The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-5/W3-2025
International Conference Applied Photogrammetry and Remote Sensing for Environmental and Industry
„APRSEI – PHEDCS 2025, Tashkent“, 23–25 September 2025, Tashkent, Uzbekistan

Application of Terrestrial Laser Scanning for Geodetic Control of Industrial Facilities

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Keywords: Terrestrial Laser Scanning, Point Cloud, Three-dimensional Model.

Abstract

Industrial facilities regularly require reconstruction or replacement of individual elements. To solve such problems, design organisations are increasingly using digital 3D models, which are created using data from terrestrial laser scanning, among other sources. s an example, several facilities of “Kazzinc” LLP were examined, covering the entire workflow from field surveys to the final results. During laser scanning, the average error in point cloud alignment was no more than 7 mm, which meets the requirements for data accuracy between stations of no more than 15 mm.
The article highlights the advantages of terrestrial laser scanning (TLS), such as high measurement accuracy and reduced human error. The analysis of deviations from design specifications revealed potential conflicts, which helps to prevent delays and additional costs.
Despite these achievements, the main limiting factor remains the lack of regulatory and technical documentation in Kazakhstan governing the use of TLS. In conclusion, it is emphasized that the further development and standardization of TLS methods could significantly enhance the quality and safety of engineering works.

1 Introduction

At present, geodetic science and practice face an important task: to increase the efficiency of engineering and geodetic work at minimal cost. This requires the use of accurate and detailed geodata that can describe the situation with high precision. However, traditional geodesy methods and instruments have their limitations, such as poor visibility and a lengthy process of data acquisition and processing.
In this regard, many modern design and construction tasks require new approaches and technologies in geodesy. One such approach is the use of laser scanning (Seredovich, V. and Seredovich, A., 2011).
The use of laser scanning in manufacturing has many advantages. First, the data obtained in this way allows for a complete representation of the geometric parameters of an object, as well as its characteristics. Second, laser scanning is an ideal solution for many engineering and surveying tasks that require high accuracy and reliability. Thirdly, the use of laser scanning significantly reduces the human factor's influence on measurement results and increases safety during work (Kamnev and Seredovich, 2017; Shults et al., 2025).
Research into the capabilities of terrestrial laser scanners (TLS) will enable us to assess the relevance of using this modern device for solving various engineering and surveying tasks and to justify methods for performing field and office work on the industrial facilities studied.
The most promising area of application for laser scanning appears to be technical diagnostics based on the results of determining a number of parameters characterising the quality of structures and equipment, which can be briefly referred to as operational deviations of geometric parameters. Many geometric parameters are controlled using geodetic methods and measuring instruments (Seredovich et al., 2022).
This gives reason to refer to the measurement process with a short expression - geodetic control of engineering structures.
Thus, the introduction into production and wider use of laser scanning technology in solving geodetic control problems, as well as the development and research of methods for applying this technology, are highly relevant.
Engineering structures such as high-rise buildings, bridges, tunnels, foundations, and others are subjected to varying loads not only during the construction phase but also throughout their entire operational lifespan. This generally results in deformations and structural changes. It is therefore crucial to understand the mechanisms of deformation and to test various theoretical hypotheses regarding the behaviour of deformable objects, which is primarily achieved through continuous monitoring and structural analysis. First and foremost, this is related to ensuring the safety of controlled objects and guaranteeing their long-term operation. Monitoring the displacement and deformation of natural and man-made spatial structures and objects is one of the most complex and responsible areas of geodetic research. A comprehensive understanding of the types, characteristics and scales of structural deformations is fundamental to accurately determining their origin and subsequently assessing the occurrence of irreversible damage or partial destruction of structures (Vezočnik et al., 2009).
The main advantage of terrestrial laser scanning over other surveying methods is the large amount of data it provides, which allows for the detection of deformations that are significantly smaller than the nominal measurement accuracy of individual points (Gordon et al., 2007). In recent years, a number of studies have been published in which TLS technology has been used to monitor deformation processes. Dams, tunnels, bridges, towers and various buildings were considered as objects of study.
Research has been conducted on the monitoring of engineering structures, including buildings (Jaafar et al., 2017), dams (Li et al., 2021), bridges (Erdelyi et al., 2020), (Kermarrec et al., 2020), tunnels (Jiang et al., 2020), (Xu et al., 2020), stations (Acikgoz et al., 2017), pipe trestles (Ham et al., 2018), towers (Artese et al., 2020) and many others.
The main factor currently holding back this technology in the Republic of Kazakhstan is the almost complete absence of approved regulatory and technical documentation governing and

describing methods for conducting field and office work using terrestrial laser scanners. The only items mentioned in the official regulatory and technical documentation are a glossary for 3D scanning, a professional standard passport and professional cards.
In addition, poor-quality technical documentation negatively influences the results of laser scanner measurements. The presence of substandard technical documentation has the potential to exert a detrimental influence on the calibration process of laser scanners. In the event that the information regarding measurement errors is not precise, this has the potential to impede the process of setting up and calibrating the device. Consequently, the measurement accuracy may be compromised, a circumstance that is unacceptable when utilising a laser scanner.
This study examines the possibilities of using TLS for geodetic monitoring at industrial facilities of varying complexity.

2 Materials and Methods

2.1 Monitoring Object

Industrial facilities regularly require reconstruction or the replacement of individual structural elements. To address such tasks, design organizations increasingly rely on digital three-dimensional models, which are often created using terrestrial laser scanning data. The surveys were carried out using a Leica ScanStation P50 laser scanner.
As an example, several facilities of “Kazzinc” LLP were examined, covering the entire workflow from field surveys to the final results. “Kazzinc” LLP occupies an extensive area for its operations. This space includes mining sites, processing facilities, and related infrastructure, allowing the company to efficiently carry out its activities in the mining and metallurgy sector.

2.2 Assessment of structural element deformation of the portal building at the industrial site

The survey was carried out to assess the technical condition of the structural elements and to analyze the impact of defects on the load-bearing capacity of the structure.
The following structural components of the portal building were examined: prefabricated monolithic portal walls and steel roof beams. The general view of the portal building structure is shown in Figures 1 and 2.
During the laser scanning process, nine scanning stations were completed. Preliminary alignment (registration) of the point clouds was carried out directly in the field using Leica Cyclone FIELD 360 software. Final alignment of the point clouds was performed on a computer in Leica Cyclone Register 360.

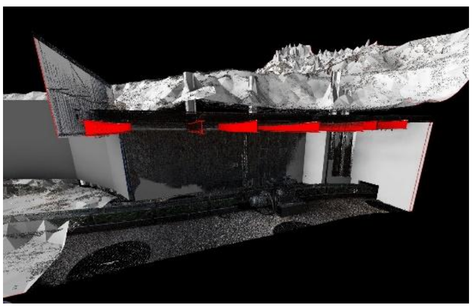

Figure 1. General view of the portal building structure.

Using laser scanning in the course of geodetic monitoring of industrial buildings in real time, the geometric characteristics of the studied objects were obtained. These data were acquired by a non-contact method, which makes it possible to monitor the condition of the structure at any convenient time.

Figure 2. Profile of the portal building structure

The main advantages of using terrestrial laser scanning (TLS) are as follows:
1.Completeness and comprehensiveness of the acquired data;
2.Applicability of the obtained information across various industries;
3.Reduction of labor intensity during measurements;
4.Minimal influence of the human factor on the final results;
5.High level of safety during field operations.
Processing of the TLS measurement results was carried out using Cyclone software. At the initial stage, the survey data had to be merged into a single point cloud model. Subsequently, segmentation of the areas describing the control elements was performed. In this study, the control elements are represented by three planes of the longitudinal and transverse stiffening ribs of the portal span structure (Figure 3).

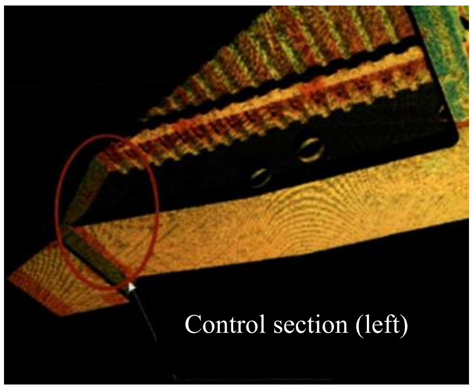

Figure 3. Control section of the portal building structure.

To determine the spatial coordinates, the «virtual point» coordination method was applied. This method is based on the intersection of three geometric origins, commonly referred to as «planes». To employ this method, the Grow Region function must be used. According to the results, the root mean square (RMS) registration error of the planes was 2 mm in all control areas.
To define the display of a three-dimensional coordinate, the «Extend All Objects» function must be used. In this way, the three-dimensional coordinate is determined based on the intersection of the planes. This procedure should be repeated for each span of the structure.
Based on the obtained three-dimensional coordinates, a graph is constructed showing the vertical deformation of the span

structure as well as the horizontal displacement relative to the launching trajectory (Figure 4).

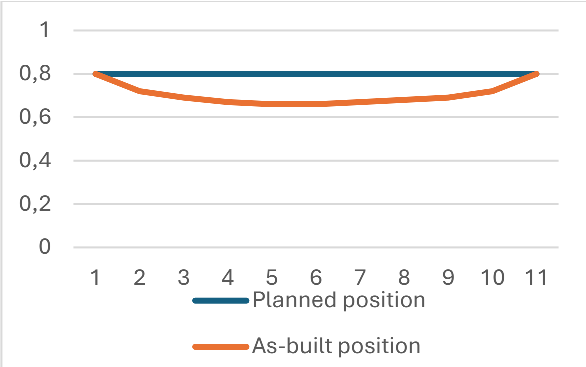

Figure 4. Graph showing vertical deformation of the portal building's superstructure.

The use of terrestrial laser scanning (TLS) in this study made it possible to obtain information on the geometric parameters of the load-bearing structures and to assess the vertical deformation of the portal beam span. Based on the results of the survey, decisions were made to dismantle the monolithic roof slab as well as the overloaded damaged roof beams.
Implementation of these measures restored the walls and roof structure of the portal to their original design configuration, eliminating the risk of collapse of the overloaded roof beams

2.3 Assessment of the geometric parameters of the roasting workshop building of the zinc plant

For the purpose of developing a working design project for the reconstruction of the roasting shop building at the zinc plant, terrestrial laser scanning was carried out (Figure 5)

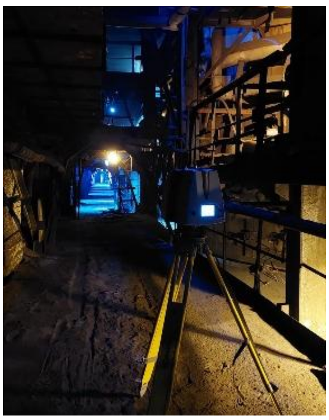

Figure 5. Scanning process of the roasting shop building section.

Laser scanning was performed using a Trimble M3 DR 2″ total station and a Leica ScanStation P50 terrestrial laser scanner. Distance measurement accuracy was 1.2 mm + 10 ppm over the entire operating range, while the angular accuracy was 8″/8 ″.
During the scanning process, 547 standing stations were completed, covering all engineering structures within the boundaries of the scanned area.
Preliminary adjustment (stitching) of point clouds was carried out directly in the field using Leica Cyclone FIELD 360 software. Final point cloud registration was performed on a computer using Leica Cyclone Register 360. The average alignment error of the point clouds was 7 mm. Registration of scan targets (for geodetic control network adjustment) was also performed in Leica Cyclone Register 360, with an average error of 5 mm (Figure 6).
The accuracy meets the requirements of the technical specifications, namely:
1 The accuracy of the mutual position of the data between the laser scanning stations is at least 15 mm.
2 The density of the laser scanning points provides a coverage grid of at least 3.1x3.1 mm on the scanned surface.

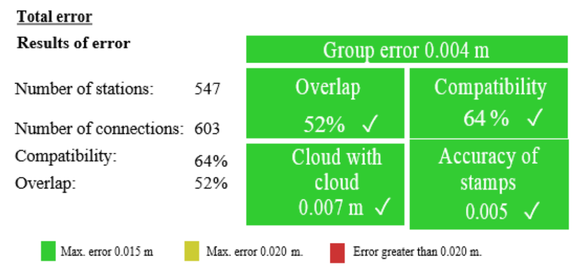

Figure 6. Results of point cloud registration (reconstruction of the roasting shop building at the zinc plant).

During final processing, the laser scanning data underwent a desk check, was filtered and cleaned of reflections (steam, water, etc.), as well as objects that were not related to the survey object and were not stationary. Work was carried out to coordinate the point cloud with respect to the survey justification.
Special black and white markers were coordinated to tie the point cloud to the survey reference points (Table 1).

№	Name of points, kind of sign, type of center	Class, category	Coordinates X, У, m	High H, m class
1	2	3	4	5
Coordinate system “Zavodskaya”				
Height system “Lengidep”				
Control Points				
1	1612 – metal. note (footnote)	Second-order polygonometry	876,80 1098,12	299,087
				technical
2	1613 – metal. note (footnote)	Second-order polygonometry	886,43 1348,54	299,242
				technical
3	Target M5		854.743 1155.479	299.989
4	Target M6		869.227 1126.856	300.005
5	Target M7		834.892 1105.151	299.723
6	Target M8		776.060 1113.165	299.704
7	Target M9		773.254 1088.490	300.587
8	Target M10		877.845 1145.614	300.288

Table 1. List of coordinates of geodetic control points.

The office processing of terrestrial laser scanning (TLS) data for the creation of a three-dimensional model was carried out in the following sequence:
- Orientation of scans in the project coordinate system and export of the results into Leica Cyclone software.

- Construction of the digital model using Leica Cyclone software.

The pipeline modelling workflow is considered as an example. Pipeline modelling was performed along the outer contour of the insulation, with additional modelling of the actual pipe diameters. To optimize labour costs, the contour geometry of objects previously generated for the topographic plan was utilized. For pipelines, this geometry was represented by polylines describing their axes lying in a defined plane (Velizhev, 2008; Volkovich, 2007).

Leica Cyclone software has the necessary set of tools for editing polyline data. When using it, the actual position of each pipeline axis in space is displayed, and the curvature of the bends is drawn. In other words, the task is to create 3D polylines from 2D polylines. At the same time, the insulation diameter was immediately determined for each pipeline based on ground-based laser scanning data and using the appropriate tool.

The diameter was marked using Leica Cyclone software. The diameter of the pipeline was determined by measuring the distance between the inner and outer lines of the field sketch or process diagram. The resulting pipeline axes were then exported to AutoCAD software, where two pipeline models were constructed based on identical initial 3D polylines using the 'extrusion' technology of primitives along the axes.

In order to facilitate the working with multiple pipeline axes, they are distributed across thematic layers, in this case by purpose. The most effective approach to this process is to undertake it concurrently with the construction of polylines for the topographic plan. The advantage of this construction method is that the pipeline is a single object (i.e., it does not consist of a set of straight cylinders and bends between them) (Radzyukevich, et.al., 2012).

Let us consider the methods of modelling other objects in Leica Cyclone software. For building reconstruction, 2D polylines describing their contours were used. By means of Leica Cyclone tools, these polylines were converted into planes, which were then “extruded” to the required value corresponding to the building height derived from terrestrial laser scanning data.

Technological platforms were represented in a simplified form. Similar to buildings, planes generated from platform contours were “extruded” to the required distance and fitted in height to the corresponding point cloud. Stairs and platform supports were modelled in a semi-automatic or interactive mode using such primitives as cylinders and extruded planes. Railings and barriers of the platforms were represented schematically with 3D polylines, reflecting their configuration and height (Figures 7 and 8).

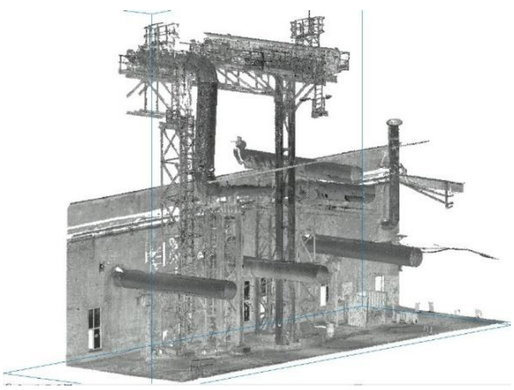

Figure 7. Fragment of the point cloud.

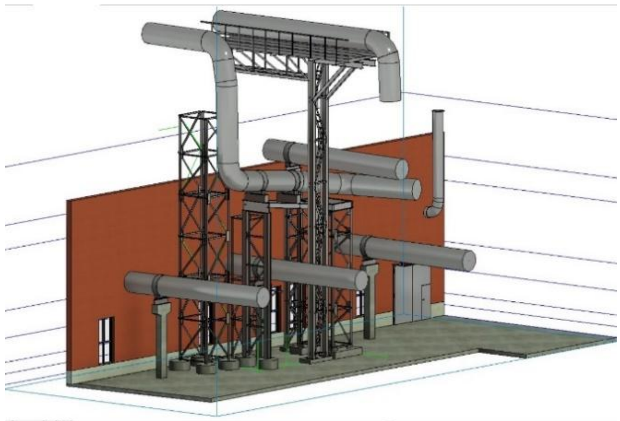

Figure 8. Fragment of the 3D modelling process.

An important component for reconstruction is the supports for pipelines and cable lines. These were modelled in an automatic or semi-automatic mode in a simplified manner while preserving their dimensions. Such elements of the trestle as cable shelves were modelled using a set of extruded planes, which were then duplicated and fitted to the corresponding point cloud (Figures 9 and 10).

Figure 9. Fragment of the point cloud.

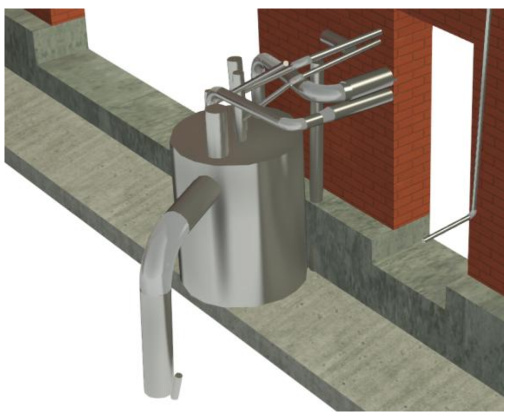

Figure 10. Fragment of the 3D modelling process.

Pipeline valves were represented schematically using the Valve primitive available in Leica Cyclone software. Lighting masts, fences, equipment, metal cabinets, and similar elements were

also modelled in a simplified form, while preserving their overall dimensions. Cable lines on the shelves were not modelled.
The results of this work demonstrated that the application of terrestrial laser scanning (TLS) technology is highly demanded, and this trend is expected to continue growing. Furthermore, during the construction of industrial facilities, design shortcomings related to collision detection frequently arise due to the high density of development. This often leads to time delays and increased labour costs (Seredovich, V. and Seredovich, A., 2011).

2.3 Analysis of the point cloud data with reference to the design model of the drying and absorption system

For the purpose of construction, monitoring of the drying-absorption system No. 3 at the sulphuric acid plant of UK MK LLP “Kazzinc” terrestrial laser scanning was carried out.
The survey was performed using a Trimble M3 DR 2″ total station and a Leica Scan Station P50 terrestrial laser scanner. The distance measurement accuracy was 1.2 mm + 10 ppm across the entire operating range, while the angular accuracy was 8″/8″.
Preliminary adjustment (stitching) of point clouds was carried out directly in the field using Leica Cyclone FIELD 360 software. Final point cloud registration was performed on a computer using Leica Cyclone Register 360. The average alignment error of the point clouds was 4 mm. Registration of scanning targets (for integration with the geodetic control network) was also performed in Leica Cyclone Register 360, with an average error of 5 mm
During the scanning process, 101 scanning stations were completed, covering all engineering structures within the boundaries of the surveyed area.
Preliminary point cloud alignment (stitching) was performed directly in the field using Leica Cyclone FIELD 360 software. Final point cloud alignment was performed on a computer using Leica Cyclone Register 360 software. The average error in point cloud registration was 4 mm. The registration of scan marks (for linking to the survey justification) was performed in Leica Cyclone Register 360 software. The average error was 5 mm (Figure 11).

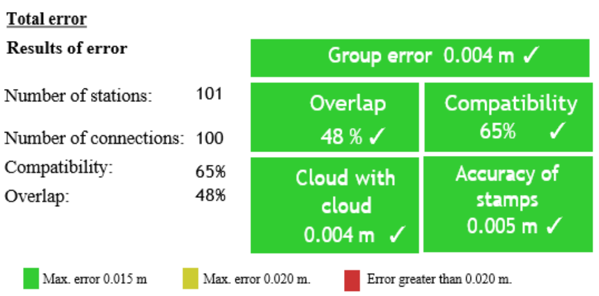

Figure 11. Results of point cloud registration.

The accuracy of the work performed complies with the requirements of the technical specifications.
During the final processing stage, the laser scanning data underwent office verification. The point cloud was filtered and cleaned of secondary reflections (caused by steam, water, etc.) as well as objects not related to the survey site and those that were non-stationary. Additional work was carried out to align the point cloud with the geodetic control network.
For this purpose, special black-and-white targets were coordinated and used to reference the point cloud to the survey control points (Table 2).

№	Name of points, kind of sign, type of center	Class, category	Coordi-nates X, У, m	High H, m class
1	2	3	4	5
Coordinate system “Zavodskaya”				
Height system “Lengidep”				
Control Points				
1	1612 – metal. note (footnote)	Second-order polygonometry	876,80 1098,12	299,087
				technical
2	1613 – metal. note (footnote)	Second-order polygonometry	886,43 1348,54	299,242
				technical
3	Target T1		779.154 1272.223	300.782
4	Target T2		788.221 1269.345	300.752
5	Target T3		833.677 1287.502	300.549
6	Target T4		849.152 1218.289	300.797

Table 2. List of coordinates of geodetic control points

The office processing for collision analysis based on terrestrial laser scanning (TLS) data was carried out in the following sequence:
- Orientation of scans in the project coordinate system and export of the results into Leica Cyclone software.
- Comparison of the design model with the actual point cloud.
Using laser scanning data and Leica Cyclone software tools such as «Measure Deviation» and «Edit Colors», an analysis and comparison were performed between the design model and the actual point cloud. Color maps were applied to the analysed objects, and labels indicating deviations from the design were assigned.
Deviations within the specified tolerance were marked in green, while deviations outside the allowable tolerance were marked in red (Figure 12).

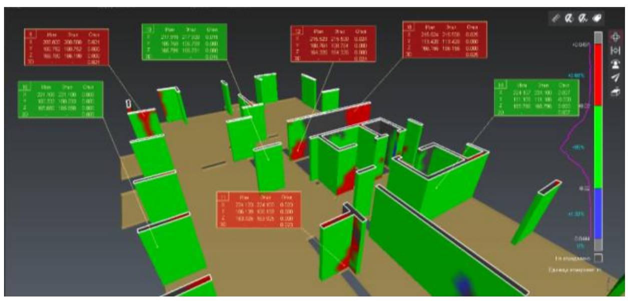

Figure 12. Deviation analysis.

To enable Cyclone 3DR to interact with cloud-based construction and operation management solutions (BIMTRACK, Solibri, Revizto, BimCollab, OpenProject, BimSync, Dallux, etc.), the open BCF format must be used. This format is used to export marks with deviation values, model element ID coordinates, configured views, and comments from Cyclone 3DR (Seredovich et al, 2011).
The collision analysis tool is designed to identify intersections between 3D model elements and point clouds. It can be used to quickly and clearly identify all possible design errors before the construction stage. This can reduce potential financial losses and time costs.
The point cloud, coloured based on the analysis, reflects the most complete picture of the object's condition. Nevertheless, it can be used to create a 2D working drawing. This drawing will

have a classic appearance, designed in accordance with GOST standards. Another task is to search for missing elements. Fragment of a detected clash based on the comparison between the actual point cloud and the design model presents on Figures 13 and 14.

Fig. 13. Fragment of a detected clash based on the comparison between the actual point cloud and the design model.

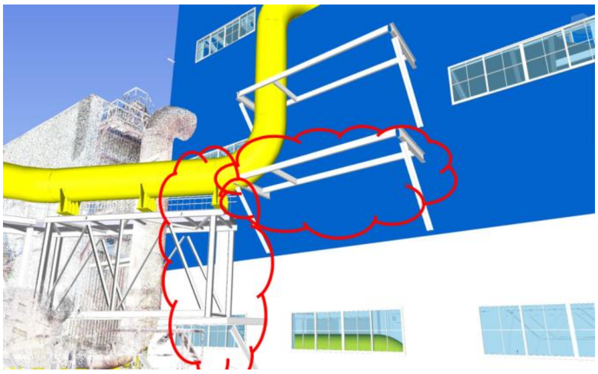

Fig. 14. Fragment of a detected clash based on the comparison between the actual point cloud and the design model.

After analysis, a report can be generated with a list of elements involved in collisions for subsequent determination of the status of each collision (Fig. 15).

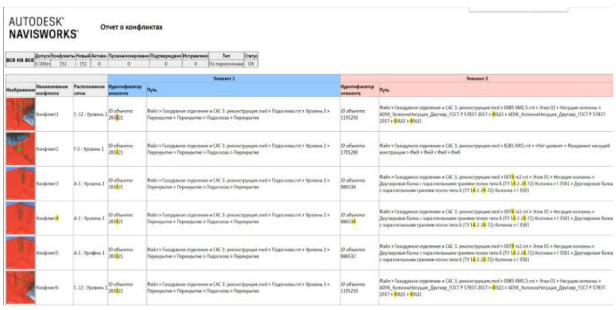

Figure 15. List of elements involved in collisions.

To take measurements at collision points and make a decision regarding the conflict, move the cursor over the selected conflict in the list and press the left mouse button (Figure 16).

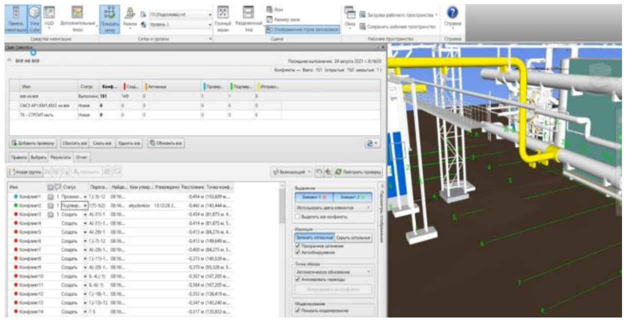

Figure 16. Analysis of Deviations from the Design.

The work carried out has demonstrated that the use of terrestrial laser scanning (TLS) technology for collision analysis is highly relevant, since the traditional approach is associated with the following issues:
- numerous collisions when integrating different project sections;
- lack of access to up-to-date information.

The application of TLS at construction sites enables the prompt identification of deviations from design solutions and potential collisions, which helps to avoid delays in project implementation and additional financial costs.

Conclusions

The use of terrestrial laser scanning (TLS) at construction sites makes it possible to detect deviations from the design and identify collisions, which helps to avoid delays and additional costs.
However, the main limiting factor for this technology today is the near-complete absence of approved regulatory and technical documentation in Kazakhstan that governs and describes methodologies for conducting field and office work using TLS, which is critically important for improving geodetic monitoring practices.
Thus, the implementation of laser scanning technologies in engineering practice will not only enhance the efficiency and safety of operations but also provide a foundation for more accurate and reliable monitoring of structural conditions in the future.

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