KATASTRSKA IZMERA S TEHNOLOGIJO TLS - NATANČNOST IN GOSPODARNOST

CADASTRAL SURVEYS USING TERRESTRIAL LASER SCANNING – ACCURACY AND ECONOMY

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IZVLEČEK

Terestrično lasersko skeniranje (TLS) je zaradi široke uporabnosti že dolgo prisotno tudi na področjih gradnje objektov in spomeniškega varstva. Prednost te tehnologije je zajem 3D-posnetka okolice, ki vključuje vse vidne predmete v obliki 3D oblaka točk. Iz podatkovnega niza lahko z ustrezno programsko opremo pridobimo vse potrebne informacije v pisarni. Da bi preizkusili primernost TLS za izdelavo katastrskih načrtov v skladu z avstrijsko uredbo o katastrski izmeri (VermV), smo izvedli študijo primera z uporabo tahimetra in TLS. Oba posnetka smo ovrednotili in primerjali glede natančnosti, stroškovne učinkovitosti in zakonitosti. Natančnost TLS je odvisna predvsem od skrbnosti analize podatkov. Odstopanja se pojavijo, če napačno interpretiramo geometrijo, napake je mogoče popraviti v pisarni. Z ekonomskega vidika TLS zahteva 14 % manj skupnega delovnega časa, terenskego delo se zmanjša za 68 %, posledica česar je znižanje stroškov in zmanjšanje motenj na območju izmere. Avstrijska uredba VermV legalizira uporabo sistema TLS za katastrsko izmero.Glavna prednost tehnologije je snemanje celotnega okolja, posnetki pa so primerni za dokumentiranje, ohranjanje dokazov in pomenijo dodano vrednost za načrtovalce. Odločitev o uporabi TLS je treba sprejeti za vsak primer posebej.

ABSTRACT

Due to the wide range of possible applications, terrestrial laser scanning (TLS) has long since found its way into monument protection and construction. The advantage of this technology is the resulting 3D image of the surroundings including all visible objects as a 3D point cloud. At the office, all necessary information can be derived from the data set using specialized software. In order to test the suitability of TLS to create partition plans according to the Ordinance on Cadastral Surveying (VermV), a case study was conducted using both, a total station and a TLS. Both recordings were evaluated and compared for accuracy, cost-effectiveness, and legality. The accuracy of a TLS mainly depends on the care taken in the evaluation. Deviations occur if geometries are misinterpreted, however, such mistakes can be corrected in the office. From an economic point of view, the TLS requires 14% less total working time. The workload is shifted from the field to the office, with a 68% reduction in field work time. This leads to a reduction in costs and less disruption in the surveyed area. The use of a TLS is legally covered by the VermV. A major advantage of the technology is the recording of the entire environment suited for documentation, preservation of evidence, and added value for planners. However, the decision on the use of a TLS needs to be done case-based.

KLJUČNE BESEDE

kataster, parcelacija, elektronski tahimeter, terestrični laserski skener, točnost, stroški

KEY WORDS

cadastre, partition plan, total station, terrestrial laser scanning, accuracy, costs

1 INTRODUCTION

Surveying equipment is in permanent change and new developments have an impact on the instrumentation of surveyors.Examples for the changes in the last decades are total stations, GNSS receivers, digital cameras, drones, and also terrestrial laser scanners (TLS). Although the equipment is expensive and requires specific knowledge, it can significantly improve the economic efficiency of surveys if used adequately. Total stations and GNSS receivers already proved their value and are used on a daily basis and for all kinds of tasks handled by licensed surveyors. This is not (yet) the case for TLS.

Due to its versatile application possibilities, a TLS is already state of the art in architecture, construction, deformation monitoring, forest inventories, or heritage building information modelling (e.g., Kregar et al., 2015; Liang et al., 2018; Liu et al., 2023; Quattrini et al., 2016; Vezočnik et al., 2009;Wu et al., 2022). It is also used in factory planning and plant construction, as well as for as-built surveys in the course of modernisation. A modern TLS does not only provide a high resolution point cloud but also color information making the result comparable to photographs. This more complete documentation the situation provides a clear advantages over classical surveys using GNSS and total station.

However, there are always a few prerequisites to be clarified when using the technology for new areas of application. When using TLS for cadastral surveys, particular attention must be paid to whether all relevant objects can be recorded, whether the specifications for accuracy can be met and whether the use is even covered by the legal framework. All these questions are addressed in this paper for the Austrian cadastral system on the basis of a concrete case. In addition, the economic efficiency of the application is examined by recording and comparing the internal costs for conventional surveying and surveying using TLS.

2 BACKGROUND

A cadastre provides a tessellation of an administrative area, usually a country, into smaller pieces with unique identifiers, the parcels. Depending on the country, the cadastre may reflect the neighborhood relations, the shape, or even the exact position of a parcel. Since the use of land changes over time, so do the parcel boundaries. Cadastral updates are documented in map documents representing these changes. The map documents are either created by private surveying companies (often in the form of licensed surveyors) or by administrative bodies. Although there is a trend to document land information in 3D (Polat, 2019), most of the maps are still purely 2D and the geometries are only represented by plane coordinates for the updates. This is also the case for Austria (Lisec and Navratil, 2014).

Maps for cadastral updates must contain information on the boundaries and should contain additional information to support land owners and surveyors to identify the boundaries in the field. This additional information can either be objects located directly on the boundary like boundary marks, fences, or walls or it can be objects that remain in place for an extended period like trees and houses. A method used for field survey must be suited to document these objects.

The quality required by the Austrian cadastre is specified in the Ordinance on Cadastral Surveying (Vermessungsverordnung, VermV), which was introduced with the change from a pure tax cadastre to a legal boundary cadastre (Ernst et al., 2019). Instrument positions must be determined with a “standard average point accuracy" of 4 cm (63% likelihood that the true position is within a circle with a radius of 4 cm) when using terrestrial survey. The requirements for GNSS are based on the internal quality of the GNSS point ("standard average point accuracy" of at most 2 cm) and the maximum residuals (less than 5 cm) of the Helmert transformation into the datum of the cadastre (MGI). The tolerance of disagreement between coordinates and control measures for boundary points is restricted to 5cm, which constitutes a local quality measure.

The VermV does not specify any methodological approach for the survey. A "method suitable according to the state of the art in science and technology" has to be chosen for connecting the survey to the control point network. For the detailed survey, only the positional quality is stipulated but no method. Typically, the surveys are performed using GNSS and/or total stations. However, using a TLS should be a legal approach if the quality requirements are met.

TLS describes a ground-based, active, non-contact measurement method that uses a reflected laser to scan a specific area and perform distance measurements. The associated measuring devices are referred to as terrestrial laser scanners or widely as (3D) laser scanners (Thiel et al., 2020, p. 8). The principle of a TLS is emitting a laser pulse and measuring the time it takes to travel to an object and back. Since the direction is known, the coordinates of the object point can be determined relative to the TLS (Park et al., 2007). This is done with a high frequency and covering as much of the space around the TLS as technically possible and feasible. Larger areas or complex situations are scanned from multiple positions. The resulting point clouds are then merged based on recognized geometries, e.g., survey marks with easily detectable patterns that can be identified in several of the point clouds, as tie points. The point cloud can finally be georeferenced using a transformation based on by station points (TLS positions) with known coordinates or identified onjects with known coordinates.

Holst (2019) describes one difference between TLS and total stations as being the measurement duration of the systems. A TLS requires only a fraction of the measurement time for each 3D point. A Leica RTC 360 has a maximum measurement frequency of 2 MHz or 2 million points per second (Leica Geosystems AG, 2018). Although, while surveying with total station, the operator concentrates on the points defining the object geometry in an optimal way, the number of measurements will rarely exceed 5 to 10 measurements per minute.

3 EXPERIMENT

In order to test the concept, to identify challenges, to test solutions for these challenges, and to assess the resulting quality and the costs, a survey was performed using both, the traditional approach (GNSS and total station) and TLS. The comparison of the results provides a quality assessment that can then be compared to the requirements stipulated in the cadastral laws. Time sheets and realistic costs per hour allow assessing the cost incurred for each method.

3.1 Sample Parcel

A suitable plot for surveying resulted from an enquiry to the surveying office Guggenberger ZT GmbH in Berndorf. In the course of upgrading the existing buildings located on plot 108/14 in KG Felixdorf, the client requested securing the parcel boundaries and creating site and an elevation plan of the parcel including the buildings. Fig. 1 shows some impressions of the parcel and Fig. 2 presents the an orthoimage with superimposed parcel boundaries as documented in the cadastre.

Figure 1: Some views of the sample parcel (pictures by Prof. Dipl.-Ing. W. GUGGENBERGER Ziviltechniker-GmbH)

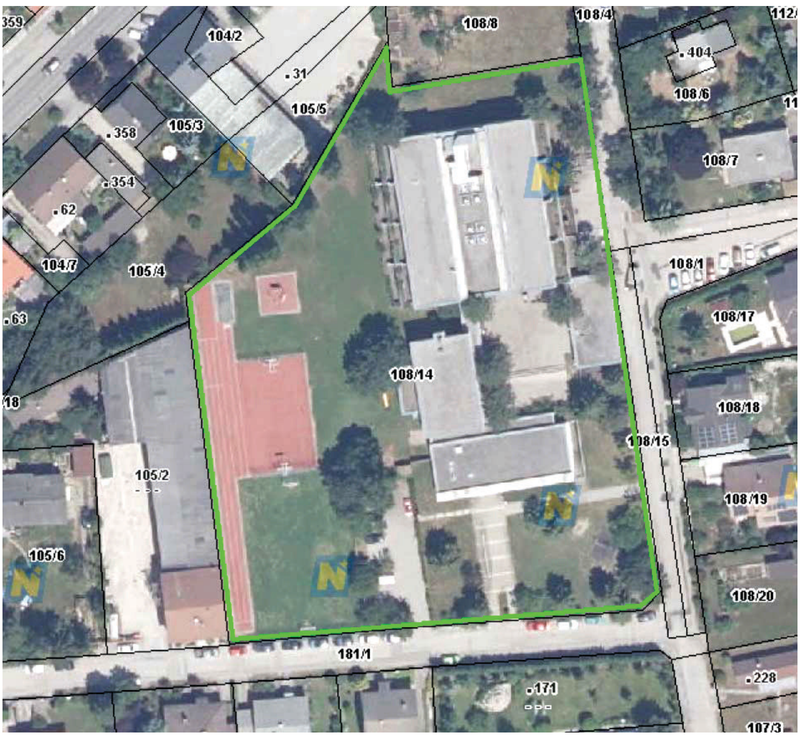

Figure 2: Orthoimage with cadastral map overlay, sample parcel marked in green, Source Orthoimage: NÖ Atlas (https://noe.gv.at), Source Cadastral data: BEV [accessed May 21 2021]

3.2 Equipment

A Leica TS15 total station and a Leica Viva GS15 GNSS-receiver were used for the conventional survey. A Leica RTC 360 was used for the TLS-approach in combination with the Leica Viva GS15 GNSS-receiver to determine the coordinates of the TLS positions.

The aim of a laser scan is to obtain a three-dimensional image of the area of interest. When using this technology, one must be aware that the actual work is transferred from the field to the office. A large amount of data is recorded in a very short time but in contrast to conventional surveys, the relevant objects need to be extracted later. Point clouds created with the RTC 360 have an accuracy of 1-2 mm (Kersten et al., 2020).

An important step for both approaches is the generation of the geometries required for the map document. The most significant difference between the two surveying approaches is the derivation of the geometries (compare Fig. 3). While the necessary points are observed directly with total station and the coordinates result from simple calculations, the required point positions must be derived manually or semi-automatically from the TLS point cloud. Which points are required depends on the respective requirement and the plan type (subdivision plan, site elevation plan). For this reason, the use of suitable software is essential. In the context of this work, software from Leica and RMData is used.

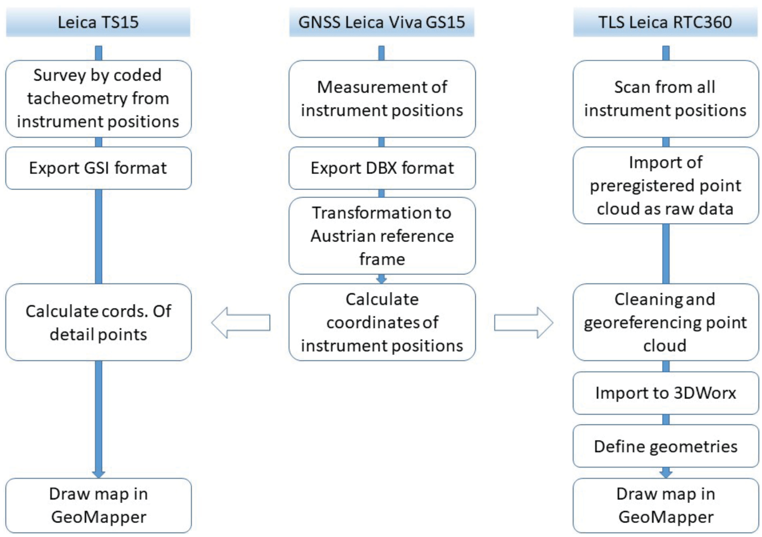

Figure 3: Workflow for the map creation for the conventional and the TLS approach.

3.3 Approach for Quality and Cost Analysis

The goal of the experiment was to assess, whether the technical requirements for cadastral surveys are fulfilled by TLS. The check was performed by comparing the result from a TLS-survey with the results of a conventional survey using a total station. The overlay of the resulting geometries shows deviations between the surveys and these were analysed.

- The following list of requirements were set:
- Preparation of a site elevation plan as a project basis for a planned building project
- Creation of a site plan in accordance with the building regulations

- Recording of the terrain shape by means of individual points
- Measurement of identification points for the incorporation of existing survey documents
- Recording of above-ground visible pipelines and fixtures
- Representation of the property boundary according to the cadastre

In order to maintain the comparability of the two types of survey, work such as staking out the boundaries in nature or the holding of a boundary hearing were not taken into account. These tasks are independent of the surveying method. Depending on the type of survey all necessary work steps are carried out and compared based on quality and costs. The aim is to determine whether all requirements listed above are met.

Besides the field work, the work in the office was compared. In doing so, not only the amount of work in hours was discussed, but also the different processing steps and the used software. Working hours were used as observations but they were transferred to financial costs using realistic hourly rates of a civil engineering office.

3.4 Survey with Total Station

For the survey with the total station, 11 points were established with metal and plastic marks. Seven of them were determined using GNSS RTK. Based on these points, 471 individual points were recorded.

The survey was carried out by a surveying team consisting of an engineer and an assistant operating the total station. The surveyed points were coded, i.e., each point received a measurement code which was translated in the office to a symbol and enables automatic drawing of lines. A network was measured around the building to ensure that every corner could be surveyed. The field work took 5 hours and 30 minutes.

In the office both, the GNSS data and the data from the total station were imported in the geodetic software rmGEO. There the transformation of the GNSS coordinates in the system of he Austrian cadastre were performed and the final coordinates of all points were computed. The result of this process is the survey document shown in Fig. 5 (top).

3.5 Survey with TLS

The survey was carried out by a single operator using the Leica RTC260. The TLS is positioned on 132 station points around the building including the 7 determined using GNSS RTK. The latter 7 points were used for georeferencing. For each point, a complete scan including color was performed. The field work took 3 hours and 30 minutes.

The point clouds were imported in the the software Cyclone Register 360 provided by Leica[1]. The resulting report contains the result for the deviations in the point cloud as well as the achieved overlapping and stability of the individual points. A root mean square error of 5 mm was calculated for the entire image. This includes the overlap of the individual point clouds of each viewpoint and the resulting stability.

The point cloud was then loaded into rmDATA 3DWorx[2] that enables manipulation of the point cloud and extraction of geometries for the survey document. The tracing of the relevant geometries is done by

[1] *https://leica-geosystems.com/en-gb/products/laser-scanners/software/leica-cyclone/leica-cyclone-register-360*

[2] *https://www.rmdatagroup.com/produkte/rmdata3dworx/*

creating a horizontal section plane through the point cloud. This helps filtering out the desired geometry from the totality of the data because points close to the ground can be displayed from which walls, buildings, fences, curbs and the like can be recognised and recorded.

3.6 Practical Problems of the TLS and Their Solution

A challenge for TLS are objects not extruding from the ground, e.g., stones or metal tubes marking the location of the parcel boundary. These objects need to be made accessible to the TLS. In the experiment, ranging poles and ranging pole tripods were used, which also helps to deal with vegetation restricting the visibility. Fig. 4 shows an example of the use.

Figure 4: Improving the visibility of a point in the point cloud with a ranging pole.

4 RESULTS

The description of the methods showed, that the interaction of the software solutions as well as the management and processing of the enormous number of points are crucial for the success of the TLS process. If the product of a 3D laser scan recording is to be the creation of a plan in accordance with the cadastral laws, the workflow described is quite purposeful.

4.1 Analysis of Positional Quality

The accuracy of the point cloud is reported with 5mm by Cyclone Register 360. Fig. 5 shows the two surveys. In certain areas, differences between the geometries are visible. An example can be found within the red rectangle: The TLS data show a shed, terrain points, and trees. These geometries are missing in the data from the total station. When using a total station, the surveyor decides what is recorded and what is not recorded. The reason for the absence of the described geometries may be that the area was difficult to see, the objects were rated as irrelevant, or they were simply forgotten.

Figure 5: Results of the surveys: Total station (top) and TLS (bottom).

For further analysis, the survey results were superimposed, as shown in Fig. 6. The total station survey is shown in grey while the TLS survey is coloured blue for better visibility. Accuracy problems occur when incorrect points are taken from the 3D data set. This can happen, for example, when tracing a leaning wall if the points are taken at different heights. In a second step, the horizontal offset between corresponding elements in the two data sets were added and color coded. It can be seen that many of the offsets shown in red (large) compare different objects. On the left side of Fig. 6, the kerbs to the parking lot show considerable deviations. The reason is vegetation, because bushes obscure the visibility of the kerb corners, therefore mapping these corners in the point cloud is a challenge. In the case of the wall in the middle of Fig. 6, the deviation can be explained by the fact that the point cloud was blended too far up and thus the timber covering was mapped instead of the rising wall. Errors in mapping are possible due to the high information content of the point cloud, but at the same time the “re-mapping” or correction of such errors is possible precisely because of this high level of detail.

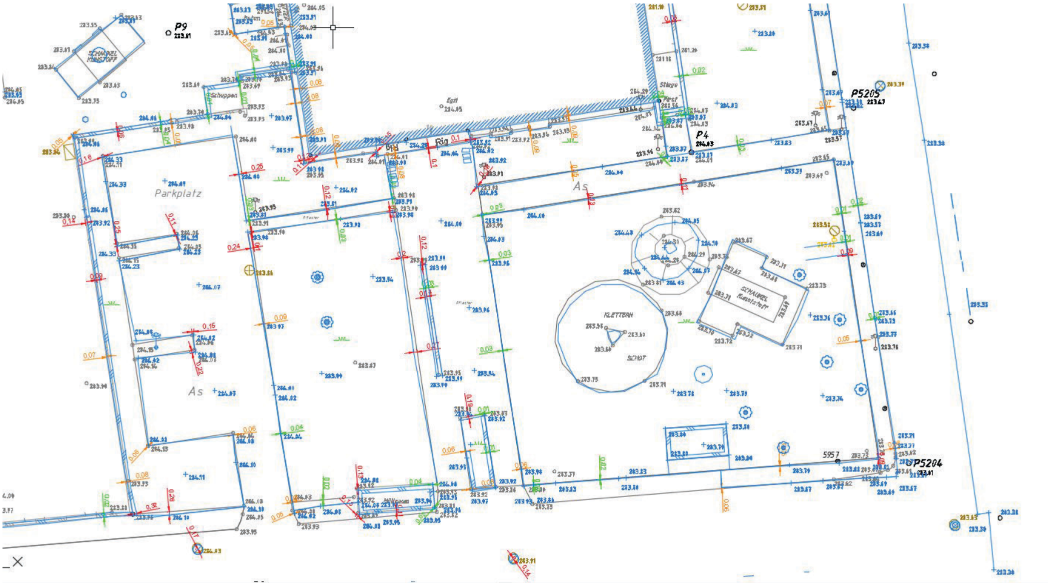

Figure 6: Overlay of the surveys with horizontal deviations between the surveys (total station in gray, TLS in blue) classified as low (green, up to 4 cm), middle (orange, 5 to 9 cm), and large (red, 10 cm and more).

Fig. 7 shows the wall separating the parcel from the neighbouring parcel. The largest deviation of 8cm is in the top-right part. In this area the wall has a bend and the deviation could indicate a leaning wall in this area. In the further course, the two images coincide with deviations of 4 to 5 cm.

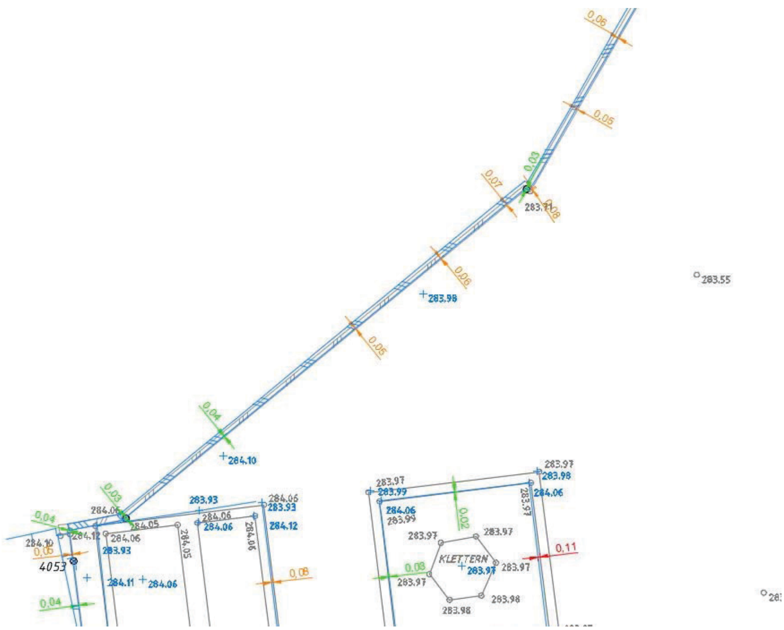

Figure 7: Detail of the comparison showing the wall to the neighboring parcel (total station in gray, TLS in blue) classified as low (green, up to 4 cm), middle (orange, 5 to 9 cm), and large (red, 10 cm and more).

The comparison in Fig. 8 shows many red marks along the building (top), i.e. deviations of more than 10 cm. In this case a wrong line was systematically mapped. The difficulties in evaluating a 3D point cloud lie primarily in the correct recognition and interpretation of the geometries and mistakes like that can happen.

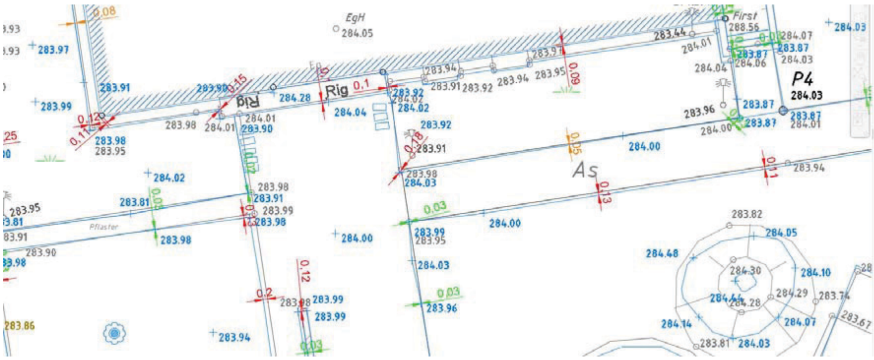

Figure 8: Detail of the comparison showing a part of the building (total station in gray, TLS in blue) classified as low (green, up to 4 cm), middle (orange, 5 to 9 cm), and large (red, 10 cm and more).

In addition to the positional accuracy, the accuracy of the elevation data is also an important quality aspect. The analysis shows deviations up to a maximum of 4 cm. The deviations found in the evaluation area do not indicate systematic errors or tensions in the elevation system, but rather uncertainties in the point determination itself. However, there might also be systematic problems, e.g., in the case of kerb, where the difference between a point on top or a point at the bottom might be 10 cm or more.

4.2 Analysis of the Costs

The costs for personnel split into

– survey in the field and
– evaluation in the office.

In order to compare the economic efficiency of the two methods, the times spent for surveying and evaluation are assigned the corresponding tariff rates. The differentiation between the various tariff rates for assistants, engineers, technicians, and licensed surveyor is important, as the requirements for the personnel and their level of training also differ for the individual processing steps depending on the procedure. The tariffs were assessed by Guggenberger ZT GmbH in 2021.

Table 1: Costs for different tasks, Type is Auxiliary Service (A, EUR 43.60 per hour), Engineer (E, EUR 86.84 per hour), or Technician (T, EUR 69.68 per hour), time is in [h:mm], costs in EUR.

Task	Total Station			TLS		
	Time	Type	Costs	Time	Type	Costs
Survey in the field	6:00	E	521.04	3:30[3]	E	303.94
	6:00	A	261.60			
Survey GNSS	0:30	E	43.42	0:30	E	43.42

[3] *It should be mentioned that the recording was carried out in colour mode. The scanning time increases by about one minute per scan when recording in colour. Recording without colour would probably reduce the time from 3.5 hours to 1.5 hours.*

Task	Total Station			TLS		
	Time	Type	Costs	Time	Type	Costs
Data import	0:05	E	7.24	0:45	T	52.26
Transformation ETRS	0:55	E	79.60	0:55	E	79.60
Registration point cloud	-	-	-	2:00	T	139.36
Net adjustment & polar points	1:30	E	130.26	-	-	-
Construct geometries	-	-	-	6:00	T	418.08
Mapping	2:00	E	139.36	1:00	T	69.68
Total hours	17:00			14:40		
Net costs	1,182.52			1,106.34		

Table 2: Approximated purchase costs of the used equipment with and without required software, based on prices from 2021 (source: Guggenberger ZT GmbH).

Equippment	Costs in EUR
Leica TS15	40,000.-
Leica TS15 with software	50,000.-
Leica RTC360	51,000.-
Leica RTC360 with software	70,000.-

The hourly rates multiplied by the workload of the case study result in the costs that are used as the basis for the economic efficiency considerations. These costs are calculated in Tab. 1 for the individual work steps, whereby not every step is necessary in both procedures. The steps are separated into engineering, technician and auxiliary services. The sum of these costs results in the "net costs" at the end of the table. The comparison shows a cost saving of around 6% when using the laser scanner recording. In terms of working time, the difference is 2:20 hours, which represents a reduction of around 14%. A simpler or even more complex recording situation could lead to different results. These savings must be put into perspective with the increased acquisition costs of the TLS. The compilation in Tab. 2 shows that the acquisition costs for a terrestrial laser scanner are almost 30% higher than those of a total station. Looking at the total package of hardware and software, the costs are 40% higher than for the comparable total station. The reason for this is the required software because two programs are necessary for surveys with the total station and four programs are used in the described workflow with the TLS.

A closer look at Tab. 1 shows a difference in working hours in the field and in the office between the two methods. TLS requires more time in the office while the majority of the working time with the total station takes place in the field. This results in an hour reduction from 12:30 hours to 4 hours and has an effect on the field service's diets. This also means that any disturbance on the site is much shorter than with the total station recording, which can be important on a factory site. However, it must be said that the acquisition of a TLS for boundary surveys only might not pay off or pays off very late, if the acquisition costs of the two devices are included in the analysis. On the other hand, the case study has shown that the additional use of an existing device for this type of recording is not an economic disadvantage. In addition, only a single person is required for the whole process, which might enable cadastral surveys even in times of personnel shortage.

4.3 Legality

A final step for assessing of the suitability is the legality of the procedure. In Austria, the Federal Office of Metronomy and Surveying (BEV) is responsible for maintaining the cadastre. It ensures that the plans submitted by the civil engineers for surveying comply with the Ordinance on Surveying and the Surveying Act. Among other things, the surveying offices are responsible for checking and certifying plans.

For this reason, officials from the BEV were asked to assess the use of terrestrial laser scanners for cadastral surveys from the perspective of the authorities. Rainer Feucht (deputy head of the group of calibration and surveying offices) and Andreas Kuprian (head of the surveying offices in Baden and Wiener Neustadt) were interviewed. The main results of the two meetings are:

- Legally, TLS is covered if §5 and §6 of the VermV are fulfilled by the survey.
- The achieved accuracy of the used TLS of less than 2mm on 10m is sufficient for the determination of a boundary course in nature.
- It was found that the extensive documentation of the surroundings is a clear advantage over a total station. The point cloud at a recorded date can become important evidence in case of boundary disputes.
- The issue of storage space for the point cloud data is not seen as crucial, because storage capacity is becoming "cheaper" and more readily available.
- In the case of soil movement, critical issues are "area delineation" and "movement of fixed points". For a TLS survey, this means that it may have to be extended very far in order to ensure that the fixed points do not move, but at the expense of the economic efficiency of a survey.

In addition to the possibility of applying the survey by a TLS for boundary survey, the method has some other advantages:

1. Documentation of evidence
2. Documentation of the actual state
3. Planning basis (detailed terrain model)
4. Surveying of the surrounding areas

5 CONCLUSIONS

The accuracy of a TLS recording is dependent on many different factors, with the distance and angular measurement accuracy of the device itself forming the basis. The manufacturer's specifications suggest that an increase in the achieved accuracy can be achieved by increasing the angular measurement accuracy. Careful work in registering and cleaning the point clouds as well as conscientious selection of geometries from the 3D point cloud are essential for the accuracy of the result. The accuracy reached in the experiment was sufficient for the goal of the cadastral survey since the survey quality of the relevant elements exceeded the stipulated quality level.

In terms of cost-effectiveness, the TLS can compete with the established technology using a total station. The economic efficiency was determined on the basis of the working hours used for the office and field staff. Within the framework of a case study, a reduction in total costs (office and field service) of around 6% was achieved through the use of a TLS. The working hours in the field are 68% lower for the TLS. However, the acquisition costs for TLS and software are 40% higher than the costs of a total station including the required software.

The legal situation in Austria is clearly covered by the VermV. If the requirements for the preparation of plans are met, a TLS can also be used for the surveying of boundaries and subsequently for the preparation of document for the cadastral update.

A clear advantage of the TLS is the documentation of the entire area at a high level of detail. Geometries that are larger than twice the scanning frequency and are in the scan field can later be reproduced in the office and displayed in the plan. In addition to the components of the nature survey generated from the point cloud that are essential for the creation of a plan in accordance with the VermV, the entire surroundings are recorded and can subsequently be used for the preservation of evidence and documentation of the actual state.

The TLS makes no sense if heavily overgrown areas are to be surveyed. Furthermore, when scanning an open meadow, linking the individual viewpoints becomes almost difficult due to the lack of geometry. In both cases, aids such as alignment poles or target markers can provide the appropriate remedy. The use of these aids is generally highly recommended during work with TLS. The assessment of whether a property should be surveyed using a laser scanner or a total station must be decided separately from job to job due to the advantages and disadvantages of both technologies.

TLS is on the rise and in the future there will be further developments, innovations and research work, especially in the areas of evaluation, automated point recognition and automatic plan generation from point clouds. This will lead to further potential savings in working time and thus to increasing economic efficiency. Especially in the field of planning, there is a lot of potential in point cloud recording with regard to BIM-capable as-built surveys.

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