Testing the measurability of steel sections with terrestrial laser scanners

Arpad SOMOGYI1, Akos SZABO-LEONE2, Tamas LOVAS1*

1Budapest University of Technology and Economics, Faculty of Civil Engineering, Department of Photogrammetry and Geoinformatics, Müegyetem rkp. 3, H-1111 Budapest, Hungary; somogyi.arpad@emk.bme.hu; lovas.tamas@emk.bme.hu (*corresponding author)
24iG PLC, Montevideo u. 8, H-1037, Budapest, Hungary; akos.szabo-leone@4ig.hu

Abstract

When assessing the health of steel structures, capturing, and modelling the geometry is especially important. Point cloud-based technologies have special requirements; previous studies revealed certain challenges that are to be resolved. In this paper, we aimed to develop a method to investigate the effects that the surface reflectance, incidence angle, and distance have on the quality of the point cloud of steel sections. A controlled environment was established for the research, where three terrestrial laser scanners were used to measure four different steel specimens. For validation, we also made reference measurements with a structured light scanner. Due to a large amount of data, a workflow with own routines has been developed for processing the prepared measurement datasets. For standard steel sections, the comparative study clearly showed a significant influence of the section shape, resulting in occlusion and unfavorable incidence angles. Of the devices tested, the one designed for high-precision measurements showed the intensity highlighting phenomenon for highly reflective surfaces, however, the measurements demonstrate that with careful selection of measurement conditions and a few pre-processing steps, the technology is well suited for the assessment of steel structures.

Keywords: TLS; steel section; geometry; measurement

Introduction

Terrestrial laser scanners (TLS) are becoming more important in civil engineering practice, where they need to fulfill a basic requirement for accuracy and precision (±5 mm) (Somogyi and Lovas, 2017). TLS can support several tasks during the life cycle of a building: the conceptual design (environmental impact assessment), construction, facility management, and even demolition or restoration (cultural heritage) (Quattrini et al., 2015; Guarnieri et al., 2017; Sánchez-Aparicio et al., 2018; Oniga et al., 2021). In addition to the point measurement errors (primarily the ranging accuracy) of the instrument (X-Y-Z coordinates), the quality of the point cloud is influenced by several other factors like the surface properties of the measured object, the incidence angle, and the distance. These all affect the intensity of the return signal, which
fundamentally determines the quality of the result point cloud. In recent years, numerous studies have examined the effect of changes in intensity and angle of incidence in the point clouds (Voegtle et al., 2008).

Kaasalainen et al. (2005) investigated the effect of the angle of incidence on the intensity of points measured by TLS. Their initial assumption is that there is a correlation between the reflected signal strength, intensity, and the angle of incidence. The study also analyzed the relation between measurement distance and angle of incidence, as well as the effect of other characteristics. Their results showed that distance and angle of incidence affect the intensity independently of each other, so the correction values derived by them under laboratory conditions can be well applied to the intensity correction of point clouds.

Correction procedures were validated by comparing both real and laboratory measurements (Kaasalainen et al., 2005). Soudarissanane et al. (2007) investigated the extent to which the orientation of the measured surface relative to the scanner, as well as surface treatment, affects the accuracy of the generated point cloud. To this end, a measuring arrangement was produced in which two surfaces were measured: a fiberboard and white-painted plywood. The FARO LS880-HE80 laser scanner was used in the study. Measurement results were available over a virtually continuous range by determining the angles of incidence associated with the scans. These data can be used to determine the relative intensity and signal-to-noise ratio relative to the angle of incidence. The measurement results corresponded to those previously expected based on light scattering theory. The authors note that saturation is a significant factor at nearly perpendicular angles of incidence (Soudarissanane et al., 2007). In their study, Gross et al. (2008) show that the same surfaces provide data points of different intensities depending on the angle of incidence. The measured intensity values were normalized based on the scanner’s position and the location and position of the measured object. The surface orientation is calculated by the eigenvectors of the covariance matrix defined by points close to each other. After normalization, the measured intensity depends only on the surface properties and is independent of the angle of incidence. However, the surface characteristics also depend on the laser wavelength used.

A series of measurements were performed to investigate the effect of the angle of incidence on intensity (Gross et al., 2008). At the time of the study by Kersten et al. (2008), manufacturers were marketing the second and third generations of terrestrial laser scanners. New measuring instruments have new features and better performance, but it is essential to test their accuracy. The Department of Geomatics of the HafenCity University Hamburg conducted comparative studies to evaluate the accuracy of next-generation laser scanners: Trimble GX, Leica ScanStation, Riegl LMS420i, Leica HDS6000, Z + F 5006, Faro LS880HE. The study includes the measurement results and their discussion in the following aspects: 3D accuracy test using 3D test field, distance measurement accuracy test using reference distances, inclination compensation accuracy, and finally, the effect of laser beam incidence angle on 3D accuracy. Based on the measurements, the Leica ScanStation achieved the best result (11.5 mm), while the Z + F IMAGER 5006 provided a bit worse by 2.5 mm. Trimble (43.6 mm) and Faro (71.8 mm) instruments performed much worse (Kersten et al., 2008).

Voegtle et al. (2008) investigated the effects of materials with different surface properties and light conditions on the laser scanner ranging accuracy. A Trimble GX scanner was used for the test measurements. Materials frequently used in building facades (e.g., colored and grayscale painted panels, various types of wood, sheet metal, gypsum of different grain sizes, transmissive elements, and surfaces with different humidity) have been investigated. For grayscale and color plates, the MSE (Mean Square Error) decreases with increasing brightness. Based on the results, the accuracy of the measurements recorded at night is significantly higher than the measurements during the day. The different wood materials and surface moisture did not considerably affect the distance measurement accuracy; however, the MSE observed with the metal plate significantly exceeded the scanner’s accuracy in the case of laser beams falling perpendicular to the surface. MSE and intensity values were examined at ten different angles of incidence. The conclusion drawn by the manufacturers is that high-precision measurements should be performed at night and on bright, non-reflective surfaces (Voegtle et al., 2008).

Berényi et al. (2010) performed two complex measurements with the Riegl LMS Z420i to check the accuracy given by the manufacturer. During the measurements, not only the accuracy values were examined,
but also the effect of different material characteristics (e.g., metal, wood, concrete), different colors, and incidence angles. When measuring the material properties, the measured reflection coefficients for each sample were presented (Berényi et al., 2010).

Roca-Pardiñas et al. (2014) developed a method for error modeling for TLS. The estimation of errors affecting measurement is based on the two most significant factors: measurement distance and angle of incidence. The Monte Carlo simulation allows the analysis of the spatial distribution of errors on the point cloud made during the measurement of a section of a pipe. Based on their results, although the angle of incidence affects the quality of the point cloud when the scanner is close to the side of the tube, this effect is offset by the density of points (whose relative position is within the error limit) when fitting the surface (Roca-Pardiñas et al., 2014). Julin et al. (2020) studied the colorization quality of the point clouds of the TLS instruments (Leica ScanStation P40, Faro Focus S 350, a Leica RTC360, and Leica BLK360). The photographic reference dataset was collected using a Nikon D800E digital single-lens reflex (DSLR) camera with a Nikkon AF-S 14–24 mm f/2.8G lens. The results showed apparent differences between the tested scanners in all measured quality aspects (color difference, white balance error, sharpness, Shannon information capacity, and signal-to-noise ratio). They derived a relation between colorization quality and scanner speed diagram (Julin et al., 2020).

Fan et al. (2015) studied the target-based registration of TLS measurements. Their study proposed a new method to evaluate the 2D transformation error of point clouds compared to the methods applied so far. They claimed that the proposed solution could aid in planning TLS surveys where a minimum accuracy requirement is known and used for subsequent analysis of the uncertainty in TLS datasets (Fan et al., 2015). Suchocki (2020) compared the usability of phased-based (Z + F 5016 IMAGER, Faro Focus3D) and time of flight (Riegl VZ400i, Leica ScanStation C10) terrestrial laser scanners in the context of intensity-based crack, cavity, moisture, and biodeterioration detection. The study concludes that the used PB scanners provide much more information about the tested surface's physicochemical properties than the used TOF scanners (Suchocki, 2020).

The inherent measurement difficulties of metallic surfaces have been highlighted in several previous studies. Thörnberg and Amir (2017) have developed a robust high-precision measurement technique that combines the tools of scanning and photogrammetry. Boesemann et al. (2000) presented the applicability of photogrammetric measurement techniques for quality control in sheet metal production. However, besides the surface treatment, certain steel sections may be of interest because of their geometric design, such as I-beams, U-beams, and angled beams in solutions such as the extraction of steel design structures from an integrated point cloud developed by Burdziakowski and Zakrzewska (2021), or the automatic 3D modelling of metal frame connections from LiDAR data presented by Cabaleiro et al. (2014). It is important that measurements are made with high accuracy, with few outliers in the initial data.

The primary objective of the study is to investigate terrestrial laser scanning measurements of steel sections. In this context, unlike previous studies, which have typically dealt with flat surfaces, in our study the significant influence of the geometry of the measured object is present in all cases. The elements were measured in different predefined scenarios to represent real-life cases. The scanners were chosen to include older (10+ years old construction), newer (<3 year old construction) and specific high-precision instruments for our study. The methods chapter describes the three TLS, the measurement arrangement, and the steps taken to move from raw point clouds to individual analyses. The results and conclusions present the main findings and considerations that can be drawn from the tests, considering the different similar measurement arrangements.
Materials and Methods

Applied devices and post-processing workflow

An inspection method was developed to investigate the effects of the steel section’s measurement setups on the scanning accuracy of the used instrument by comparing and qualifying three different TLS instruments. For this study, the Leica HDS 7000, Leica RTC 360, and Surphaser 400 (Leica Geosystems, HDS7000 Laser Scanner, 2011; Surphaser Software Basis, 2017; Leica Geosystems, Leica RTC360 3D Reality Capture Solution) were used to measure four different steel sections with distinct surface properties (Table 1). The instruments tested include a HDS 7000, and older scanner that has seen a lot of use (but regularly maintained), a Surphaser 400, designed for high-precision measurements, and an RTC 360, a newer model boasting fast and efficient measurements.

The test subjects were placed at two predefined distances (2 m and 10 m) at 12 positions based on their rotational axis (0°, 10°, 25°, 50°, 65°, 80° around the vertical axis and 0°, 45° on the horizontal axis. In addition, the scans of the Leica HDS 7000 and Surphaser 400 were performed in two quality modes, which affects the measurement time of one point. The three TLSs used during the scan process have slight differences in their technical parameters, while their cost and release date significantly differ. One of the study aims is also the confirmation or refusal of the measurement performances stated in the technical description of both manufacturers. The results obtained from TLS measurements were compared with a three orders of magnitude more accurate surface model measured with a structured light scanner (Breuckmann Smartscan 3D HE). The accuracy of the laser scanners is in the millimeter range, while that of the Smartscan is in the order of microns, making it an excellent benchmark for inspection. Point clouds from TLS measurements were also compared with cross-sections of international standards.

<table>
<thead>
<tr>
<th>Table 1. Features of applied TLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
</tr>
<tr>
<td>Distance Measuring Methods</td>
</tr>
<tr>
<td>Wavelength</td>
</tr>
<tr>
<td>Laser class</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Accuracy*</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Range noise**</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

* While accuracy indicates how close a measurement is to its true value, uncertainty takes into account any statistical outliers that don’t conform.

** Ranging Noise is described as a standard deviation of values about the best-fit plane.

A large amount of data was generated during the measurements making processing and evaluating difficult and time-consuming and would lead to human error in many places. Therefore, the process was automated using a Matlab routine (Figure 1). The program consists of six modules connected by a main
program, and several additional functions were also generated. The program execution consists of three main steps:

- Loading point clouds and input data, defining directories.
- Carrying out the transformation between the measured TLS point clouds and the reference model.
- Performing analyses, calculations, creating and saving result figures.

Figure 1. Workflow of the analysis, where M indicates the MATLAB functions

Measuring arrangements

In the case of Leica HDS 7000 and Surphaser 400, the measurements were performed with two different quality settings (“normal” and “premium”). For terrestrial laser scanners, the higher quality setting allows a point to be measured for longer, resulting in a more reliable determination. Such configurations are not available in the RTC, the scans were taken with three different resolutions (low, medium, high). The four sections differ in terms of geometry and surface properties (Figure 2). Section 1 is an IPE 270 standard in which the surface has not been treated, section 2 and 3 are of the IPE 300 standard, section 2 had no surface treatment, while section 3 had its surface painted. An IPE beam is a structural steel section with a characteristic ‘I’ or ‘H’ shape.

Figure 2. Measured steel specimens: (a) Section 1 IPE270 no surface treatment; (b) Section 2 IPE300 no surface treatment; (c) Section 3 IPE300 painted
The test subjects were placed at two predefined distances (2 m and 10 m) at 12 positions based on their rotational axes (0°, 10°, 25°, 50°, 65°, 80° around the vertical axis and 0°, 45° on the horizontal axis (Figure 3). Unique codes were introduced to clearly identify the measurement results, for example, in case of Section 1 HDS_D02_A00_N_00:
- Section 1: Section type
- HDS: Scanner type
- D02: Range
- A00: Horizontal rotation
- N: Quality in case of HDS and S, and resolution if RTC
- 00 Vertical rotation

To analyze the point clouds measured by the four TLS setups, it is necessary to make a reference measurement with an instrument that has significantly higher accuracy. For this reason, a structured light scanner was chosen, which can achieve results with an accuracy three times higher than the TLS used. The accuracy of this instrument depends on the applied optics; in the case of this study, the M-450 ensured 28 μm accuracy.

Pre-processing
The SLS scanner models were primarily delineated to retain only those visible parts in the TLS measurements and then resampled. This is done to produce more manageable surface models that ensure a faster and more reliable algorithm run. In the case of plate-like structures, when matching a point cloud mapped from only one side, the algorithm often considers both sides of the element, which leads to a matching error, which can be eliminated by considering the surface normal. The object under study had to be cut out of the environment manually during pre-processing.

Processing of the measured data
After the pre-processing of the measured data, there were 505 point-clouds in total. For this reason, it was inevitable to make a script to automate the analysis process, which is composed of three main steps: defining input and user parameters, the transformation of the point clouds, and numerical analysis.

Terrestrial laser scanners record the results of each position in the scanner-centric coordinate system; however, the orientation of the axes of each section is slightly different, so the first step in processing must be the transformation of the point cloud of the specimen to the reference model. This process consists of two steps for each measurement file. First, a robust plane fitting was done on the ridge as it is the element of each section that contains the largest amount of points. The purpose of using this plane was to direct the procedure to consider the points formed from the belts to be rough defects. Working with the normal of this plane and the center of gravity of the point cloud, using the transformation functions of MATLAB, the point cloud was
placed near the reference model (Mathworks, 2015). Then a final transformation was carried out using ICP (Iterative Closest Point) algorithm with a preset iteration step limit. Typically, these steps ensured 1 mm RMS for the measurements with low noise levels. During the comparison of reference and the measured data, a threshold to filter out the noise was determined (±1.5 mm), statistical analysis was carried out (minimum, maximum, mean, median, mode, and standard deviation), and several sections were defined along the specimens to evaluate the deviations. The relative noise could be calculated for every measured data based on the derived mesh to point cloud distances.

Since the standard cross-sectional information was available for the measured specimens, their deviation could be estimated. To achieve this, multiple 2D cross-sections were determined based on the measured points, which were defined in the first step of the analysis. For every case, a figure is created showing the position of every cross-section for each specimen. The points were grouped into three categories (upper flange, web, and lower flange), lines are fitted on each segment to calculate the measured internal height and width. To increase the accuracy of the line fitting, the rounding or at the edge of the flange has been excluded from the process. The deviation from the standard width and height is plotted on an error diagram, and the distribution of the deviation from the standard cross-section is plotted on a boxplot diagram.

Results

Terrestrial laser scanners record intensity values based on the strength of the returned signal. The intensity value is influenced by many factors: light conditions, surface treatment and the properties of the instrument. Based on previous research, surfaces composed of different materials generate varying levels of noise in the point cloud, Tan et al. (2018) also presented this phenomenon in their research. In case of specular reflection, the anomaly of intensity highlight occurs in such a way that the point cloud burns out in parts in the intensity image (Tan et al., 2018). Other studies had shown such phenomenon, where various surfaces with different reflectivity, colors, materials have been measured (Voegtle et al., 2008; Voegtle and Wakaluk, 2009).

As shown in Figure 2, in our study the sections have been scanned in multiple measurement arrangements. The goal with these arrangements was to investigate the effect of the surface treatments, the changes in the angle of incidence, the distance, and the shape of the sections.

The scanning quality, the rotations, and the tilting of the specimens had similar effects on the intensity values of the point clouds regardless of the surface treatment; however, the distance indicates unambiguous trends just in the case of specimens without surface treatment (Figures 4-7).

- The rotation angle is inversely proportional to the intensity values in all cases.
- The distance is directly proportional to the intensity values in the case of the steel surfaces that have not undergone treatment.
- Higher quality settings results in greater intensity values in the case of the Surphaser measurements.
- The 45° tilted specimens show smaller intensity values.

![Figure 4. Shifts in the intensity values: different rotation angles for each scanner, not tilted element at 2 m distance](image)
Figure 5. Shifts in the intensity values: different rotation angles for the HDS and Surphaser scanner, not tilted element at 2 m distance, with high quality setting.

Figure 6. Shifts in the intensity values: different rotation angles for each scanner, not tilted element at 10 m distance.

Figure 7. Shifts in the intensity values: different rotation angles for each scanner, tilted element at 2 m distance.

As other research has also shown, the specular reflections can lead to the intensity highlight phenomena, which leads to large distance measurement errors, and to the loss of points in the cloud. Investigations revealed that the Surphaser 400 is highly sensitive to the specular reflections. In case of the painted sections, high incidence angles (greater than 65°) cause high intensity peaks, and the ranging accuracy deteriorates significantly. Figure 8 also demonstrates that when the section was rotated by 10°, the noisy area translates in a direction opposite to the rotation, which indicates the phenomenon of intensity highlight at 2 m, meanwhile at 10 m this anomaly occurs to a lesser extent. However, such behavior did not only occur in this circumstance but also in the case of the untreated surface, where the reflecting surface acted as a specular reflector (e.g., Section 1 S D02 A00 N 80).
Based on the measurements, the intensity values do not provide enough information to clearly identify the noisy points. High intensity points can be just as likely to be erroneous as lower intensity points. Further analysis is provided by comparing point clouds with the reference surface model. Based on the specified error level (±1.5 mm), data points and noise points can be separated, and ratioed out. The measurement setups affect the three scanners differently.

The surface treatment (paint) had the most noteworthy impact on the Surphaser 400’s result; however, increasing the quality of the scan showed a clear improvement on the results (Figure 9). This manifests itself in several cases, while for the untreated surface, closer measurements give low noise levels for the orthogonal element position, in the treated surface case, the greater distance gives more favorable results. Furthermore, in the case of specular reflection, there are spiking noise levels, which are mainly observed for the painted surface (Figure 10). The tilting of the element led to a higher noise level at 2 m; however, at 10 m this trend could not be observed at every rotation angle. No clear trend was observed between the change in the rotation angle and noise level for the Surphaser 400.
In the case of Leica HDS 7000, the sections’ geometry had the most significant impact on the point cloud, the other scanners are less sensible to the object geometry, e.g., points are reflected better from the edges. In the tilted position, defective points were formed at the edges of the element which significantly altered the measurement results (Figures 11-13). As increasing the angle of rotation in this position gave a better view of the element, the flanges did not overlap the web, decreasing the noise rate. In these measurements case, increasing the distance from 2 m to 10 m raised the noise levels regardless of the surface treatment and the
tilting of the elements. The scan results did not show a significant increase in quality, and in some cases the noise level was higher.

**Figure 11.** Noise rate in case of the Leica HDS 7000 measurement for the upright positioned sections (normal and premium quality)

**Figure 12.** Noise rate in case of the Leica HDS 7000 measurement for the tilted sections (normal and premium quality)
Figure 13. Effect of the tilting of the element Leica HDS 7000, left: upright, right: tilted position

In the non-inclined position, the signal returns orthogonally from the element’s web, and therefore the noise level increases, as in the paper of Soudarissanane et al. (2009) (Soudarissanane, Lindenbergh, Menenti, & Teunissen, 2009). The amount of noise increases slightly then drops back down at 50°, and finally, it increases drastically around 65°. While in the tilted position, this case could not occur, and therefore the noise level decreases during rotation. The RTC measurement results are the most consistent of the three instruments (Figures 14 and 15). Both the surface treatment and the tilting of the sections had the least significant effect on this instrument; nevertheless, between the three scanners, at a 45° tilted position, the geometry of the element has a greater impact on the noise level than the rotation of the element and therefore the increasing noise level is not clearly evident (Figure 16).
Figure 14. Noise rate in case of the Leica RTC 360 measurement for the upright positioned sections (medium resolution)

![Figure 14](image)

Figure 15. Noise rate in case of the Leica RTC 360 measurement for the tilted positioned sections (medium resolution)

![Figure 15](image)

Figure 16. Effect of the tilting of the element Leica RTC 360, left: upright, right: tilted position

![Figure 16](image)

It should also be noted that the angle of incidence may vary significantly in different parts of the measured object, even within a given measurement; for example, while the angle of incidence on the ridge surface of the sections increased during rotation, it decreased on the end face of the sections, so that two intertwined effects may appear in the results. Because of this geometry, which has not yet been tested separately, we have not been able to consistently get back the results of the previous research.
The standard cross-sectional dimensions derived from the point clouds with all three scanners deviates the most from the correct value at positions tilted at 45 degrees. For RTC, even the larger distance causes uncertainties in determining the cross-section (Figure 17).

**Figure 17. Deviation from the standard section**

**Discussion**

Terrestrial laser scanners are playing a major role in many areas of the industry and are becoming increasingly important. During the construction of a building, TLS instruments appear in almost every stage. The measurement accuracy of instruments is affected by several factors. These can be internal, technical parameters as well as external factors, e.g., the angle of incidence of the laser beam, the surface property of the object to be measured, and the distance between the instrument and the object. These effects have been investigated several times by researchers and trial measurements have demonstrated what anomalies may occur in their point clouds; how remote measurement accuracy deteriorates (Kaasalainen et al., 2005; Suchocki, 2020; Voegtle et al., 2008; Soudarissanane et al., 2009; Tan et al., 2018). It is no coincidence that a lot of research has been done on the subject, as an in-depth knowledge of these phenomena is essential for accurate and reliable measurements and the future development of instruments.

In contrast to previous research, our study focused on the measurement of steel elements widely used in civil engineering practice (Kaasalainen et al., 2005; Gross et al., 2008; Voegtle et al., 2008; Soudarissanane et al., 2009). Four sections were measured by terrestrial laser scanners in different positions. After automatic analysis of the obtained data, conclusions can be drawn about the influences on the measurement (e.g., measuring range, incidence angle, measure quality).

The study shows that the TLS plays an important role in steel element measurements with high precision requirements. Although the scanners under investigation are somewhat similar in their distance measurement characteristics, the individual measurement factors have different effects on the resulting point cloud. Since the measurement of steel structures can only be fully performed if scanning from varying angles around the element, noise in the point clouds must be considered in all cases. However, intensity peaks, which are vital in the case of the Surphaser 400, for example, can be filtered out by an intensity threshold during pre-processing. The correct choice of the object distance can reduce the noise level. In other cases, independent revisions of the positions are required before the whole point cloud is produced. In the case of unfavourable incidence angles, the complete deletion of the affected element part may also be considered. While the distances and angles of incidence tested were not pushing the limits, there were still large differences in each case. Our
results prove that terrestrial laser scanning effectively supports the quality control of fabrication and construction of structures built from standard steel elements.

**Authors’ Contributions**


**Acknowledgements**

The research reported in this paper was supported by BOSS5D project under grant agreement No. 2017-1.3.1-VKE-2017-00040 (2018-2021). Application of networking technologies in the field of design, manufacturing, assembly, maintenance, and related services of steel structures.

**Conflict of Interests**

The authors declare that there are no conflicts of interest related to this article.

**References**


The journal offers free, immediate, and unrestricted access to peer-reviewed research and scholarly work. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, or use them for any other lawful purpose, without asking prior permission from the publisher or the author.

License - Articles published in Nova Geodesia are Open-Access, distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) License.

© Articles by the authors: Licensee SMTCT, Cluj-Napoca, Romania. The journal allows the author(s) to hold the copyright/to retain publishing rights without restriction.

Notes:
- **Material disclaimer**: The authors are fully responsible for their work and they hold sole responsibility for the articles published in the journal.
- **Maps and affiliations**: The publisher stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- **Responsibilities**: The editors, editorial board and publisher do not assume any responsibility for the article's contents and for the authors' views expressed in their contributions. The statements and opinions published represent the views of the authors or persons to whom they are credited. Publication of research information does not constitute a recommendation or endorsement of products involved.