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Application of terrestrial laser scanning to the development and updating of the base map

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Abstract: The base map provides basic information about land to individuals, companies, developers, design engineers, organizations, and government agencies. Its contents include spatial location data for control network points, buildings, land lots, infrastructure facilities, and topographic features. As the primary map of the country, it must be developed in accordance with specific laws and regulations and be continuously updated. The base map is a data source used for the development and updating of derivative maps and other large scale cartographic materials such as thematic or topographic maps. Thanks to the advancement of science and technology, the quality of land surveys carried out by means of terrestrial laser scanning (TLS) matches that of traditional surveying methods in many respects.

This paper discusses the potential application of output data from laser scanners (point clouds) to the development and updating of cartographic materials, taking Poland's base map as an example. A few research sites were chosen to present the method and the process of conducting a TLS land survey: a fragment of a residential area, a street, the surroundings of buildings, and an undeveloped area.

The entire map that was drawn as a result of the survey was checked by comparing it to a map obtained from PODGiK (pol. Powiatowy Ośrodek Dokumentacji Geodezyjnej i Kartograficznej – Regional Centre for Geodetic and Cartographic Records) and by conducting a field inspection. An accuracy and quality analysis of the conducted fieldwork and deskwork yielded very good results, which provide solid grounds for predicating that cartographic materials based on a TLS point cloud are a reliable source of information about land. The contents of the map that had been created with the use of the obtained point cloud were very accurately located in space (x, y, z). The conducted accuracy analysis and the inspection of the performed works showed that high quality is characteristic of TLS surveys. The accuracy of determining the location of the various map contents has been estimated at 0.02-0.03 m. The map was developed in conformity with the applicable laws and regulations as well as with best practice requirements.

Key words: base map, terrestrial laser scanning, cartographic material

1. Introduction

A map, as a basic source of information about land, is a depiction of the world on paper. The advancement of science and technology has led to the creation of digital maps, which have revolutionized cartography. The digitization of maps allows any land changes occurring over time to be updated without the need of producing an entirely new map. The latest, and continuously improved, surveying technology guarantee that surveys are carried out in a short time and that their results are characterized a high degree of accuracy. Terrestrial laser scanning (TLS) can be applied to the development of geodetic, cartographic, and architectural materials. Point clouds obtained from surveys can be used to continuously enhance and update the existing base map. In fieldwork, TLS offers a fast surveying rate and accurate results in the form of point clouds consisting of millions of points. Those point clouds constitute the method a scanner employs to measure the surfaces of landforms, buildings, structures, features and other items within its range. The purpose of this paper is to explore the potential application of TLS technology to the development and updating of the base map in accordance with the applicable laws and regulations as well as with technological requirements. This is achieved through description of the applied technology and of the process of conducting fieldwork and deskwork as well as through analysis of occurring measurement errors and accuracy analysis of the obtained results. The final verification measure was a field inspection including measurement checks and a comparison of the map that was developed with the one acquired from PODGiK.

1.1. The base map – development and updating rules

A map, as a depiction and representation of land, is a model of reality defined mathematically on a plane with the use of conventional graphic signs and descriptive information. It is a source of knowledge about the location of land features in space and about the Earth's vast expanses and surface. In order to preserve the right visibility in the selected format, a map is drawn to scale. The arrangement of map contents is possible thanks to land surveys referenced to a control network. The properly applied reference, coordinate system, scale, and signs should be able to ensure such qualities of a map as faithful representation of all land features, accuracy, thoroughness, cartometry readings, proper orientation, and readability. As a whole, it should be developed in an aesthetic manner and with care.

A map may also serve different purposes depending on the method of its execution, its intended use, the cartographic methods applied to its development, and the quantity and type of its contents. Maps can be classified according to the means by which they are developed, their contents, scale, or the form of representation they employ (Jagielski, 2008; Medyńska-Gulij, 2015).

There are a great many cartographic materials, with the base map occupying a distinct position among them as the Basic National Map. The Geodetic and Cartographic Law Act (Geodetic and Cartographic Law Act of 17 May 1989) provides that the base map is a large-scale cartographic material containing all the information about the spatial location of control network points, buildings, land lots, infrastructure facilities, topographic features, landforms, and land development as well as a lot of other graphic and descriptive data. This fundamental cartographic document covers the whole of Poland. Its contents are referred to by many sectors of the national economy, including land-use planning and zoning, property valuation for tax purposes, and cadastre, and are also used for land registry and strategic purposes. It is used by individual residents of Poland and many businesses for planning and construction purposes. It also serves as a basis for the development of derivative maps such as thematic or topographic maps.

The base map as a fundamental geodetic and cartographic material for the area of the whole country must be uniformly drawn, maintained, and updated in conformity with all legal requirements. The current Regulation on the database of topographic objects and the base map (Regulation of the Minister of Administration and Digitation of 2 November 2015) specifies the method for the editing, generalization, and visualization of land features constituting the contents of the base map as well as the kind of cartographic signs and descriptive information used for the creation of such contents.

Any land feature must be surveyed by means of accurate surveying instruments. Their high accuracy enables the development of a high-quality map which will constitute a representation of the reality in a digital or printed form. In order to ensure the right accuracy of surveys, land features are divided into three groups. The extent and accuracy of determining the spatial coordinates of features are specified for each group. Group I includes features that are unambiguously identifiable in a particular area and whose shape or position does not change over a long period of time, e.g. survey markers, border signs and checkpoints, buildings, and infrastructure facilities (provided they can be accessed directly for surveying). The second group includes land features that are unambiguously identifiable in a particular area and whose shape and/or position change over a period of years (embankments, excavations, levees, flood embankments, etc.). It also covers concealed buildings with equipment (including concealed infrastructure facilities) and land development features (parks, lawns, playgrounds, sports grounds, single trees, etc.). The last accuracy group includes objects whose identification is difficult and depends on the assessment of the surveying team, i.e. land use boundaries, watercourses, water basins, and forest sites. Individual features in a group must be surveyed in such a way as to ensure proper accuracy of their spatial location in relation to control network points. Position errors for individual land features cannot be greater than (respectively for each accuracy group): 0.10 m, 0.30 m, 0.50 m (Regulation of the Minister of the Interior and Administration of 9 November 2011).

1.2. Laser scanning as a source of information about land

Laser scanning is a technology which consists in first generating a light beam and then capturing it after it is reflected from an object in order to establish the object's spatial position as a set of points known as a point cloud. To achieve that, terrestrial laser scanning (TLS) relies on a system of rotating mirrors which steer the light beam. Individual points are registered as data containing their coordinates. The data also contains information on the value of the reflection and on its tone in the grayscale or as interpreted in with RGB components (Uchański, 2010). This photogrammetric measurement system enables a large quantity of comprehensive spatial data to be collected in a very short time. Depending on the type of the object being surveyed, a pulse or a phase scanner can be applied (Kraszewski, 2012).

TLS has been successfully used in various engineering and technological contexts. It is a common surveying tool for buildings, machines, and equipment. Cloud points can be a means of developing 3D models of buildings or even entire cities (Kraszewski, 2012). As its popularity has been increasing, the technology has also been continuously enhanced, and the data it yields has kept finding new and surprising applications. TLS can produce spatial data with an accuracy of a few millimetres. All the stages of surveying work contribute to the final achievement of such surveying precision, from taking actual measurements to registering and orientating the point cloud to processing it in order to attain the intended effect (Soudarissanane et al.., 2011). A lot of physical and empirical factors have an impact on the measurement error. These include rangefinder, collimation, inclination, or index errors as well as cyclical and random errors (Lichti and Licht, 2006). The accuracy of an obtained point cloud is also affected by the environment, i.e. the surroundings of the survey site, and by the nature of the surveyed object (texture, colour, building materials). The spot diameter of the laser also affects the accuracy of determining the spatial coordinates (x, y, z) of points. This directly translates into the magnitude of the edge effect and the accuracy of distance and angle measurements (Cosarca et al., 2009). The aggregation of all measurement uncertainties can lead to errors occurring during later geodetic or cartographic works. The choice of appropriate measuring positions and the location of targets are crucial issues. They should be located in such a way as to ensure maximum coverage and accuracy, while keeping the number of instrument setting configurations as low as possible. A proper set-up should also ensure a proper field of view. The distance to the scanned object cannot be too large so as not to exceed the instrument's operational range (VLAAMS Leonardo Da Vinci Agentscha, 2008).

No applicable laws or regulations provide for specific surveying equipment that should be used to obtain information about land features. What is laid down, though, are data acquisition methods and the accuracy that a survey must meet in order to conform with formal and legal rules (Regulation of the Minister of the Interior and Administration of 9 November 2011). The development and updating of maps with the use of point clouds is subject to the same rules which apply to the equivalent process involving total station data.

2. Base map development methodology

The development of the base map consists in the conduct of fieldwork intended to collect all the important information about objects located in a particular area. Surveys must be performed in conformity with applicable laws and regulations (Regulation of the Minister of the Interior and Administration of 9 November 2011). Data processing and mapping must be done in accordance with applicable standards as well as formal and legal guidelines (Regulation of the Minister of Administration and Digitation of 2 November 2015). Only if correctly drafted and thus containing reliable data, the base map can serve as a trustworthy source of information about land.

2.1. Characteristics of the survey site and description of the fieldwork

The first survey site is an urban residential area located in north-west Kraków (Bronowice Małe). The 1.5 ha area is covered with numerous trees and bushes impeding fieldwork. There is also an 11-storey building with grounds and auxiliary facilities, such as parking lots, access roads, pavements, green spaces, and playgrounds. After choosing the objects to be surveyed, a control network was established and measured with GNSS (Figure 1). The Root Mean Square Error (RMSE) of position

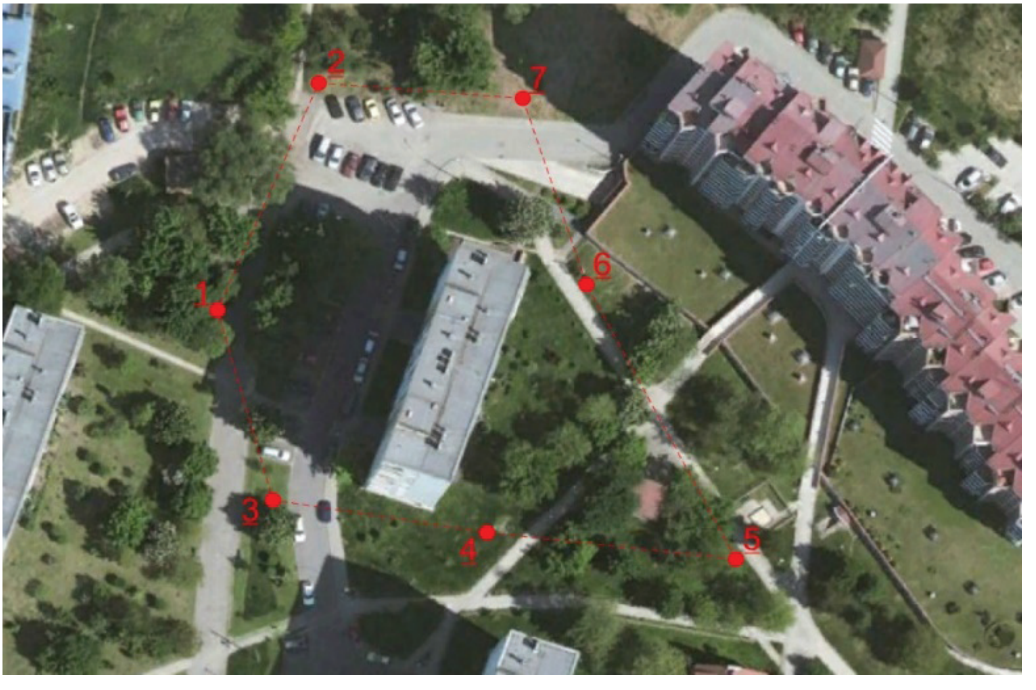

Fig. 1. The survey site with marked control network points

a control network point was determined to be ±0.03 m. Targets were placed on control network points and in auxiliary locations to be used later for merging and orientating the point cloud.
A Z+F IMAGER 5010 3D laser scanner was used to take measurements of the site from ten measuring positions. The scanning positions were chosen in such a way as to ensure that comprehensive data would be obtained on the objects within the site. The measurements were taken with high scanning resolution (3 mm/10 m) set up and during one complete rotation of the instrument. The locations where the targets had been placed were additionally scanned with the highest scanning resolution possible (1.5 mm/10 m). A high quality point cloud was obtained from each scanning position.

Also, photographic documentation was developed in order to complement the survey results, i.e. to allow all the objects within the site to be inventoried.

2.1. Description of the deskwork – preparing the point cloud and creating a map

The point clouds obtained as a result of the survey were merged with the use of the Cyclone software into one homogeneous item. A registration report from merging process was generated indicated an accuracy of ±0.005 m. Any point cloud is a permanent and geometrically immutable object, which is why this degree of accuracy refers to each single point within the cloud. In the next step, the targets placed on control network points were used to georeference the cloud. The degree of accuracy (RMSE on the matching points) of aligning the merged point cloud with the control network was ±0.002 m. After optimizing and unifying any duplicate points, the cloud was exported to the MicroStation environment, which was used to develop cartographic materials.

Creating a map with the use of a point cloud consisted in creating individual sections with set heights (Figure 2 a-c). The multi-view functionality enabled the process of selecting features to be controlled from a top view, a cut view, and customized longitudinal and cross profile views.

Land features which were to constitute the contents of the base map were mapped according to the skeleton lines of individual objects, buildings, trees, etc. Cloud settings enabled the determination of the centroids of the features, which were subsequently assigned conventional signs that indicated the type and nature of a particular object, e.g. a utility vault (storm drains, waterworks, gas, etc.) or other.

Assigned RGB values or greyscale tones are very helpful in finding land features. A point cloud can be displayed as a classification of and a change in colour dependent on the change in height (Figure 3). By using visible changes in height as well as characteristic shapes associated with such imaging, kerbs, roads, pavements, utility vaults, etc. were easily mapped.

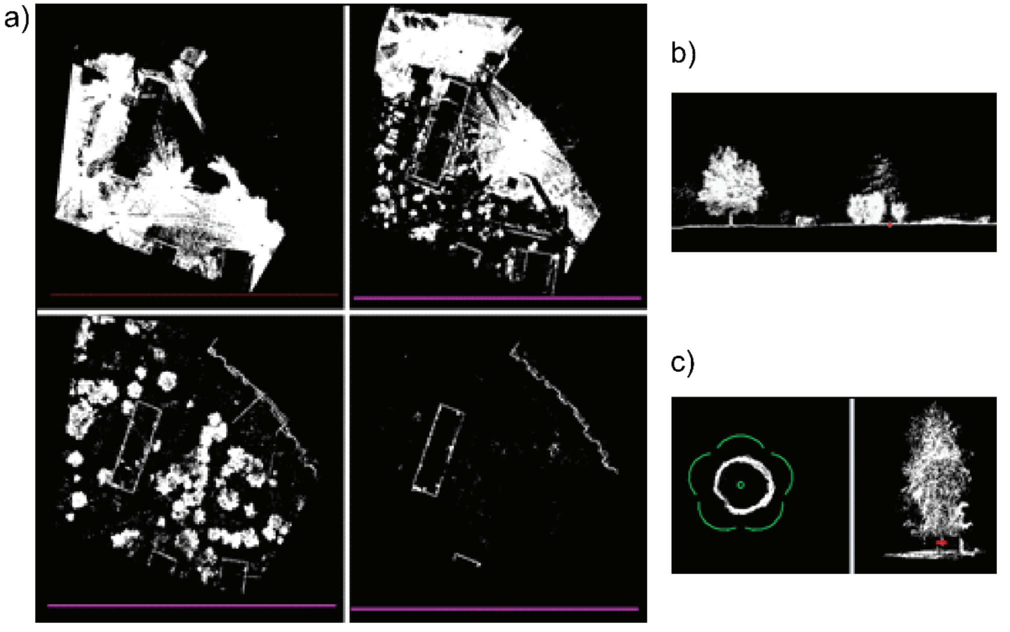

Fig. 2. Working on consecutive layers cutting the point cloud and marking land features on individual sections: a) creating individual sections with set heights, b) cross section of land, c) identification of the object

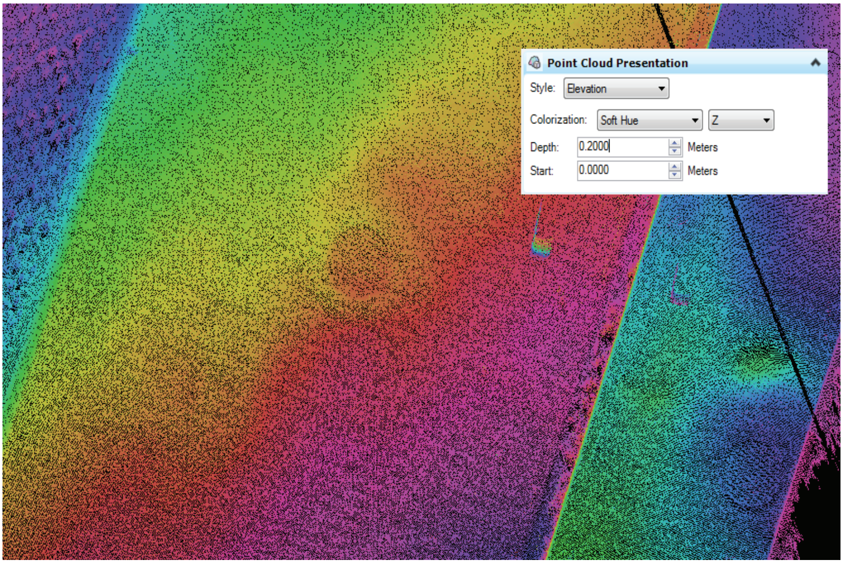

Fig. 3. Marking features with the use of information on the change in height and shape of individual points

The height coordinates of the terrain, utility vaults, road surfaces, and other features whose height must be indicated were obtained directly from the point cloud where each points had specific spatial coordinates (x, y, z).

Information about infrastructure facilities and cadaster information were obtained from PODGiK. The final result, i.e. a developed base map (Figure 4) has been saved as a computer file and can be shared for the purpose of further processing or can be printed out on paper.

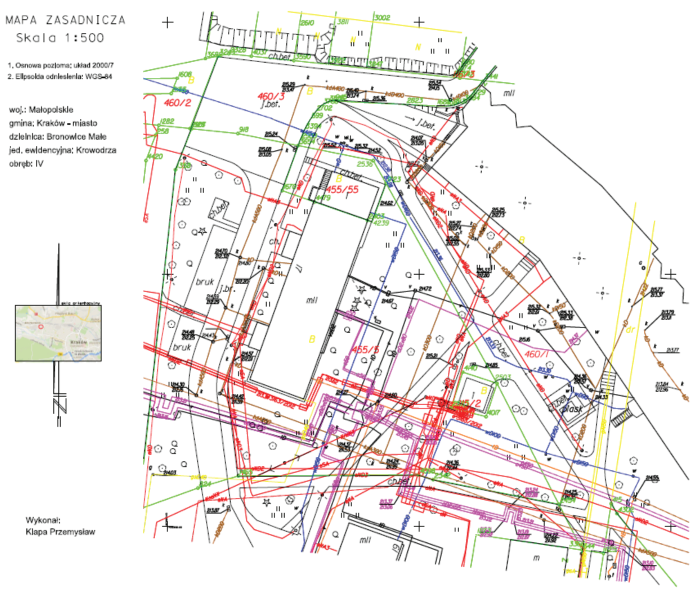

Fig. 4. The developed base map

2.2. Accuracy analysis of the obtained results and inspection of the conducted work

Accuracy analysis of the conducted work consisted in determining the mean position error for points (m_p), which was affected by a number of factors. In order to standardize the assessment of the horizontal and vertical accuracy of point clouds, the official "PUGW 2000" reference system uses the square root of individual mean errors:

- the RMSE of position for control network points – m_o = 0.030 m,
- accuracy of merging the point cloud and aligning it with the control network points – m_w = 0.005 m

$$m_p = \sqrt{m_o^2 + m_w^2} = \sqrt{0.030^2 + 0.005^2} = \sqrt{0.000925} = 0.03[m]$$

This accuracy refers to the position of the point cloud within the used spatial coordinate system (x, y, z). The RMSE for any point within the point cloud was 0.03 m. This value conforms with tolerance limits laid down in the applicable Regulation (Regulation of the Minister of the Interior and Administration of 9 November 2011 on the technial standards for the perfomance of horizontal and vertical geodetic surveys, for the processing of survey results, and for the transmission of survey results to the National Geodetic and Cartogrpahic Repository), which specifies a 0.1 m degree of accuracy for surveying group I land features.

The next step was intended as a means of inspection of the conducted work and consisted in a comparison of the developed base map with materials obtained from PODGiK (Figure 5). The contents of both maps are nearly identical. Minor details missing on the PODGiK map are single land features, e.g. trees, bushes, or playground fencing.

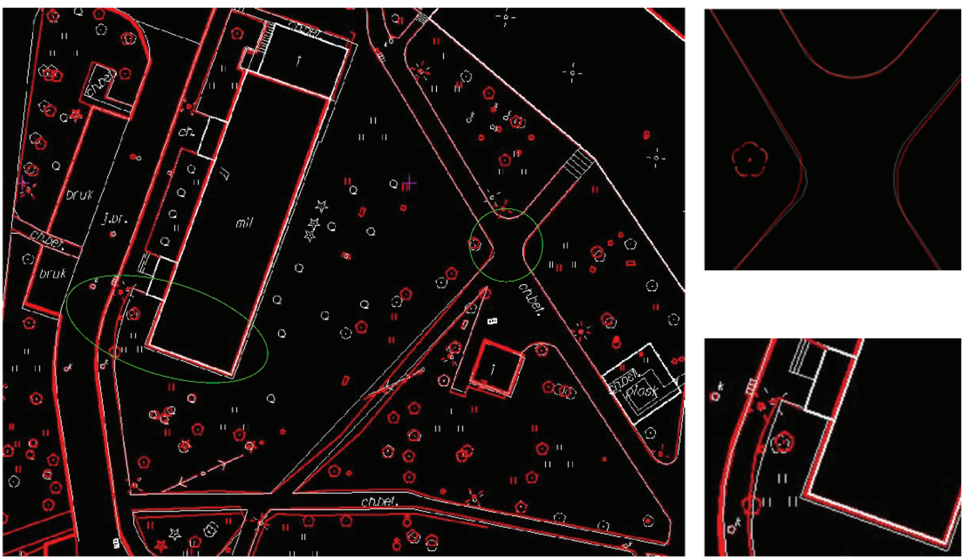

Fig. 5. Comparison of the contents of two base maps: one developed from the point cloud (white) and the second obtained from PODGiK (red)

At the following stage of the project, the contents of the map were compared to the actual land features existing in the area. The inspection consisted in applying measuring tapes to measure the distances between characteristic points and then comparing the obtained values to the ones read from the map. The following features were measured: tie distances for the buildings, distances between the corners of neighbouring buildings, the length of the fencing, the length and width of the parking lot, etc. The inspection measurements confirmed the correctness of the developed map, with any differences between the measurements being within the permissible tolerance limits (1–3 cm).

3. Base map updating methodology

The updating of the base map is one of the basic measures that ensure the reliability of information and contents of the map. A well-performed update enables any differences between the map and the reality to be corrected. Data are verified during fieldwork and when inconsistent or questionable features are surveyed.

3.1. Survey site and description of fieldwork

The survey site covered an area of undeveloped land plots in the Mydlniki district, north-west Kraków. The site is overgrown with vegetation and neighboured by roads, railway tracks, residential housing, and commercial and manufacturing plants. The surveying works consisted in the choice of measuring positions and taking measurements with a Leica P40 terrestrial laser scanner. Scans were taken from three positions, yielding 3 high resolution point clouds with additional data about colour parameters (RGB). The established control network was measured with GNSS. The obtained results were processed, and the RMSE of position points was determined to be 0.021 m. Targets were mounted on tripods and placed over control network points. These points enabled the different clouds to be merged into one that was subsequently georeferenced.

3.2. Updating the map drawing – deskwork and accuracy analysis

The imported individual point clouds were merged into one which formed a complete whole and underwent further processing. That point cloud was aligned with the control network points with the help of the targets, whose spatial coordinates (x, y, z) had been determined. The RMSE of merging the point cloud and aligning it with the control network points was 0.0016 m. The point cloud and the base map were uploaded to the MicroStation software. Having common coordinate systems, the two documents merged to form a whole (Figure 6).

The updating works are carried out according to the same guidelines as the ones described in the previous section concerning the development of the base map. By making the drawing on individual contour intervals and by using sections and different ways of displaying the point cloud, the locations which had been updated were determined.

The site was thoroughly inspected, and any effected changes were marked. The location of the sign indicating fencing was corrected. Features which no longer existed were crossed out. Trees and bushes, which had been missing on the base map, were added in the right spots. Lines marking buildings, roads, and other features located within the mapped area were inspected.

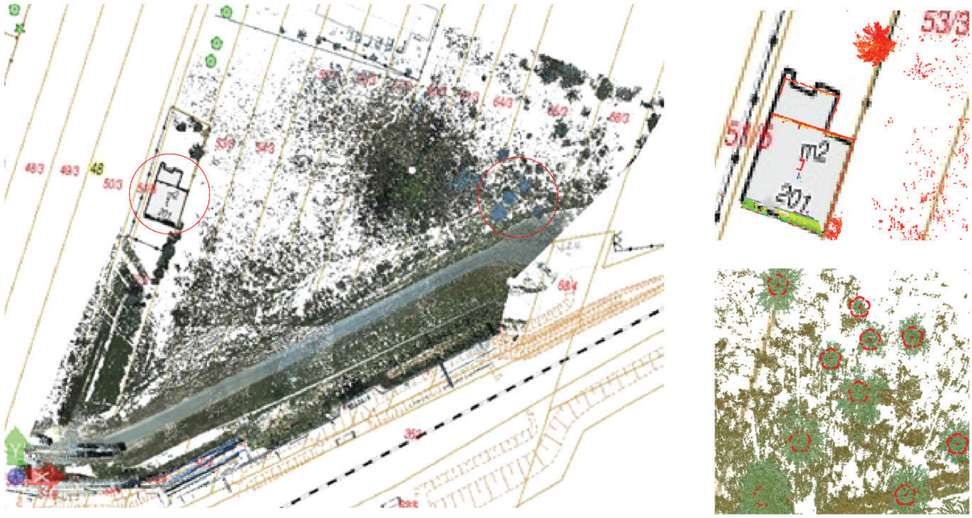

Fig. 6. The survey point cloud located on a map which is updated

The last step was an accuracy analysis of the obtained results. The RMSE of position for any point within the point cloud was determined by calculating the square root of the following mean errors:

- The RMSE of position for control network points – m_o = 0.02 m
- Accuracy of merging the point cloud and aligning it with the control network points – m_w = 0.002 m

$$m_p = \sqrt{m_o^2 + m_c^2} = \sqrt{0.021^2 + 0.0016^2} = \sqrt{0.000448} = 0.02[m]$$

The RMSE of point position was determined to be 0.02 m, i.e. to conform with requirements set for plane and vertical surveys intended to yield data about land features in a particular area. The updating of the base map is a crucial element of geodetic works as the base map serves as a base for the development of many derivative materials, including maps for planning and designing purposes.

4. Summary and conclusion

The conducted fieldwork and deskwork were intended as means of developing and updating the base map as well as a proof that a point cloud obtained through terrestrial laser scanning could be used to that end. Not only were the measurements taken at a characteristically fast rate, but also they were highly accurate and precise in terms of the spatial data yielded. Such kind of survey generate the geospatial data consist of millions of points translates into the development of a high quality base map which conforms with all formal, legal, and regulatory requirements.

Editing and updating the map with the use of a point cloud follows similar guidelines. The application of proper software enables the use of numerous projections and views as well as the creation of sections as needed. Updating work consists mainly in inspecting the existing items of the map contents and verifying any divergences. Applying this sort of spatial data ensures that all land features are complete and that the height coordinates of any points located within the survey site can be determined. A point cloud is a result of fieldwork and is a specific kind of a field drawing. When developing cartographic materials, we adhere to the space delineated by the point cloud, which precisely reflects the real world.

A survey based on a control network allows the point cloud to be highly accurately situated in the x,y,z space of a particular reference system. A base map developed from such a point cloud is a reliable source of information about land. An accuracy analysis of the individual materials allows the conclusion that a survey carried out with a terrestrial laser scanner can be used to develop geodetic and cartographic materials. The comparison of those maps with the ones from the Centre as well as the horizontal and vertical survey inspections also confirmed that the conducted survey and cartographic works met the required standard of accuracy.

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