Process of verification of earthworks execution using terrestrial laser scanning

M. Ďubek [a], T. Funtík[b], J. Erdélyi[c], P. Makýš[d] and M. Petro[e]

[a,b,c,d,e] Slovak University of Technology in Bratislava, Faculty of Civil Engineering
E-mail: marek.dubek@stuba.sk, tomas.funtik@stuba.sk, jan.erdelyi@stuba.sk, peter.makys@stuba.sk, marek.petro@stuba.sk

Abstract –

Interactive verification of construction works should provide for compliance between planned vs. completed works. The task of its fulfilment (especially for larger investment projects) is rather time and labor consuming. There is potential to reduce the duration of a verification process as well as to ensure the results are more accurate and clear with the use of digital tools and specialized software, moreover, substantial part of the process may be automated.

Faster and more accurate capturing of a data regarding actual position and shape of the construction works, resp. its parts, as well as the information about the quality of works has the potential to reduce number of disputes caused by unclear measurement data evaluation.

The technology of Terrestrial Laser Scanning (TLS) is suitable for this purpose allowing efficient data collection and automation of the process of verification. The article provides a case study comparing traditional approach vs. use of TLS for earthworks verification and the impact of different methods of measurement on the price.

Keywords –

Earthworks, Cost estimation, Quantity take-off, TLS

1 Introduction

Prior to the creation of the bill of quantity, the quantity surveyor must know the technology defined by project to set appropriate and indicative price. Indicative price includes items from the pricing database considering all relevant regulations and standards (safety, hygiene and fire protection). It is necessary to use the same or similar specifications and name conventions defined in national standard “STN 73 3050 Earthworks. General provisions” and at the same time in the software (based on reliable pricing database) where the indicative price was calculated. The bill of quantity is an integral part of the project to ensure that each tenderer can estimate the price according to the extent of work, without the risk of possible demand for additional extra work which can lead to budget overrun. The price estimation need to be well structured allowing to attach complete tasks list to invoice. This may be done after agreed period or frequency (weekly, monthly), on a task base or after complete delivery of work.

2 Terminology and Legislation

Pricing databases are based on **classification of the building construction TSKP** (Classification of Building Construction, Instruction No. 13/1977 of the Ministry of Construction of the Czechoslovak Republic on 30 December 1977 in co-operation with the Ministry of Construction of the SSR and in agreement with the FSÚ pursuant to Section 16 paragraph 2 b of Act No. 21 / 1971 Coll.) and **classification of works TSP** (Classification of Construction Works, declared by the Ministry of Construction and Regional Development Methodology No 1/2004, which entered into force on 1 January 2005. The class was issued on the basis of the Annex to Commission Regulation (EC) No 204/2002 on the statistical classification of production by activity in the European Community declaring the classification of construction works to be binding on the Member States of the European Union and on the basis of the Decree of the Statistical Office of the Slovak Republic No. 632/2002 Coll., which gives the statistical classification of production as amended issued on the basis of Act No. 540/2001 Coll. on State Statistics)[6]. According to TSKP, the earthworks are listed under code 800 - 1 Earthworks and according to the TSP Earthworks are listed under the code 01. Therefore, proper specification of the items is required.

For the proper use of items, it is also necessary to know the geology including the composition of soil that will be subject of earthworks from geological surveys. It is therefore necessary to know their class of rippability (*rippability is the ease with which soil or rock can be mechanically excavated)*, which is on national level classified in 7 classes. [1]

- 1st class - loose rocks - can be easily loaded by shovel, loader.
- 2nd class - rippable rocks - rippable by digging spade, loader.
- 3rd class - diggable rocks - rippable by digging spade, loader.
- 4th Class - solid crumbly rocks – rippable by spike, excavator
- 5th Class - Solid rocks with easy rippability – rippable by ripper, heavy excavator (over 40 tons), explosives.
- 6th Class - Solid rocks with difficult rippability - rippable by heavy rippers, explosives.
- 7th Class - Solid rocks with difficult rippability - rippable by explosives.

The items of the bill of quantity must be formally prepared so that all parties involved in the construction process have the same and unequivocal idea of the subject and that it would not be necessary to demand the extra work during the execution. In the case of a high-quality project, this requirement is fulfilled, because the most important influence on the price calculation of works on larger buildings is the chosen technology. The method of measurement is given by individual database makers. Example: The amount of excavation is determined in m^3 of soil volume in the unripped state from the dimensions given by the project, defined from the level of the adjacent terrain, while the adjacent terrain can be:

- for all terrain excavations, natural or terrain for the viewing of the orphanage or the carp after removal of the reinforced surfaces,
- in the shafts and rocks the bottom of each trench, except the bottom of the shafts and grooves,
- for pits, the bottom of the excavation or excavation or the bottom of the trench for the flowing water flows. [2]

The handling volume of the excavation obtained by the excavations in the dry environment and underwater subsoil (horizontal displacement, loading, etc.) is determined by the unripped soil volume on the trench. The volume of handling of the excavation obtained by the other excavations under water is determined in the solid state. [2]

3 Case study

The greenhouse construction of the object "SO08 Laguna" consisted in the first stage of the excavation of the Lagoon itself. Excavated soil was transferred and stored within the site (the property of investor). Next task was creation of waterproofing layer supplied with geotextile and drainage system for pumping the rain water into Lagoon. After the first stage of excavations, quantity quoted in the invoice was doubted by investor. Contractor declared that approximately half of the work was completed. Investor returned the invoice after control measurement was performed and asked for correction of values. The issue was, the results of the measurement of contractor and the investor varied. In both cases, the measurement was performed by a length scale (band).

Figure 1 Preparation of excavation works, Lagoon

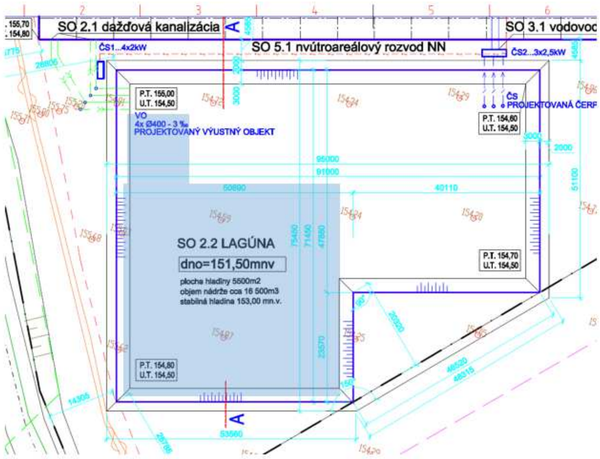

Figure 2 Layout of the Lagoon with identification of executed excavation (blue hatch)

Both the Contractor or the Investor (with notice from the other party) has the right to invite an third-party authorized person for independent measurement or to avoid dispute by specifying the subject of billing of earthworks (measurement and quantification) using an court expert in the form of a private expert opinion under *160/2015 Z.z. Civil Procedure Code, § 209* (If such a report has all the requisites prescribed and a clause that the expert is aware of the consequences of a knowingly false expert's opinion, then the procedure is followed as if it were an expert judgment ordered by the court).

3.1 Measurement and Legislation

An expert or authorized person has more options or devices to measure and verify the size of the work that was done. Differences in measurements by the construction manager and supervisor have arisen due to the use of various measuring instruments and various measurement errors. Measurement is a summary of activities to determine the value of the measured quantity. This value should be given along with the tolerance in which the right value of the measured quantity or the numbers corresponds to the corresponding values of the measurement result. This is particularly important today, where large numbers of computers are used for processing results. We do not get the correct value of the measured value by any measurement, since each measurement is made with error. The error characterizes the accuracy of the measurement by specifying deviation.

The base length is the meter (unit of length meter, symbol m is the length of the path that the light passes under the vacuum in 1/299 792 458 seconds) [4]

- a measurement unit is the specific value of a physical or technical quantity that is defined and accepted by agreement with which other values of the same species are compared in order to express their magnitude in relation to that specific value of the quantity,
- measuring instrument is device for determining the value of the measured quantity, including the measure, the measuring instrument, its components, the auxiliary equipment and the measuring device,
- the type of measuring instrument shall be a definitive design of the measuring instrument of a given design in accordance with the type-related documentation in which all components influencing the metrological characteristics are defined, manufactured by the same manufacturer,

Usage of specified instruments:

- Designated instruments may only be used for the purpose if they are validated if required.
- The entrepreneur or other legal entity is obliged (and - to use the prescribed instruments in cases where their use is stipulated (§ 8) and for that purpose there is a type of measure stipulated by a generally binding legal regulation, unless a special regulation7) has not granted an exemption, b - keeps the used measuring instruments in proper technical condition)

Designated meters according to Annex no. 1 to Decree No. 210/2000 Z.z. - Types of measured meters are rolling meters, bands, folding meters and winches in length measurements.

According to Annex no. 50 to Decree No. 210/2000 Coll., The measuring instruments referred to in point 1 (a) be broken down according to the principle of measurement

- balancing instruments,
- folding scales,
- winches.

According to the accuracy of the material length measurement, weighing instruments are divided into three classes of accuracy. The maximum permissible errors of the weighing instrument for initial and subsequent in-service verification are given in Table no. 1. [4]

Table 1 The largest permissible error

Accuracy class	The largest permissible error (positive or negative) in % of measured length
I	0,25
II	0,5
III	1

To determine the amount of work done within the excavation object in construction progress, measurement can be made by a measure (band or other meter) preferably with an accuracy class I, or with existing software support devices. Current technologies offer, in addition to measuring, simplification of measurement itself and processing of measurement results. [5] Their accuracy is significantly higher and data processing shorter.

3.2 Selected devices

The Lagoon was measured by contractor using the measurement bands and the resulting quantities are written in Table 2. The table is based on the transcript of the work done from the invoice attachment. The requirement to verify the number of works carried out arose from the investor side. The 3D Leica ScanStation2 scanner and Leica DISTO D 910 was selected to measure the excavation work on the Lagoon facility.

The procedure for determining the volume of the lagoon object consisted of:

- terrestrial laser scanning of an object,
- measurement by laser distance measure
- processing of measured data and creation of a 3D model and calculation of excavation volume

The Leica ScanStation2 was used for the measurement [6; 7; 8]. The spatial shape of the Lagoon was measured from two positions with a scanning density of 50 mm x 50 mm / 50 m. Opinions were linked through four landing points. The registering points were the Leica HDS target marks, which were stabilized on the measuring statues. The positioning points were determined in the S-JTSK coordinate system using the SK-POS Slovenian Space Observation Service.

Figure 3 On-site scanning of the Lagoon

Based on the position, the Cyclone software transformed the coordinates of the points from the individual positions of the instrument into S-JTSK and Bpv. The internal (relative) accuracy of the transformation is defined by the mean spatial error $\sigma xyz = 3$ mm. The absolute accuracy of the transformation is characterized by a value of $\sigma xyz = 10$ mm. The result of the transformation is the single point cloud of the object.

In order to determine the actual Lagoon volume, all shrubs and grassland that stood above the terrain were removed in the first stage of the measured data from the cloud point. (Figure 4)

In the second phase, a triangular network (TIN model) of the measured object was created from the combined dot cloud. The TIN model was created for the Lagoon itself (excavation pit) as well as for the original terrain.

The TIN model of the original terrain was created from the points of the Laguna surrounding. The volume of the Lagoon was determined by the difference model of the TIN models of the excavation pit and the original terrain.

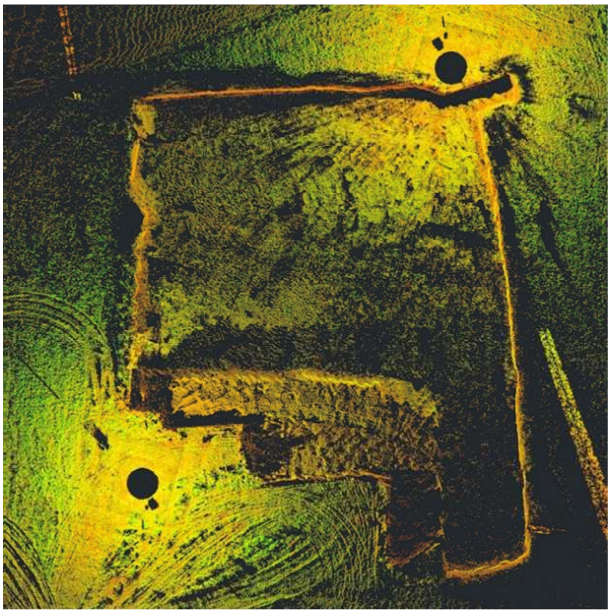

Figure 4 Point cloud, top view

3D view is generated using tools and commands in CAD programs. Moreover, it is possible to generate individual sections - Lagoon profiles and realized excavations. Using individual profiles and basic mathematical functions, volumes can be calculated, or model tools can generate volumes directly in the CAD program [9; 10; 11]. (Figure 5)

The second used tool for the measurement was Leica DISTO D 910. The Leica DISTO S910 (Figure 7) is the laser distance measurer that captures multiple, accurate measurements in three dimensions from a single location, radically improving the efficiency of common measuring tasks. The integrated Smart Base enables to measure distances (e.g. widths, distances) between any two points, angles or inclinations at the same time from one location.

Figure 5 Point cloud axonometry

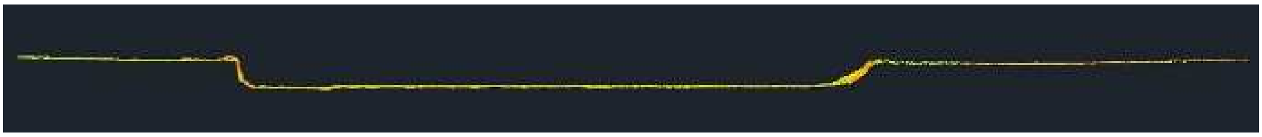

Figure 6 Point cloud, section through excavation

Figure 7 Measure with Leica S910

The Leica DISTO™ S910 can save all the measured points into a DXF file as a floor plan, wall layout or 3D point coordinates that can be downloaded to a PC via the USB interface. The schema of measurement is shown in Figure 8.

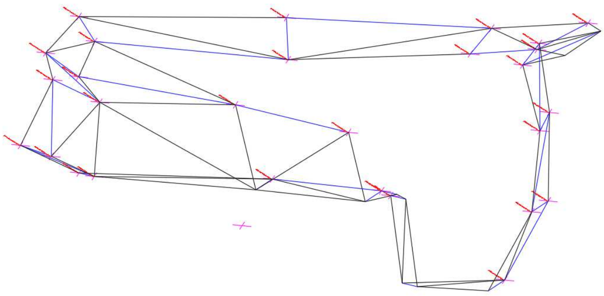

Figure 8 Measurement with Leica S910 – processed using CAD software

3.3 Measured values

In the table below, the values (dimensions) of each work are from the bill of quantity, as measured by the contractor versus scanner measurement (Tab. 3). Scanner surveys were carried out by an authorized surveyor. Cost of measurement by TLS exceeds the standard measurement (bandwidth or manual laser) available on the market, but the accuracy and processing of the results is on a diametrically different level. These instruments do not yet fall under the specified instruments, but the accuracy of the measurements is defined, and regular calibration is carried out. Scanner measurement and laser distance measure demonstrates a lower amount of actual execution of excavation work. Individual quantities multiplied by unit prices form a new total cost. The unit price is defined by the contract or by the open market [12; 13]. In the case of the use of the following materials in the excavations: concrete [14], underlying aggregates [15] or prospective materials [16], inaccurate measurement would result in increased price due to higher volume of material calculated.

Individual columns represent subsequently: number of the item, code of the task, task name, measuring unit, measurement value, unit price and price of task.

Tab. 2 Bill of quantity delivered by Contractor

1 – Earthworks 44 651,54

1	131201104	Excavation in soil, 3rd Class, over 10000 m3	m3	3 037,52	2,500	7 593,80
2	162301181	Transfer of soil in soil 1st -4th Classover 10000 m3, distance 50 to 500 m	m3	3 037,52	2,200	6 682,54
3	171203111	spreading of soil without compaction, max slope 1:5	m3	3 037,52	10,000	30 375,20

Tab. 3 Bill of quantity delivered by Surveyor (TLS)

1 – Earthworks 38 923,68

1	131201104	Excavation in soil, 3rd Class, over 10000 m3	m3	2 647,87	2,500	6 619,67
2	162301181	Transfer of soil in soil 1st -4th Classover 10000 m3, distance 50 to 500 m	m3	2 647,87	2,200	5 825,31
3	171203111	spreading of soil without compaction, max slope 1:5	m3	2 647,87	10,000	26 478,70

Tab. 4 Bill of quantity delivered by Surveyor (S910)

1 – Earthworks 40 359,18

1	131201104	Excavation in soil, 3rd Class, over 10000 m3	m3	2 745,52	2,500	6 863,80
2	162301181	Transfer of soil in soil 1st -4th Classover 10000 m3, distance 50 to 500 m	m3	2 745,52	2,200	6040,15
3	171203111	spreading of soil without compaction, max slope 1:5	m3	2 745,52	10,000	27 455,23

4 Conclusion

Measurement is a process that results in a measured value. Its accuracy often affects other aspects. The purpose of this case study was to compare the various measurement tools that allow to capture actual progress of work - in this case earth excavations. The measurement (volume of work) submitted by the contractor exceeded estimated quantity specified in the quantity take-off calculated from project documentation. To verify individual quantities, modern technologies and devices were used. TLS scanning and laser distance measurement in a combination with specialized software proven that the differences in the measured values are significant as the contractor used classical measurement methods.

As a result, the volume of 3 037.52 m^3 was measured by contractor. When multiplying by unit price, the amount of the work was calculated to € 44,651,544. By means of a verification, surveyor quantified the volume of works to 2 647.87 m^3 using TLS. After multiplying by unit price, the value equals to € 38,923,689. Secondary verification method – using distance laser measurement, the value of 2 745,523 m^3 was quoted. After multiplying by unit price, the value equals to € 40,359,188.

Both verification methods by professional devices (3D Leica ScanStation2 and Leica DISTO S 910) proven different – lower amounts of actual volume of work executed. The cost deviation between the calculation of contractor (using traditional technique) and surveyor is significant resulting in the reduction of costs by € 5,727.86 resp. € 4,292.35. In percentage terms, the savings are 9-12% compared to the original requirement of the contractor and that is considerable figure for both large and small-scale construction works in this sector. The cost of verification measurement is in most cases irrelevant to the potential savings of the investor and the digital technology needs to be an integral part of the construction industry.

References

[1] STN 73 3050 Zemné práce. Všeobecné ustanovenia

[2] Čavojský J. Oceňovanie stavebných prác, (Klasifikácie, kalkulovanie, oceňovanie a rozpočtovanie), ISBN: 978-80-970678-1-6, CENEKON spol. s.r.o. 2012

[3] CENEKON databáza smerných orientačných nákladov v triednikoch TSKP a TSP, II/2011

[4] Vyhláška č. 206/2000 Z. z. Vyhláška Úradu pre normalizáciu, metrológiu a skúšobníctvo Slovenskej republiky o zákonných meracích jednotkách

[5] MAKÝŠ O. and MAKÝŠ, P. Technologický projekt. Stavenisková prevádzka a zariadenie staveniska. Bratislava : Vydavateľstvo STU, 2003. s. 203. ISBN 80-227-1847-5.

[6] Mesároš P. and Kozlovská M. and Hrubý K. and Mandičák, T., Terrestrial laser scanning and aerial photogrammetry - why we need combination of these two technologies. In: Zvyšovanie efektívnosti výstavby prostredníctvom informačného modelovania stavieb : zborník vedeckých prác 2017. - Košice : TU, 2017 S. 90-96. - ISBN 978-80-553-2689-4

[7] Tkáč M. and Mesároš P., 3D laser scanning of the historic greek catholic church - case study. In: Czech Journal of Civil Engineering. Vol. 2, no. 1 (2016), p. 123-128. - ISSN 2336-7148

[8] Du J. Teng H. 3D laser scanning and GPS technology for landslide earthwork volume estimation, Automation in Construction, Volume 16, Issue 5, August 2007, Pages 657-663

[9] Siefko S. Hack R, 3D Terrestrial Laser Scanning as a New Field Measurement and Monitoring Technique, Engineering Geology for Infrastructure Planning in Europe pp 179-189, 2004

[10] Čabala J. and Kozlovská M. and Struková Z., The methodology of interactive parametric modelling of construction site layout. In: International Journal of Applied Engineering Research. Vol. 12, no. 23 (2017), p. 13534-13540. - ISSN 0973-4562

[11] Mesaros P. and Kozlovska M. and Hruby K. and Mandicak T., Potential of IT based reverse engineering tools in civil engineering and architecture. In: SGEM 2016. - Sofia : STEF92 Technology, Ltd., 2016 P. 765-772. - ISBN 978-619-7105-54-4 - ISSN 2367-5659

[12] Ellingerová H. Náklady a ceny v stavebníctve. 1.vyd. Brno : Tribun EU, 2014. 85 s. ISBN 978-80-263-0557-6.

[13] Adamuščin A. and Liptajová D. The Comparison of the Retail Development in the Visegrad Group with Focus on the Development of Macroeconomic and Retail Indicators. In Swiat Nieruchomošci. World of real estate Journal. Vol. 94, No. 4 (2015), s.57-66. ISSN 1231-8841.

[14] STN EN 13242 – Kamenivo do nestmelených a hydraulicky stmelených materiálov používaných v inžinierskom staviteľstve a pri výstavbe ciest

[15] STN EN 206+A1 - Concrete. Specification, performance, production and conformity

[16] Gregorová V. - Ledererová M. - Štefunková Z. Investigation of Influence of Recycled Plastics from Cable, Ethylene Vinyl Acetate and Polystyrene Waste on Lightweight Concrete Properties. In Procedia Engineering: 18th IC Rehabilitation and Reconstruction of Buildings, CRRB 2016. Brno, Czech Republic, 24 - 25 November 2016. Vol. 195, (2017), online, s. 127-133. ISSN 1877-7058.