XXV INTERNATIONAL SYMPOSIUM ON MODERN TECHNOLOGIES, EDUCATION AND PROFESSIONAL PRACTICE IN GEODESY AND RELATED FIELDS

Sofia, November 3 - 4, 2016

XXV МЕЖДУНАРОДЕН СИМПОЗИУМ
СЪВРЕМЕННИТЕ ТЕХНОЛОГИИ, ОБРАЗОВАНИЕТО
И ПРОФЕСИОНАЛНАТА ПРАКТИКА В ГЕОДЕЗИЯТА
И СВЪРЗАНИТЕ С НЕЯ ОБЛАСТИ
София, Ноември 03 - 04, 2016

VERTICAL PLANNING BASED ON 3D TERRESTRIAL LASER SCANNING AND GNSS TECHNOLOGIES

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Key words: 3D terrestrial laser scanning, GNSS, vertical planning, geodetic measurements

SUMMARY

The possible application of combined usage of 3D terrestrial laser scanning and GNSS gives the geodesists one opportunity for fast, precise and productive way for gathering of large amount of spatial information in the field. Both technologies could be applied in a number of specialized tasks in the practice and one of them could be for determination of the 3D coordinates of the existing terrain and cadastral details for the process of the vertical planning.

This paper studies the technical details in the implementation of the field procedures, also the data processing of the measurements in order to deliver the necessary data for the terrain and the existing cadastral objects for preparation of project for vertical planning.

Analysis of the advantages and disadvantages of both technologies, which were met in the process of the implementation of this particular task are given, based on the technical requirements of the surveying instruments.

In the paper are given the relevant graphical examples to illustrate the specifics of the carried work. Assessment of the accuracy of the conducted geodetic measurements is also done in the study.

Conclusions, recommendations and proposals for future work are given in the paper.

РЕЗЮМЕ

Възможното приложение на комбинираното използване на 3D наземно лазерно сканиране и GNSS предлага на геодезистите възможност за бърз, прецизен и продуктивен начин за събиране на големи масиви от пространствена информация. Двете технологии биха могли да бъдат приложени в голям брой специализирани задачи от практиката и една от тях би могла да бъде за определяне на пространствените координати на съществуващия терен и кадастрални детайли за дейностите по вертикалното планиране на обекти със сложна пространствена структура.

Този материал изучава техническите детайли при изпълнение на геодезическите дейности както и обработката на измерванията с цел доставяне на необходимата информация за терена и съществуващите кадастрални обекти за създаване на проект за вертикално планиране.

Даден е анализ на предимствата и недостатъците на двете технологии, които бяха констатирани по време на процеса на изпълнение на тази специфична задача, извършен на база на техническите изисквания на геодезическите инструменти.

В настоящото изследване са дадени съответните графически примери с цел илюстриране на спецификата на извършената работа.

В материала е извършена и дадена оценка на точността на извършените геодезически измервания.

Заключение, препоръки и предложения за бъдеща работа са дадени в статията.

1. INTRODUCTION

3D terrestrial laser scanning could be treated as productive way for accurate and thorough gathering of spatial data – the coordinates of each measured point and the intensity of the returned laser signal in the scanner [Milev, 2012]. Other literature sources could be listed also here: [http://tinyurl.com/pmz2hf6] and [http://tinyurl.com/pttjzxh].

The object under study in this paper consists of: industrial and administrative buildings, shaped in various geometric forms, open field, linear and point cadastral objects. Due to the existence of large volume of cadastral information, also to avoid any kind of errors it was decided that one combination of laser scanning and GNSS technologies would satisfy the requirements for quality and fast delivery of the final digital product.

Reasons, which imposed the usage of 3D laser scanning:
-existence of buildings shaped in various geometry;
-low chance (almost impossibility) to be produced error in the representation of the existing cadastral information;
-ease in the extraction of the information in the process of data delivery.

Reasons, which lead to the necessity of application of GNSS technologies:
-fast and accurate gathering of spatial information for the terrain;
-productivity in the determination of the position and level of the linear and point cadastral objects, like fences, shafts, etc.;

This paper studies the specific details and the technical implementation of the following key moments:
- conducting of geodetic measurements, using two types of instruments in order to be created complete digital model of the objet;
- production of high-quality and accurate 3D digital model using terrestrial laser scanning;
- extraction of the necessary information in the 2D space;
- minimization of the chances for any errors during the whole process;
- gaining productivity and minimization of the human efforts in the field work;

2. SOME OF THE POSSIBLE APPLICATIONS OF 3D TERRESTRIAL LASER SCANNING FOR MEASUREMENTS OF CADASTRAL OBJECTS

There are number of applications of the terrestrial laser scanning in the area of surveying, cadastre, 3D modelling, etc. Several of them could be listed below:
- in cadastral modelling and producing representations [http://tinyurl.com/gqk9d4t];
- in 3D modelling of urban areas [http://tinyurl.com/gtogvbm];
- for layouts showing cross sections [http://tinyurl.com/zugtvj6];
- for 3D cadastre [http://tinyurl.com/hjv785u];
- in the building design and construction [http://tinyurl.com/jjugclx];
- for generating DTM's [http://tinyurl.com/j7traoy].

Another application is proposed here, which uses the results from both 3D terrestrial laser scanning and GNSS technologies. It is important to be noted, that in this project were also involved the following software products: Trimble RealWorks [http://tinyurl.com/pdckrlr], Geomax Geo Office [http://tinyurl.com/h9s4aop], Mkad [http://tinyurl.com/hapgj9l] and AutoCAD [http://tinyurl.com/zc9mot3]. The listed software is given in the chronological order of its application in the process of the geodetic activities.

The final product is intended to be used for further project activities in the area of applied geodesy and investment design.

3. THE SPECIFIC USAGE OF 3D TERRESTRIAL LASER SCANNING IN THIS PROJECT

Although, as described in the previous chapter there are a number of possible applications of 3D terrestrial laser scanning in geodesy, one unique usage together with GNSS technologies will be described in this paper.

The application of the 3D laser scanning was chosen as an appropriate technology in this project, due to its ability to measure all visible cadastral details in the relevant range. In this way it was guaranteed, that all existing edges and unique details of the buildings would be captured. The human factor for producing of errors was eliminated. The field work for the crew was minimized, the productivity and reliability were increased.

Here could be listed some of the specific applications of terrestrial laser scanning for this project:
- contactless measurements of hard to access cadastral details from objects;
- possibility to measure and afterwards to extract information for huge number of terrain heights of the ground in the vicinity of the buildings;

- 3D panoramic photos available later for better interpretation of the results;
- technical possibility to export and present the spatial information in *.html format for interpretation of the results from the measurements to other professionals.

It should be noted, that taking in mind the above listed possible applications of terrestrial laser scanning, the usage of classical surveying technique in this project was not preferable for implementation.

4. APPLICATION OF GEODETIC MEASUREMENTS IN RTK MODE IN OUR SPECIFIC CASE

It is known, that RTK mode for performing of geodetic measurements is one of the most productive ways and the risk for producing of erroneous results is almost impossible [Minchev et al., 2005].

Taking in mind the above facts it was decided, that for the needs of this project all measurements, required for the coordination of the cadastral objects like fences, shafts, etc., excluding the buildings, will be measured using satellite technology in RTK mode.

The necessary georeferencing of the laser scanning data was done using spheres, placed over the specially created for the case control points. The 3D coordinates of the last were determined in RTK mode.

Due to the quality requirements especially for the height component, GNSS permanent network [http://tinyurl.com/gsuc6pw] and [http://tinyurl.com/hl6nf4v] was not used Own reference receiver was involved in order to be achieved maximum quality results.

5. REQUIREMENTS OF THE USED TECHNOLOGIES IN THE PROJECT. ADVANTAGES. DISADVANTAGES

In this chapter will be given the requirements of each one of the used ways of measurements, also their advantages and disadvantages, which are of significant importance for the current project.

5.1 Advantages and disadvantages of 3D terrestrial laser scanning, according to the specific requirements of this task

Here are listed some of the requirements, which should be observed and are of

essence especially for the laser scanning of the current project. It should be noted that the accuracy was of essence for the creation of the final digital product. For producing data with the required quality, several environmental factors should be met before the start of the laser scanning:
-Measurements should not be conducted in dusty environment;
-Scanning against direct sunlight should be avoided;
The complete list is given in [http://tinyurl.com/pnqqabg].

Also, here could be noted some of the advantages and disadvantages of the laser scanning, with significant importance for our aim:

a) **advantages**:
-possibility to capture every detail of the cadastral objects (especially for those with various 3D shapes);
-no need for coding;
-high accuracy of the measurements;
-high productivity in the field work;

b) **disadvantages**:
-direct visibility between the scanner and the object is required;
-the position of the stations must be carefully chosen, based on the spatial geometry of the cadastral object, subject of measurements

5.2 Some of the advantages and disadvantages of the satellite technology, especially for our case

The specifics of the object lead to the necessity that at about half of the field work to be done by GNSS technologies. Satellite measurements were performed in the open field, away from buildings, trees and electric power sources. In this way the geodesist could produce results with possible highest accuracy in the position and height.

Here will be given the advantages and disadvantages of the used technology, of essence for this project:

a) **advantages**
-high productivity in the field work;
-possibility to obtain high accuracy for the conducted geodetic measurements in the open field;

b) **disadvantages**:
-impossibility for measurements of buildings, if the accuracy is of essence;
-clear sky required in order to obtain the necessary quality results;
- input of the point code/description.

Despite of the mentioned disadvantages, satellite technology was chosen as a way for conducting highly productive and precise geodetic measurements.

6. ACTIVITIES, DONE PRIOR PERFORMING OF THE GEODETIC MEASUREMENTS

The buildings, subject of measurements were examined in details, taking in mind the following requirements:
-the necessary distances between the object and the scanner;
-the required visibility between the scanner and the artificial spheres;
-the visibility of the spheres between each two adjacent stations;
-the distances between the scanner and the targets.

The places for the stations of the scanner were carefully chosen, according to the existing large number of details of the scanned object [Kostov, 2015].
The area of the whole object was divided into parts, where the relevant instruments were used to perform the measurements.
The required settings for outdoor scans were applied in order to be achieved balance between quality and productivity.

7. CONDUCTING OF THE 3D TERRESTRIAL LASER SCANNING OF THE BUILDINGS FOR THE NEEDS OF THIS PROJECT. SPECIFICS

After assuring, that the preparatory activities for performing of laser scanning were completed, the field work was done in the following steps:
a) Choosing the appropriate places for the stations of the scanner in order to capture all necessary cadastral details of the objects, fig. 1;
b) Denoting the places for the spheres for each station;
c) Setting the relevant parameters for each scan;

Fig. 1 3D laser scanning of administrative building with various shapes

A polygon of stations for the scanner was created and used. It was necessary in order to be assured that all the cadastral details will be measured for the 3D digital model. The stations in the polygon were chosen very carefully as to be fulfilled several requirements:

-short distance between each building and scanner;

-angle of incidence in the relevant bounds;

-appropriate distances between the stations.

On fig. 2 could be seen the existing unique geometry of one of the buildings. The presence of these and similar concrete details required the application of laser scanning along with carefully considered places of the stations for the instrument.

Fig. 2 3D laser scanning of specific cadastral details of an indusrial building

Due to the types of the buildings (both for industrial and civil purposes) were chosen several redundant stations in order to assure the capturing of all existing 3D cadastral details.

8. PERFORMED GNSS MEASUREMENTS IN THE PROJECT

The satellite measurements were used in the open areas of the territory of the object, also for the determination of the control points for the scanner.

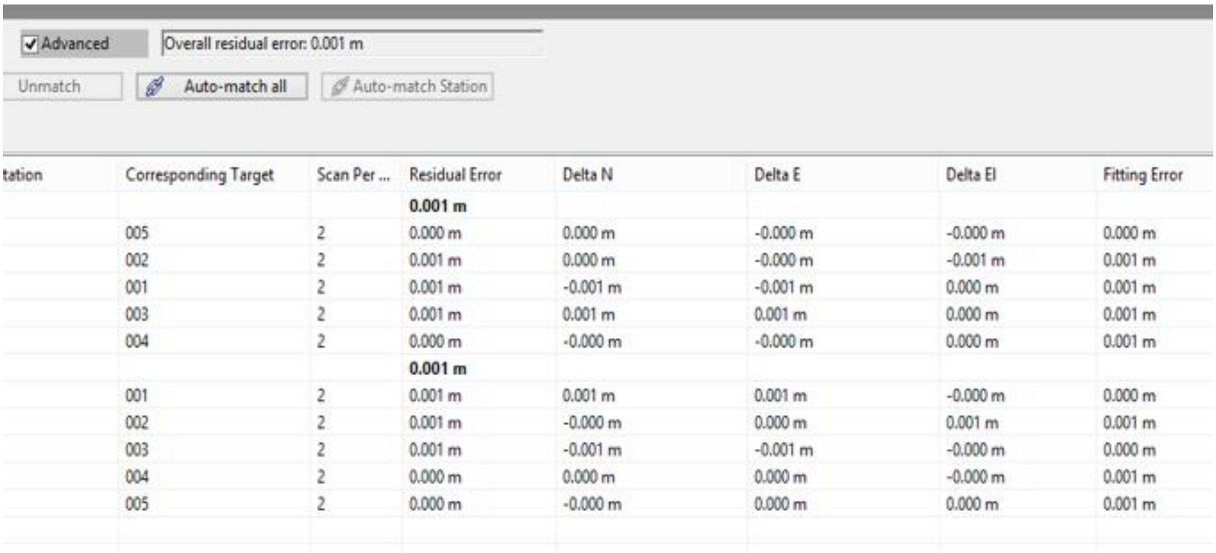
One own reference station was used, situated in the vicinity of the object. With the application of GNSS technologies significant productivity in the measurements was accomplished.

GNSS measurements were used for the coordination of the following parts of the existing situation: the terrain, the fences, the shafts, etc.

It should be noted, that using this highly productive method for measurements, also the own reference station, high quality results were obtained in the open field, especially for the height component.

9. RESULTS FROM THE GEODETIC MEASUREMENTS AND DATA PROCESSING. ANALYSIS

The relevant scans were imported and registered in Trimble RealWorks, using the "Auto-extract Targets and Register" menu option. The results from the registration process and its quality control from two of the stations are given in fig. 3 below.



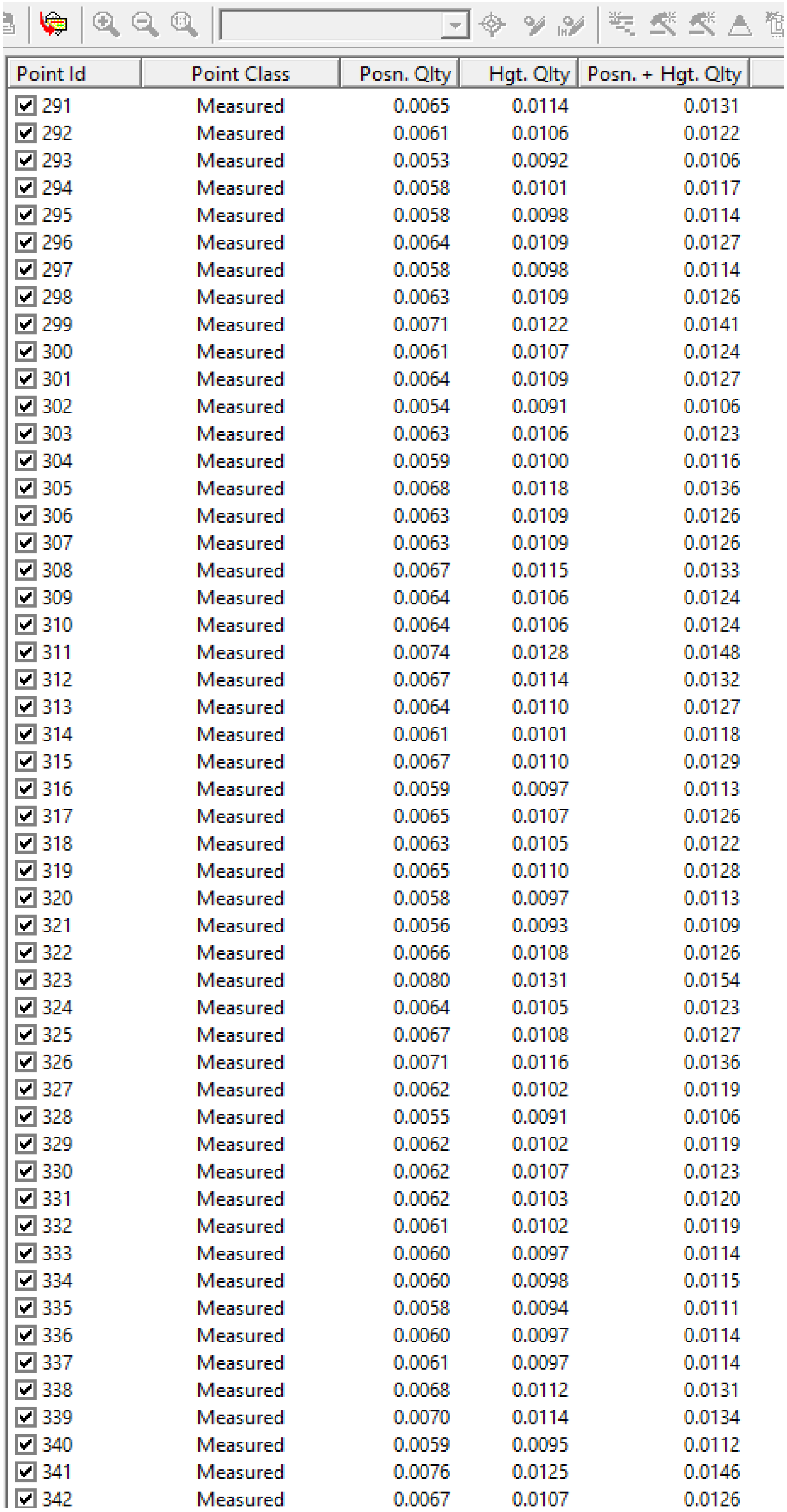
Advanced | Overall residual error: 0.001 m

Unmatch | Auto-match all | Auto-match Station

tation	Corresponding Target	Scan Per ...	Residual Error	Delta N	Delta E	Delta El	Fitting Error
			0.001 m				
	005	2	0.000 m	0.000 m	-0.000 m	-0.000 m	0.000 m
	002	2	0.001 m	0.000 m	-0.000 m	-0.001 m	0.001 m
	001	2	0.001 m	-0.001 m	-0.001 m	0.000 m	0.001 m
	003	2	0.001 m	0.001 m	0.001 m	0.000 m	0.001 m
	004	2	0.000 m	-0.000 m	-0.000 m	0.000 m	0.001 m
			0.001 m				
	001	2	0.001 m	0.001 m	0.001 m	-0.000 m	0.000 m
	002	2	0.001 m	-0.000 m	0.000 m	0.001 m	0.001 m
	003	2	0.001 m	-0.001 m	-0.001 m	-0.000 m	0.000 m
	004	2	0.000 m	0.000 m	0.000 m	-0.000 m	0.001 m
	005	2	0.000 m	-0.000 m	0.000 m	0.000 m	0.001 m

Fig. 3 Results from the quality control - registration of two of the stations of the scanner

In fig. 4 below is given a screenshot from the results of the measurements in RTK mode, taken from Geomax Geo Office environment, containing information for: position, height and combined position and height quality. It could be seen the obtained high quality of the GNSS measurement in the open field. The error for the height component was at about 10 mm. and even less, which satisfies the quality requirements for this task.



Point Id	Point Class	Posn. Qlty	Hgt. Qlty	Posn. + Hgt. Qlty
291	Measured	0.0065	0.0114	0.0131
292	Measured	0.0061	0.0106	0.0122
293	Measured	0.0053	0.0092	0.0106
294	Measured	0.0058	0.0101	0.0117
295	Measured	0.0058	0.0098	0.0114
296	Measured	0.0064	0.0109	0.0127
297	Measured	0.0058	0.0098	0.0114
298	Measured	0.0063	0.0109	0.0126
299	Measured	0.0071	0.0122	0.0141
300	Measured	0.0061	0.0107	0.0124
301	Measured	0.0064	0.0109	0.0127
302	Measured	0.0054	0.0091	0.0106
303	Measured	0.0063	0.0106	0.0123
304	Measured	0.0059	0.0100	0.0116
305	Measured	0.0068	0.0118	0.0136
306	Measured	0.0063	0.0109	0.0126
307	Measured	0.0063	0.0109	0.0126
308	Measured	0.0067	0.0115	0.0133
309	Measured	0.0064	0.0106	0.0124
310	Measured	0.0064	0.0106	0.0124
311	Measured	0.0074	0.0128	0.0148
312	Measured	0.0067	0.0114	0.0132
313	Measured	0.0064	0.0110	0.0127
314	Measured	0.0061	0.0101	0.0118
315	Measured	0.0067	0.0110	0.0129
316	Measured	0.0059	0.0097	0.0113
317	Measured	0.0065	0.0107	0.0126
318	Measured	0.0063	0.0105	0.0122
319	Measured	0.0065	0.0110	0.0128
320	Measured	0.0058	0.0097	0.0113
321	Measured	0.0056	0.0093	0.0109
322	Measured	0.0066	0.0108	0.0126
323	Measured	0.0080	0.0131	0.0154
324	Measured	0.0064	0.0105	0.0123
325	Measured	0.0067	0.0108	0.0127
326	Measured	0.0071	0.0116	0.0136
327	Measured	0.0062	0.0102	0.0119
328	Measured	0.0055	0.0091	0.0106
329	Measured	0.0062	0.0102	0.0119
330	Measured	0.0062	0.0107	0.0123
331	Measured	0.0062	0.0103	0.0120
332	Measured	0.0061	0.0102	0.0119
333	Measured	0.0060	0.0097	0.0114
334	Measured	0.0060	0.0098	0.0115
335	Measured	0.0058	0.0094	0.0111
336	Measured	0.0060	0.0097	0.0114
337	Measured	0.0061	0.0097	0.0114
338	Measured	0.0068	0.0112	0.0131
339	Measured	0.0070	0.0114	0.0134
340	Measured	0.0059	0.0095	0.0112
341	Measured	0.0076	0.0125	0.0146
342	Measured	0.0067	0.0107	0.0126

Fig. 4 Results from the quality control of the GNSS measurements in RTK mode

The large set of the data in fig. 4 shows information for the scale of the object and productivity of the applied technology. The results in fig. 3 and fig. 4 give information for obtained high accuracy both in the creation of the 3D digital model of the point cloud and also for the measured spatial coordinates of the points using GNSS technologies.

10. MERGING OF THE RESULTS FROM THE GEODETIC MEASUREMENTS. CREATION OF THE REQUIRED DIGITAL MODEL

The processing of the delivered spatial information further on consisted of three major parts:
Part I. Preparation of a register with coordinates (x,y) in the relevant projection and height for each measured point by GNSS technologies;
Part II. Creation of the 3D digital model of the point cloud, exclusively for the buildings and the nearby terrain. Extraction of the necessary information;
Part III. Unity of the data from part I and part II for the creation of the final product (*.dwg model).

Here will be given the important details for each part of the work separately.

Part I. The created register (x,y,h) was imported in the environment of a specialized bulgarian geodetic software Mkad. The measured points were connected in the respective geometric form (e.g. contour or line) using the point description, recorded during the field work. Furthermore, the digital model (in the plane) was styled in a way as to be used by other professionals for their work. The final digital model for this part was exported in *.dxf format.

Part II. Here, the 3D digital model of the buildings was georeferenced in the official coordinate system of the region as this was later on needed for the unity of the data from part I.

One of the useful features of Trimble RealWorks was used for the work in this part, i.e. creation of cross sections, one of which is given in fig. 5.

Fig. 5 Creation of a horizontal cross-section of an industrial building

The necessary cross-sections were extracted at the appropriate levels and delivered in *.dxf format. It is important to be noted that due to the specific spatial geometry of the buildings the model had to be carefully examined in the environment of Trimble RealWorks. In this way were eliminated the redundant details, which were not necessary for the further project activities by the professionals and the volume of the data was reduced.

Using the extracted data of the cross-sections, also applying the human factor to determine and eliminate the redundant details in the point cloud, the necessary data was exported in small volume of *.dxf file for usage in the next part of the workflow.

Part III. The specific process of the unity of the delivered data - in the plane (part I) and the extracted data (cross-sections and coordinates – part II) from the environment of Trimble RealWorks was done in *.dxf format for data exchange. The information from the sources, described in details in previous parts was united in AutoCAD environment. The process was performed with the mandatory human factor as some technical details (line types, colours, etc.) should be fixed in order to meet the requirements for further work and usage of the combined model.

11. CONCLUSION. RECOMMENDATIONS. FUTURE WORK

The paper studied the technical details of the implementation of one possible combined usage of the results from the measurements from: 3D terrestrial laser scanning and GNSS technologies, used for the creation of precise digital model of buildings with various shapes, adjacent terrain and existing cadastral elements. The surveying activities were required for the creation of project for vertical planning of the territory. The advantages and the disadvantages of the applied technologies were discussed in details in chapter 5.

It should be explicitly noted, that the mentioned disadvantages of the 3D terrestrial laser scanning and GNSS did not in any way decreased the overall productivity of the workflow. The listed disadvantages (in chapter 5) of each one of the technologies were “eliminated” by the advantages of the other. In this way – by one possible combination of the nowadays technical possibilities, the geodesist could benefit from efficient and productive way for conducting of the necessary geodetic measurements, data processing and interpretation of the results.

In our specific case were used highly accurate data from both 3D terrestrial laser scanning and satellite measurements. The data, given in chapter 9 proved the high accuracy (errors in the position and height of each measured point about several millimetres) of the delivered data from the performed geodetic measurements. The applied technologies produced large volume of spatial information, which was used for the creation of the project for vertical planning of the territory.

The ready-for-use results from this study – digital model in the plane in *.dwg with all existing information in the relevant type was created in the way, described in details in chapter 10.

Taking in mind the specific 3D details of the buildings and the scale of the object, it could be noted that the applied way of combination of the data from the measurements successfully fulfilled the requirements for productivity, accuracy and completeness of the created information.

Based on the given data for: the registration report from the performed laser scanning, the accuracy of the GNSS measurements also the technical details in chapter 5, it could be highly recommended the joint usage of the equipment (described in details at the end of chapter 2) in the geodetic practice.

Future work. The necessary attention should be concentrated on the needed update of the relevant normative documents in order to meet the existing technical possibilities of the contemporary geodetic instruments and software.

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10. http://tinyurl.com/pnqqabg
11. http://tinyurl.com/jjugclx
12. http://tinyurl.com/j7traoy
13. http://tinyurl.com/gsuc6pw - (in Bulgarian)
14. http://tinyurl.com/hl6nf4v - (in Bulgarian)

USED SOFTWARE

1. Autodesk AutoCAD (http://tinyurl.com/zc9mot3);
2. Geomax Geo Office (http://tinyurl.com/h9s4aop);
3. Mkad (http://tinyurl.com/hapgj9l- in Bulgarian);
4. Trimble RealWorks (http://tinyurl.com/pdckrlr);

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