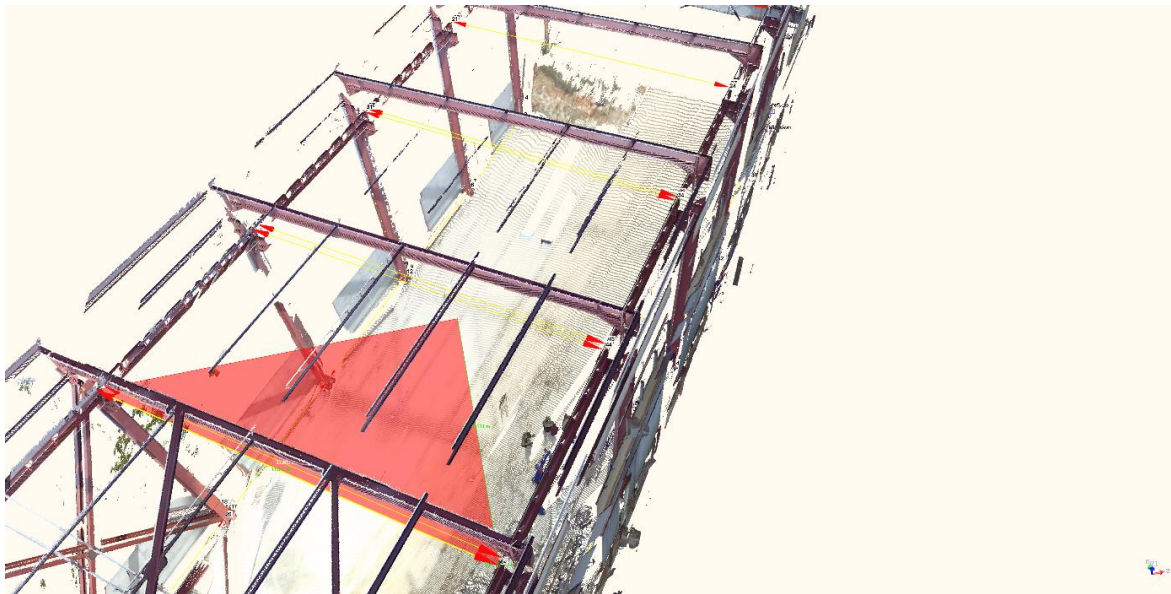


Fig. 4 Created dimension lines at the upper part of the construction, between the beams

The information, given in points 6.1 and 6.2 was used for further analysis (in the plane, see fig. 10 and in the space) of the current condition of the spatial geometry of the steel construction.

Figures NN: 5, 6 and 7 show the various possible ways of the interpretation of the produced 3D information for the steel construction. They are screenshots of one essential advantage of the software (with the point cloud) – its possibility to show from various points of view the difficult or impossible for human access places of the object.





Fig. 5 The steel construction and its dimension lines – virtually view from above

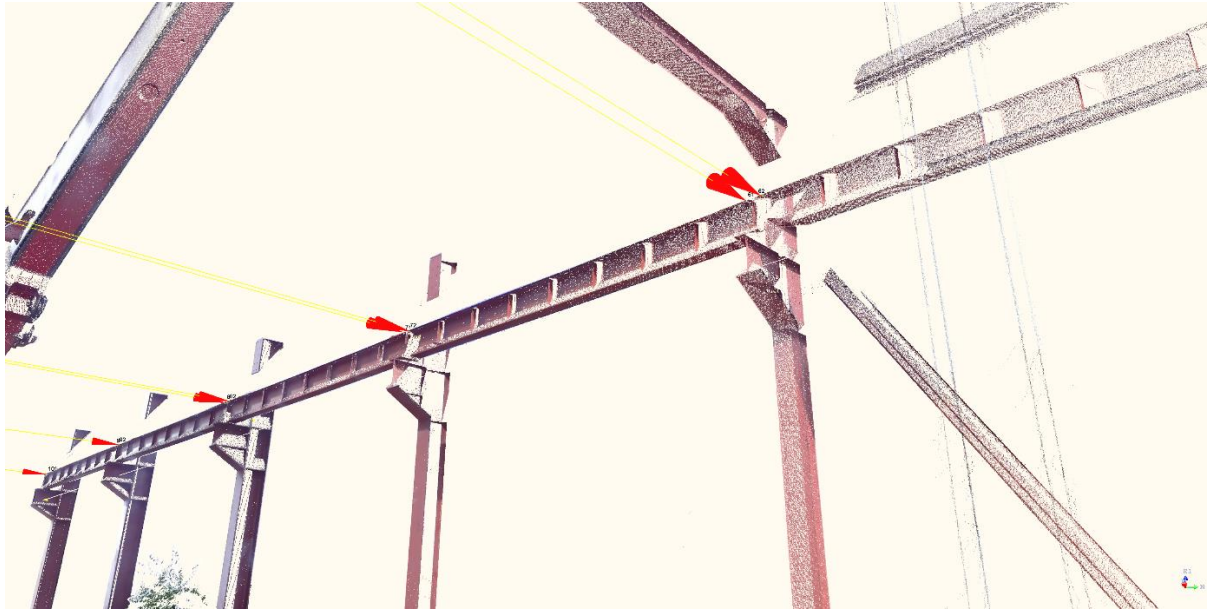


Fig. 6 Dimension lines in the point cloud, between the beams – virtual view from the ground

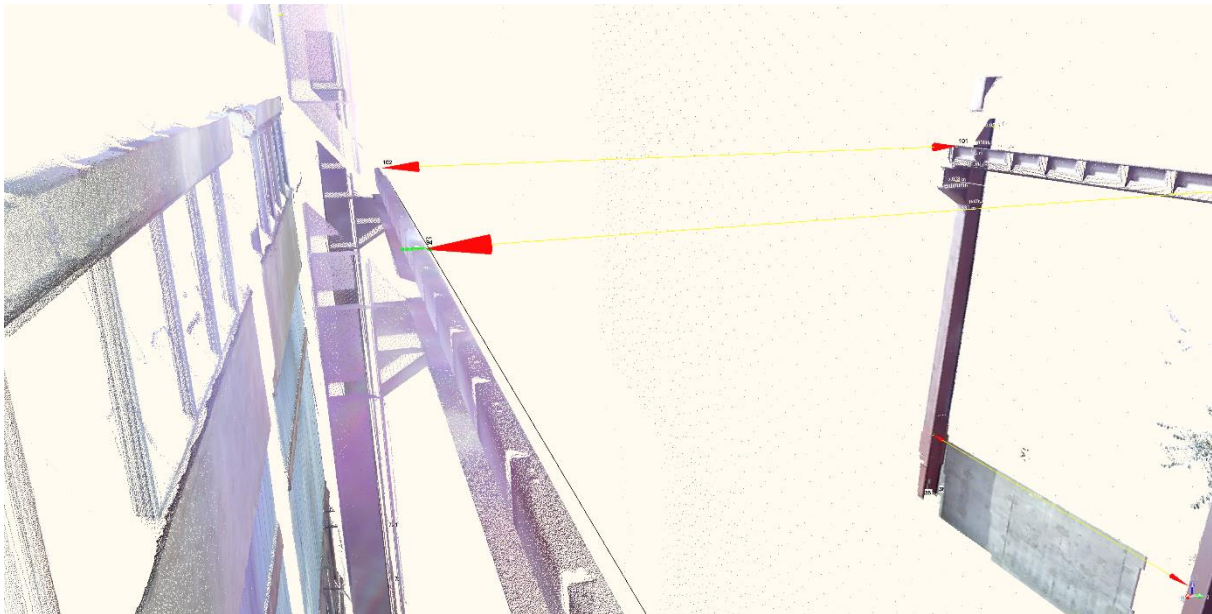


Fig. 7 The under-crane beam and its dimension lines – virtual view from its height

## **7. RESULTS AND ANALYSIS FROM THE PERFORMED 3D TERRESTRIAL LASER SCANNING**

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TS number – Session title, paper no 7625

Gintcho Kostov

Application, specifics and technical implementation of the 3D terrestrial laser scanning for measurement and analysis of the spatial geometry of a steel construction

9/14

FIG Working week 2015

From the Wisdom of the Ages to the Challenges of the Modern World  
Sofia, Bulgaria, 17-21 May 2015

The information (control points and dimension lines), listed in the previous chapter was used to perform the required thorough spatial analysis of the condition of the steel construction. It should be noted that in our specific case under “the condition of the steel construction” should be understood the values of: the inclination of each column, the discrepancies between the actual and the theoretical axes of the columns and beams, etc.

Figure 8 shows both the graphical and numerical information for the deviation in the axis of the beam under study. The values of the discrepancies were provided to the relevant engineers for further actions, related to the maintenance of the steel construction.

On figure 9 are shown the variations in the heights of the edges of the under-crane beams. As it could be seen from the chart, there are a number of variations in the level of the beams. This information served to be determined - “how much” and “where” to adjust the under-crane beams in order to be met the required standards. Note, that due to the privacy measures, the real values are not shown, but the graphic represents the actual condition of the steel construction. The numerical information was used along with data, shown on fig. 7, giving the users visual information in the 3D space.

Figure 10 (graphic created by external specialized geodetic software Mkad) represents the required information in the 2D space for: distances between the columns and the beams, the deflection of the vertical for each column of the steel construction, also the points where the data was extracted from. It can be clearly seen the various directions of the discrepancies (between the upper and lower parts of the columns of the steel construction), denoted with arrows.

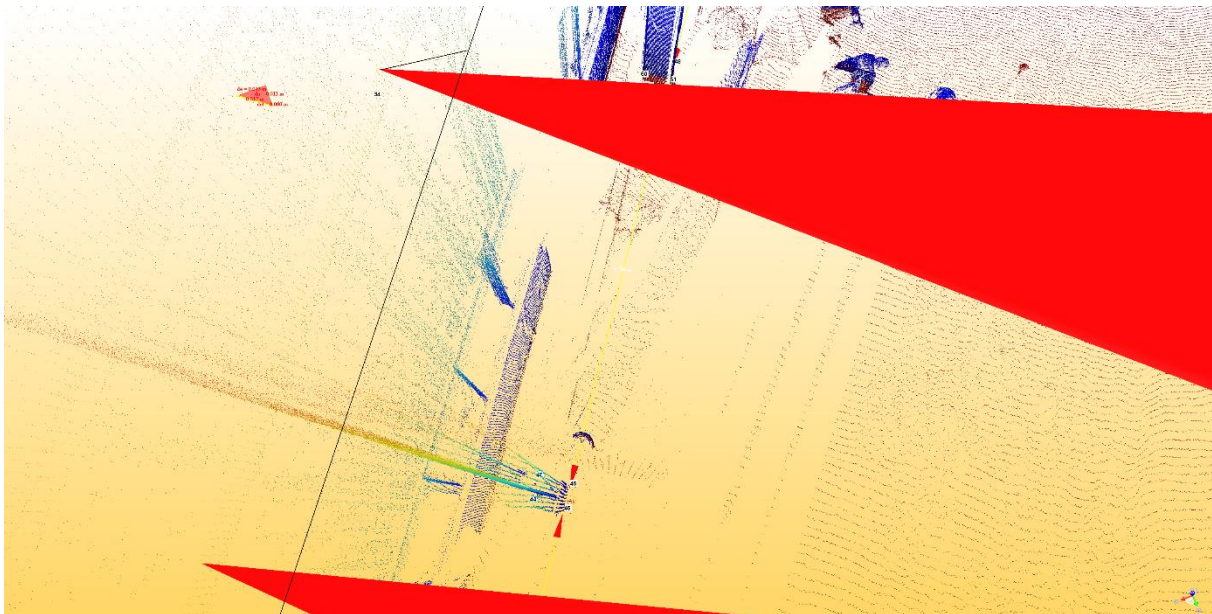


Fig. 8 The deviation in the position of the beam's axis, highlighted as small triangle (top-left)

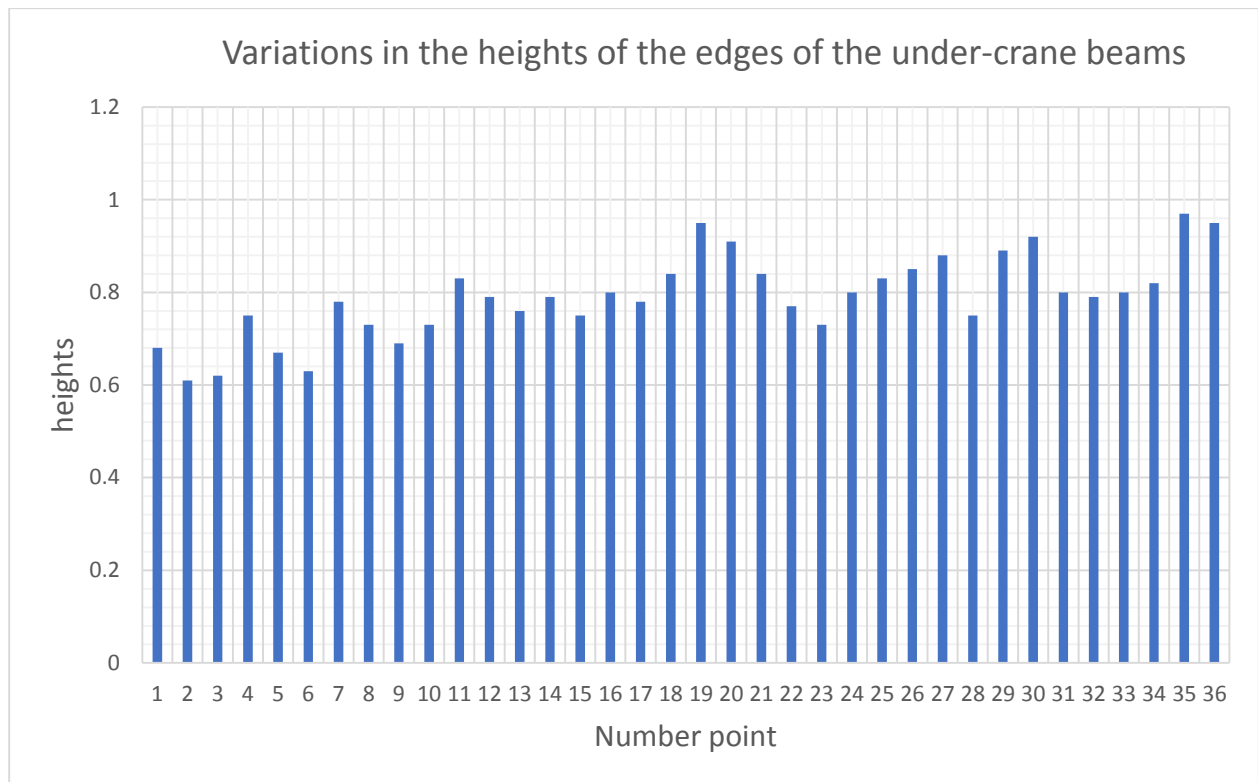


Fig. 9 The heights (reduced) of the inner edges of the under-crane beams

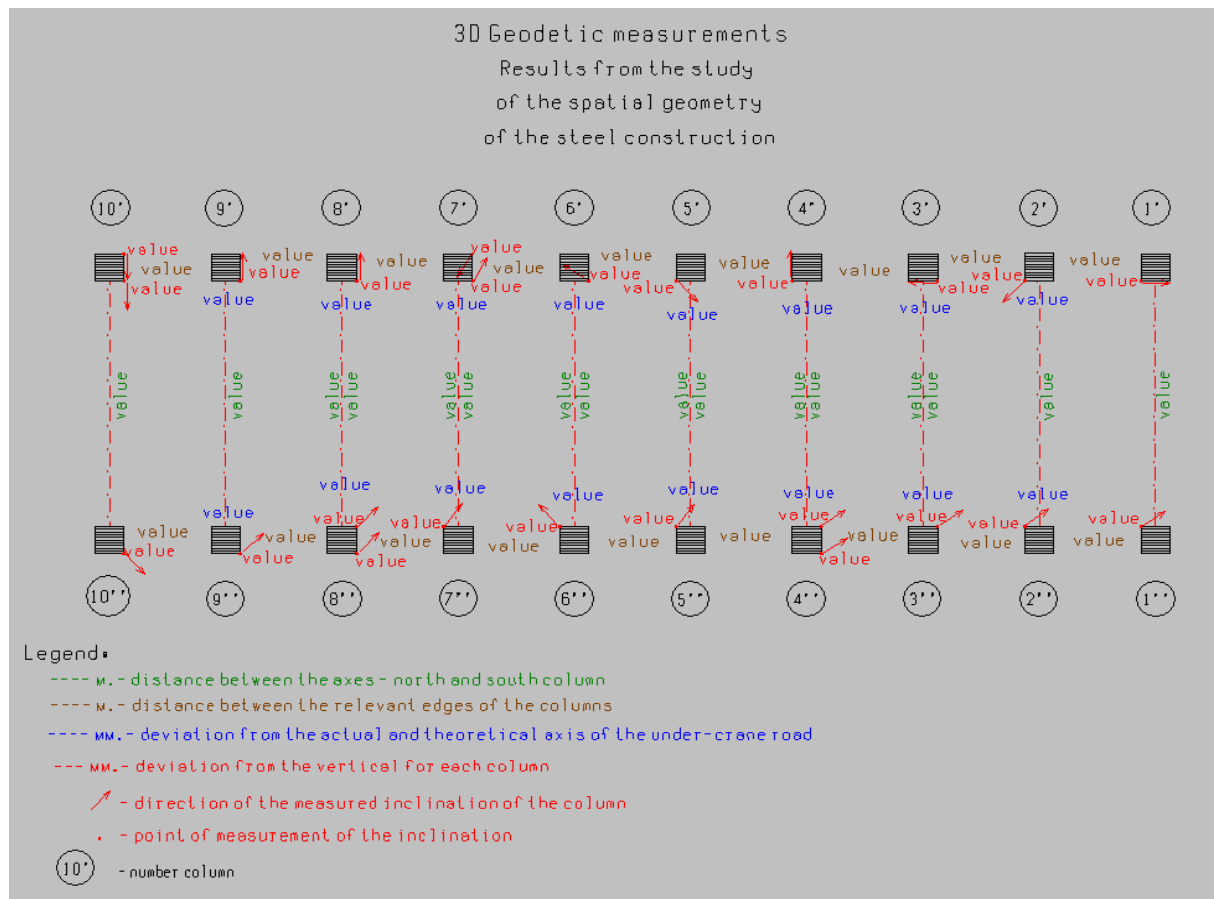


Fig. 10 Graphic with combined information for the current condition of the steel construction

The graphical and numerical information, given in this chapter served as a source, so that the required measures for maintenance of the spatial geometry of the steel construction to be undertaken.

## 8. CONCLUSION. RECOMMENDATIONS. FUTURE WORK

This paper studied the highly-accurate spatial information, derived from the created point cloud of the 3D terrestrial laser scanning of a steel construction. One contemporary, precise and very productive way for gathering of large amounts of spatial information was used for measurements and analysis. The spatial geometry of the steel construction was successfully analysed using a combination of: phase laser scanner, Trimble RealWorks, Mkad and Internet Explorer.

The final results from this project – the data, represented in the space and in the plane (using the relevant geodetic software) was delivered in the appropriate way for decision making of the condition of the steel construction.

Taking in mind the structure and the size of the object, it could be noted that the used technology successfully fulfilled the conditions of the following major factors:

- the time limitations in the field;
- requirements for accuracy;
- the necessity to be obtained large amount of spatial data.

The information in this project consisted of various sources of deliverables – coordinates, values of the dimension lines, screenshots, drawings, tables, etc., (some of them included in the paper) which were derived by one contemporary way for geodetic measurements – 3D terrestrial laser scanning. The produced data, as shown in chapters NN 6 and 7 was successfully applied for the urgent maintenance of the steel construction.

According to [\[https://www.linkedin.com/redirect?url=http%3A%2F%2Fwww%2Etrimble%2Ecom%2Fglobal%2FRLTAB%2Easp%3Fnav%3DCollection-31049&urlhash=bX5v&t=tracking\\_disc\]](https://www.linkedin.com/redirect?url=http%3A%2F%2Fwww%2Etrimble%2Ecom%2Fglobal%2FRLTAB%2Easp%3Fnav%3DCollection-31049&urlhash=bX5v&t=tracking_disc) it should be noted, that even in the sector of the contemporary paid geodetic products for 3D laser scanning exists problematic discrepancies with the linked external software – Internet Explorer. The issue was solved with update at the time of writing the paper.

Based on the technical possibilities of Trimble RealWorks, it could be recommended - the export of the data from this software to be feasible also via some of the other browsers like Mozilla Firefox, Google Chrome, etc., but not only through Internet Explorer.

Future work – this study could also be used as an appeal for improvement of the existing professional software for 3D terrestrial laser scanning, taking in mind the fast development in the area of IT.

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[alTRLTAB%2Easp%3Fnav%3DCollection-31049&urlhash=bX5v&t=tracking\\_disc](https://www.linkedin.com/redirect?url=http%3A%2F%2Fwww%2Etrimble%2Ecom%2FglobalTRLTAB%2Easp%3Fnav%3DCollection-31049&urlhash=bX5v&t=tracking_disc)

<http://www.trimble.com/globalTRLTAB.asp?nav=Collection-31049>

## USED SOFTWARE

1. Trimble RealWorks (<http://www.trimble.com/3d-laser-scanning/realworks.aspx>);

2. Mkad (<http://www.kolma.bg/> - in Bulgarian).