The measuring of real state of the residential complex Vlčince II in Žilina by using of TLS technology

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Construction of blocks of flats Vlčince II in Žilina, realized by the building company Doprastav a.s., consists from two blocks A and B. For measuring of real status construction was used terrestrial laser scanner Leica ScanStation. Processing of measured data was applicated in software Cyclone Scan, Register and Cloudworx for Microstation. Through measured objects was created horizontal sections in more high levels. Founded deviations are presented in attached tables.

Key words: *terrestrial laser scanning, measuring of real situation, Leica ScanStation*

Introduction

The use of terrestrial laser scanning is becoming more applicable in civil engineering and related fields. In addition to close range photogrammetry, which is used for measuring of industrial buildings, facades, but also for monitoring of spatial changes of terrain and objects in time; especially terrestrial laser scanning is often used recently. Not only fast and comprehensive survey of objects and surrounding terrain is advantage of TLS, but also easy processing of measured data and final visualization of 3D models.

Construction of the residential complex Vlčince II in Žilina (working title Arboreum) was performed by the Doprastav a.s. construction company; it consisted of two residential blocks, but also of reinforced surfaces in the area, access roads and sidewalks, as well as reloading of networks or connection to different networks. The construction was carried out over a time horizon from April 2008 to May 2009.

Arboreum

The new residential complex and its residential blocks are situated on flat open area that is covered with grass and low greenery. The Vlčince II complex consists of 4 residential blocks with underground garage; blocks A and B were objects of realisation by Doprastav a.s. company. Purpose of the object is to create new residential units with community amenities. There are 60 dwelling units located in the object. Apartments are designed: 15pcs - one-room flat, 23pcs - two-roomed, 17pcs – three-roomed, 4pcs – four-roomed and 1 pcs – five-room apartment.

Fig. 1. Set of residential blocks Vlčince II in Žilina.

Mass-architectural solution of the residential complex is a reaction to urban planning and architectural design of the whole sector. The size, shape and character of the plot meet the requirements of the investor in terms of functional content of objects. Proposed residential blocks A and B were designed as L-shaped in the ground plan.

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Fig. 2. Set of residential blocks Vlčince II in Žilina under construction.

Technological construction of structure, in a simplified view, consist of 2 underground floors – monolithic reinforced concrete underground parking lot, 8 above-ground floors (NP) – on 1 NP commercial area, on other NP's standard dwelling-units and high standard units – monolithic reinforced concrete skeleton filled in with walling (with several load-bearing reinforced concrete walls and elevator shafts, of course).

Real state measurement of the Arborea realisation

Positional and vertical measurement of actual realisation of the residential complex was carried out by terrestrial laser scanner Leica ScanStation in April 2009.

Leica ScanStation scanner (Fig. 3 and Table 1) is full panoramic pulse scanner determining measured distance by the transit time – Time of Flight (ToF) technology, with instantaneous scanning speed up to 4000 points per second, with the accuracy of electronic total station, built-in digital camera, controlled by an external computer and control software Cyclone SCAN that allows to set scanning parameters as needed. Positional accuracy of individual points is determined by a priori mean error $\sigma_{xyz\ apriori} = 6$ mm.

Tab.1: Technical specification of Leica ScanStation

Technical specification of ScanStation	
Accuracy of single measurement	
Position /distance **Horizontal angle** **Vertical angle**	6 mm /4 mm 60 μrad 60 μrad
Modelled surface precision	2 mm
Range	300 m (90 % albedo) 134 m (18 % albedo)
Min. step of scanning	1 mm
Scan rate **Laser class**	20 000 points / horizontal 5 000 points / vertical 3R, green
Spot size	0-50 m ≈ 4 mm
Field of view	
Vertical **horizontal**	270° 0° - 360

Fig. 3. Laser scanner Leica ScanStation.

Joining individual scans into uniform coordinate system was realized in the REGISTER module of Cyclone software. Result of the registration processing is the Registration report, giving statistical results of the registration. The number of iterations performed for joining of individual scans was 500. Leica flat targets, supplied by the manufacturer, were used for the data registration.

Advantage of the ScanStation is 300 range m at 90 % surface reflectivity, high accuracy and minimum scanning interval of 1 mm.

Measurement and processing was performed in several stages. Field works consisted of preparatory works - reconnaissance of the locality to determine the optimal scan stations, signalisation of ground control points, scanning (Fig. 4). Office work consisted of the registration of individual scans into a single uniform coordinate system of the scanner, georeferencing or transformation of measured points into the JTSK system, removing unnecessary points and modelling of the facade surfaces by the method of point approximation with planar surfaces. Cross sections at horizontal and vertical planes defined by the investor were made through these final data (Fig. 9).

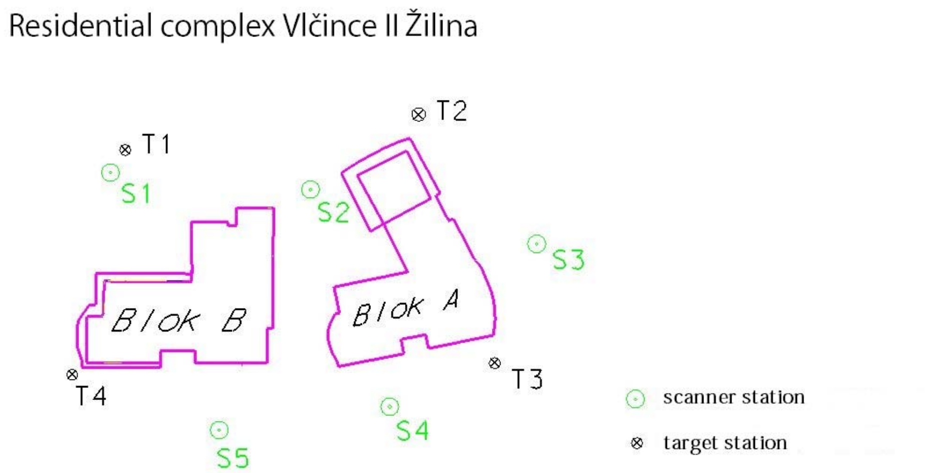

Fig. 4. Positions of scanner and targets.

Registration of scans

Registration is the transformation of multiple point clouds (scans) into a common coordinate system (CS), that is CS of a chosen scan [4] – i.e. global registration (Fig. 5). Since the measured objects were considerably spacious, the measurement had to be performed from four free stations and joined into a single CS with the origin located in electro-optical centre of the scanner at the first station. Leica flat targets were used as ground control points; positions of these targets were determined by the electronic total station Leica TCR 1203.

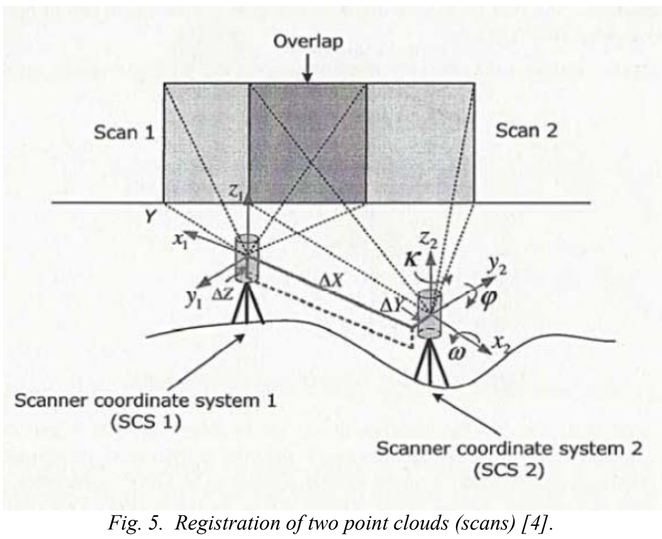

Fig. 5. Registration of two point clouds (scans) [4].

Registration on the basis of targets utilisation is the most common method for joining individual scans. In order to determine the 6 transformation parameters between scanner coordinate systems 1 and 2 (SCS1 a SCS2) we need to know at least 6 coordinates of 3 points that are located in the conjunctive overlay of both stations. The global registration is then computed as a result of a least square adjustment. [4] (Fig. 6).

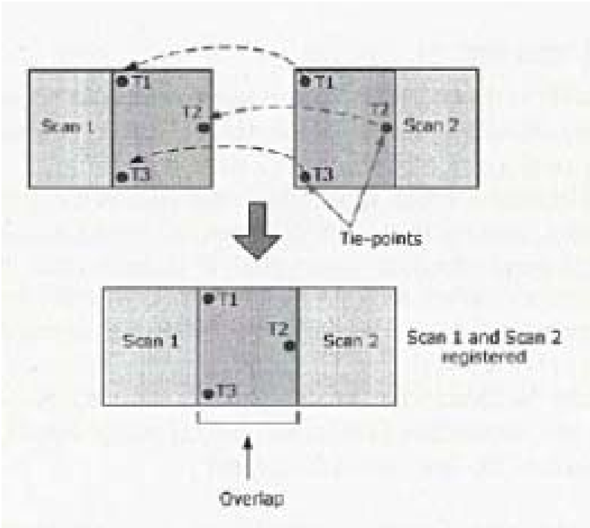

Fig. 6. Registration using targets [4].

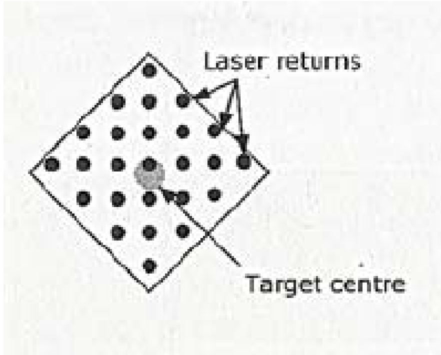

Fig. 7. Target reduction error [4].

In order to determine coordinates of targets centers with the highest accuracy, scanning of targets had to be done with the highest density, i.e. 1x1 mm. Coordinates of the center can be estimated from the number of reflected laser beam spots which cover target surface (Fig. 7). The process is called "centering the target". The inaccuracy of determining the center of the target increases with decreasing scan resolution of the target. The accuracy of determining the position of the target center achieved 1 mm.

Indirect georeferencing

Georeferencing is the transformation of the point clouds from the scanner coordinate system – after the global transformation, to the external coordinate system. This may be either a national or local system. In indirect georeferencing one can use of the targets with known coordinates in the external system [4]. It is therefore a two-step approach (Fig. 8).

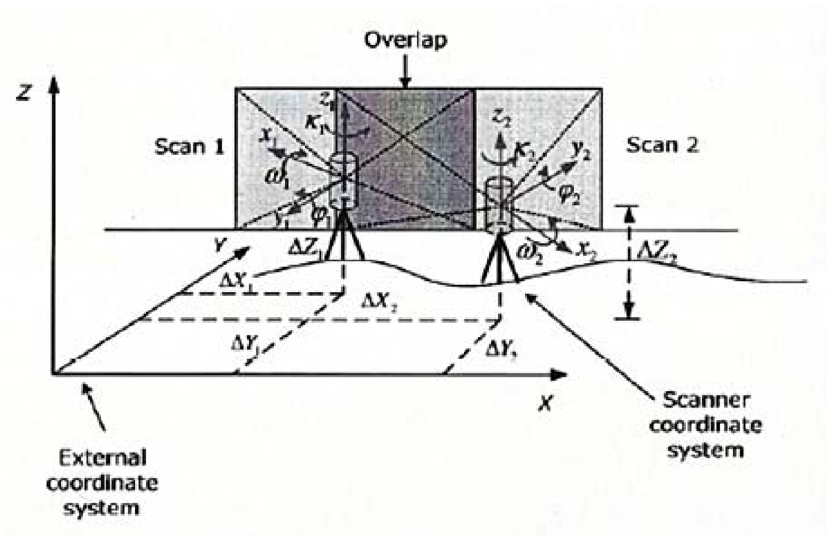

Fig. 8. Relationship between the scanner and external coordinate systems [4].

If $\mathbf{X}_i = [x_i\ \ y_i\ \ z_i]^T$ is the vector of coordinates of a point in the point cloud in the scanner coordinate system, $\mathbf{X}_g = [x_g\ \ y_g\ \ z_g]^T$ is the vector of coordinates of a point in the global coordinate system and $\mathbf{X}_e = [x_e\ y_e\ z_e]^T$ is the vector of coordinates of a point in the external or national coordinate system; then

$\Delta\mathbf{X}_{ig}$, $\Delta\mathbf{X}_{ge}$, $\Delta\mathbf{X}_{ie}$ are the translation vectors from the scanner to the global, the global to the external, and the scanner to the external coordinate systems, respectively. Each translation vector looks as follows:

$$\Delta\boldsymbol{X} = [\Delta X \;\; \Delta Y \;\; \Delta Z]^T. \tag{1}$$

The rotation matrices $\mathbf{R}_{ig}$, $\mathbf{R}_{ge}$, $\mathbf{R}_{ie}$ are expressed similarly. They are function of the rotation angles ω, ϕ, κ about the x, y and z coordinate axes, respectively [6]. Each rotation matrix can be expressed as follows:

$$\boldsymbol{R} = \boldsymbol{R}_3(\kappa) \cdot \boldsymbol{R}_2(\phi) \cdot \boldsymbol{R}_1(\omega), \tag{2}$$

kde:

$$\mathbf{R}_1(\omega) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{pmatrix}, \tag{3}$$

$$\mathbf{R}_2(\phi) = \begin{pmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{pmatrix}, \tag{4}$$

$$\mathbf{R}_3(\kappa) = \begin{pmatrix} \cos & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{pmatrix}. \tag{5}$$

Two-step procedure was performed during the registration and georeferencing, while the first step was the transformation $\mathbf{X}_i \rightarrow \mathbf{X}_g$, i.e. $\mathbf{X}_g = \Delta\mathbf{X}_{ig} + \mathbf{R}_{ig}\,\mathbf{X}_i$ and the second step was the transformation $\mathbf{X}_g \rightarrow \mathbf{X}_e$, while $\mathbf{X}_e = \Delta\mathbf{X}_{ge} + \mathbf{R}_{ge}\,\mathbf{X}_g$ [4]. The achieved error of georeferencing (transformation of the scans) ranged from 1,9 to 2,5 mm.

Processing of the measured data in the software Cloudworx for Microstation 3.3

Thus, the transformed data then entered into the processing while the real position of external façade of the residential complexes A and B from the projected state was compared. Vector drawing of the project, which was identified with the measured real state, served as basis. Since the measured state consisted of point clouds (Fig. 9), it was necessary to fold points of façade through surfaces in vertical and horizontal planes. The measurement was realised before thermal insulation of the external cladding and before applying façade plaster. In the case that the modelled surface was situated opposite to the projected façade surface outwards from the building, a positive value was assigned to its deviation. Otherwise, if the modelled surface was situated inside the building, a negative value was assigned to its deviation (Fig. 10a).

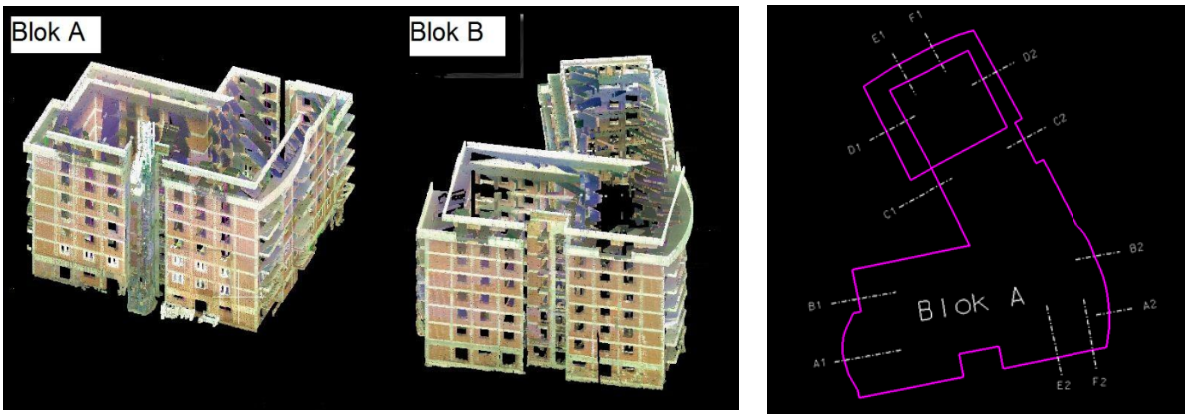

Fig. 9. Point cloud of the residential complex and cross sections through Block A.

Two algorithms are used to create a planar surface through points – algebraic and orthogonal; pursuant to the function of minimisation of finding the best solution. Application of function of approximation of 3D points by mathematically defined surfaces is possible if the measured surface is geometrically close to the geometric entities - plane, sphere, cylinder, cone and their elliptical variants. Most algorithms that execute this task are based on the least-square adjustment method [5]. Since the accuracy of determining individual points in the point cloud, which is given by the a priori mean spatial error, set by the manufacturer had the value of $\boldsymbol{\sigma}_{xyz\ apriori}$ = 6 mm, maximal setting permissible deviation when folding planar surface was set to 0,006 m (Fig. 10b). This resulted in many folded surfaces of building facades in horizontal and vertical cross sections. This method can be used mainly for documentation of industrial buildings, linear features and facades of buildings in laser scanning [3].

8 vertical cross sections were made through both blocks A and B at height levels of 0,5 m; 7,5 m; 16,5 m; resp. 14,0 m; and at height level of 1,0 m of each above ground floor; specified by the contractor of the construction. Thus 160 measurements of deviations were performed within the block A, while only 95 could be de facto measured due to the missing data in hidden and obscured areas. 120 measurements were performed within the block B, 115 values were actually obtained. Data are presented in Table 2 and 3.

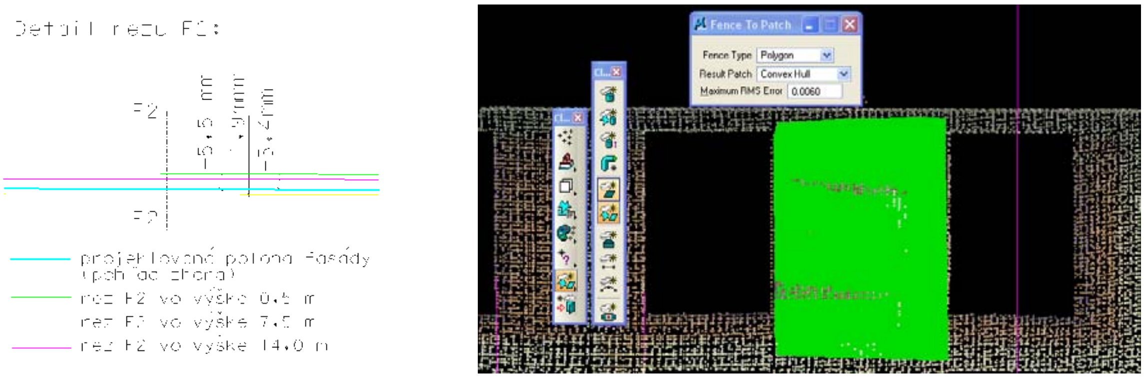

Fig. 10. a) Detail of deviations in cross section, b) Surface of façade folded through the point cloud in cross section.

Tab. 2. Table of deviations in cross sections of block A.

Block A	Deviation at cross section 1	Deviation at cross section 2	Deviation at cross section 3	1 NP	2 NP	3 NP	4 NP	5 NP	6 NP	7 NP
	H = 0,5 m	H = 7.5 m	H = 16,5 m	H = 357,5 m	H = 361 m	H = 363,97 m	H = 366,87 m	H = 369,77 m	H = 372,67 m	H = 375,57 m
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
A1	1,1	-3,7	x	x	x	x	x	x	x	5
A2	-11,1	-10,7	-10,4	x	-13,9	-14,3	-15,8	-7	x	x
B1	2,7	-2,8	x	x	x	x	x	x	x	-8,1
B2	-17,5	-25,5	-7,4	x	-8,1	-16,5	-40,5	-18	-12,3	-10,8
C1	4,2	3,6	-7	x	x	x	7,2	5,5	x	-8,1
C2	-8,8	-5,4	-5,8	x	5,4	x	9	3,7	0	-9,7
D1	3,7	16,2	6,1	13	x	x	1,5	0	x	6,2
D2	0,8	-8,7	x	x	1,3	-9,5	3,9	1,2	9,5	x
E1	-7	14,7	3,9	x	x	x	12,5	x	9,7	6,2
E2	-2,2	-1,8	6,2	x	-2,3	-3,8	0	4,1	4,1	-5
F1	x	x	x	x	x	x	x	x	x	x
F2	-5	-3	6,7	x	x	x	x	-7,8	0	6,1
G1	x	x	x	x	x	x	x	x	x	x
G2	0,5	-7,5	-2	x	x	x	x	-6	5	10,2
H	20,7	11,8	24,6	19	x	1,5	20,5	20,3	x	0
I	21,3	7,3	0,5	20	x	9,5	15,5	12,3	x	8,1

Tab. 3. Table of deviations in cross sections of block B.

Block B	Deviation at cross section 1	Deviation at cross section 2	Deviation at cross section 3	1 NP	2 NP	3 NP	4 NP	5 NP	6 NP	7 NP
	H = 0,5 m	H = 7.5 m	H = 14,0 m	H = 357,5 m	H = 361 m	H = 363,97 m	H = 366,87 m	H = 369,77 m	H = 372,67 m	H = 375,57 m
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
A1	1	-1,6	-10	-3,2	-1,2	-2,1	0	0	x	x
A2	-22,5	-3,8	-8,2	-9	-2,8	5,6	-4,5	-5,1	-5,5	-8,4
B1	0	4,5	11,2	1,5	2,6	2	0	-3,8	0	7,7
B2	-2,3	-6,7	17,3	-19,8	5,2	-9	0	-7	9,1	2,4
C1	6,5	8,2	4	2,1	1,8	1,9	0,8	12,5	10,6	7,2
C2	-1,2	1,4	3,7	-25,8	2,9	-2,9	2,7	0	12,1	3,8
D1	15,3	7,1	6,4	11,9	6,2	6,1	0	1,7	-7,8	5,2
D2	-1,6	0,2	2	-1	4,1	-1,5	0	8,8	0	10,8
E1	13,1	-9,5	6,7	3	3	4,1	2,5	6,4	12,6	x
E2	1,1	3,3	4,6	-4,2	0	4,3	6,2	1,2	-6,6	-3,2
F1	4,8	6,1	8	11,6	5,2	x	4,6	-4,6	5,3	x
F2	-5,5	1,9	-3,4	-9,8	-3,7	0	4	-4,1	-6,9	1,6

The error ε_{max}, which represents the maximal permissible deviation in the interval – permissible deviation Δ_{max}, was determined in the set of actual errors ε with normal distribution, listed in tables of deviations (tab. 2 and 3). Values that lie outside this interval are considered as gross errors. The confidence coefficient was set to t_α= 2,5 [2]. If the ε_{max} is the function of confidence of t_α and the standard of $\sigma_{xyz\ apriori}$, then:

$$\varepsilon_{max} = \pm t_\alpha \sigma_{xyz\ apriori}, \qquad (6)$$

where ε_{max}= ±15 mm.

We found during the processing that the permissible deviation was exceeded in some cross sections, as it is highlighted in colour in tables.

Conclusion

Application of terrestrial laser systems is of immense importance in the civil engineering. Speeding up the workflow, accuracy of the measurement and ease of surface modelling are just some of benefits. In this case, it has been also shown that for finding partial results – such as finding positional deviations in the shape of construction, it is not necessary to perform complicated modelling of measured data, but partial spatial data in cross section planes are sufficient. Thereby the work is significantly accelerated and one can proceed to the final 3D visualisation of the whole residential complex at the final stage of construction and handover of the project.

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References

[1] Fraštia, M., Bajtala, M., Sokol, Š.: Photogrammetric determination of the spatial shape of the clinker silo, *vol. 12 (2007), Special issue 3, pp. 361-365*.

[2] Jakub, V., Sabová, J: Influence of bad measurements in properties of Geodetic network, *Acta Montanistica Slovaca, vol. 13 (2008), No 4, pp. 480-484*.

[3] Pukanská, K.: 3D modelling of cultural heritage of Slovakia by the terrestrial laser scanning, *PhD thesis, 2010.*

[4] Reshetyuk, Y.: Terrestrial laser scanning, Error sources, self-calibration and direct georeferencing, *VDM Verlag Műller A.G., ISBN: 978-3-639-17550-9.*

[5] Štroner,M., Pospíšil,J.: Terrestrial scanning systems (Terestrické skenovací systémy), *Czech technical university in Prague (České vysoké učení technické), Praha 2008, ISBN 978-80-01-04141-3.*

[6] Weiss, G., Gašinec, J., Leššo, I., Šadera, M., Zemen, M.: Applying transformation parameters for 3D transformation between systems WGS 84 and RES (B), *Acta Montanistica Slovaca, vol. 6 (2001), No. 3, pp. 253-259*.