APPLICATION COMPARISON OF 3D TERRESTRIAL LASER SCANNING BETWEEN TERRAIN AND NON - TERRAIN OBJECTS

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ABSTRACT: 3D terrestrial laser scanning technology is a revolution in the field data collection for various three-dimensional applications. It is used very effectively in the establishment of Digital Terrain Model (DTM), terrain changing assessment, as well as the non-terrain objects, especially tangible and intangible cultural heritage. The aim of the article is to compare the similarities and differences between the use of 3D terrestrial laser scanning technology in the terrain applications and the cultural heritage conservation. Several aspects were compared in details such as technical equipment, processes, and the actual products in the case study (Bac Ninh province, Vietnam). The results show that each field when using this technology has the advantages and disadvantages. The research will be very useful for scientists and technicians in different studies. They may combine the benefits of both fields in the future for the best outputs.

1. INTRODUCTION

The applications of the 3D terrestrial laser scanning to the terrain and the non-terrain objects have been becoming widely popular over the world nowadays [8]. The distances from the scanning stations to the objects are measured with the high accuracy by using this technology. Then, it records the corresponding scanning directions including the vertical and horizontal scanning angles. The terrestrial laser scanning system produces a big number of coordinated points at the same time with the 3D scanned images [2].

Terrestrial laser scanning has certain outstanding advantages. For example, (a) a very high density (up to millions of points) with the accuracy of mm; (b) a reduction of the volume of field work and an increase of labour productivity comparing to other traditional methods; (c) working all day or night (active scanning system); (d) a very stable data collection method; (e) real-time 3D visualization allows dead zones to be identified; (f) high point measurement accuracy; (g) allowing measuring the topography of very difficult areas, including hard-to-reach areas; (h) various products and applications of terrain and non-terrain objects; and others [4,5,9,14].

The different applications of 3D terrestrial laser scanning technology on the terrain and non-terrain objects has been studied by many researchers around the world. The changes of plant biomass were studied with the terrestrial laser scanning technology and quantitative structural modelling. Then, this study will provide a quick and efficient means of forest growth monitoring, mortality and biomass in 3D models [9]. Another research was measured the forest scale [3]. It helps to increase the use of terrestrial laser scanning for assessment the parcel-scale forest and monitoring the forest.

The study of modern caves in a decade was surveyed with terrestrial laser scanning technology. This research is very interesting because of the overview of sensors, methods, and the useful application providing the correct accuracy, speed, and point density for small and medium scale topographic maps [6]. The terrestrial laser scanning is effectively used also for the automated and efficient method for extracting tunnel segments [10].

In Vietnam, the terrestrial laser scanning technology is used in different research. The GeoMax Zoom 300 terrestrial laser scanning was applied for the establishment of 3D models of open pit mines [7]. The application of the terrestrial laser scanning allows the construction of thematic maps, digital elevation models, and terrain digital models. They are the necessary geospatial products for the calculation of the amount of peeled soil and minerals, for making and adjusting mining plans, for building pits, drilling and blasting [13]. Another study was studied about the combination of drones and terrestrial laser scanning to create the 3D models of urban areas [12].

2. CHARACTERISTICS OF TERRESTRIAL LASER SCANNING

The principle of 3D terrestrial laser scanning technology is to use a laser signal to measure the distance from the scanner to the object. Simultaneously with the distance, the scanner will measure the horizontal angle β and vertical angle γ. From the principle of polar coordinates, the machine's software will determine the X, Y, Z coordinates of the points.

The evaluation of the terrestrial laser scanning system is based on the following specifications [13]:
- Accuracy of measuring distances, horizontal and vertical angles
- Maximum resolution when scanning
- Maximum scanning distance
- Scanning speed, scanning angles
- Dispersion of the laser beam
- Safety level of laser use
- Lightweight, easy to handle and transport

In the laser scanners, the distance from the transmitter to the objects can be determined according to the principle of pulse measurement or phase measurement [6]. Terrestrial laser scanning in geodesy uses one of the following technologies to accurately determine the distances to objects:
- Time of flight
- Phase based

* Working principle of terrestrial laser scanners using pulse measurement "Time of flight" [11]

Terrestrial laser scanners with the pulse measurement technology "Time of flight" which are also known by another name "Pulse based", are the popular types of laser scanners in civil surveying. This is because the scanning beam has the ability to travel far (from 125 to more than 1,000 meters) and the data collection rate reaches 50,000 points to 1,000,000 points per second. Figure 1 presents the examples of 3D terrestrial laser scanners working by the pulse based method.

The structure of the "Time of flight" terrestrial laser scanner includes the following main parts:
- The laser emitter generates the beam;
- Mirror deflection system to direct the laser beam towards the object or drawing area;
- Secondary optical receiver system to determine the laser signal reflecting back from the measured objects.

So, the speed of light is a known value. The moving of time of the laser signal can be converted into an accurate distance data. Then, the distance from terrestrial laser scanner to the reflection point is determined by this formula (1):

$$D = \frac{1}{2}.\frac{c}{n}.\Delta t \qquad (1)$$

where,

c - velocity of spread laser wave;

n - environmental extraction coefficient;

Δt - time of going and back signal

* Working principle of terrestrial laser scanners using phase measurement "Phase based" [11]

The phase based technology scanners modulate the emitted laser light into multiple phases and compare the phase shift in the laser energy back to the receiver of the machine. The scanners use the phase shift algorithm to determine the distances based on the unique characteristics of each independent phase. The phase based laser scanners have shorter scanning distances than the pulse based scanners (25 - 27 meters). Besides, the phase based laser scanners have much higher data collection speed than the pulse based scanners. The accuracy of distance measurement depends on signal strength, noise, etc. Figure 2 shows the examples of 3D terrestrial laser scanning system working by the phase based method.

The distance is calculated using the formula (2):

$$D = \frac{1}{4\pi}.\frac{c}{f}.\Delta\phi \qquad (2)$$

where,

c - velocity of spread laser wave;

$\Delta\phi$ - phase difference in signal transmission and reception

f - signal modulation frequency

Δt – time difference

Leica P50 **Trimble SX 10** **GeoMax SPS Zoom300**

Figure 1. 3D terrestrial laser scanning system working by the pulse based method (Time-of-Flight)

FARO Focus S350 **Cyran 2500** **Leica HDS 6100**

Figure 2. 3D terrestrial laser scanning system working by the phase based method (Phase based)

Today, there are quite a few companies in the world that manufacture terrestrial laser scanning systems. For instance, Trimble (USA), Leica (Switzerland), Riegl (Austria), I-Site (Australia), Zoller & Frohlich (Germany), and others. They market their scanners with different purposes and many specifications. The FARO Focus 3D S350 was used for this study.

The FARO Focus3D S350 scanner which was introduced by FARO in Vietnam since 2019. It is a device that uses phase shift technology to determine the distance. The measuring range is 350 m. The measurement speed is up to 976,000 points per second. The accuracy is about ± 3.5 mm [1]. In addition, this is a product that integrates a camera with a resolution of up to 70 megapixels. The camera has the HD mode. The device has the most compact size in products with equivalent features. The size is 240 x 200 x 100 mm and the weight is 5.2 kg. The price is reasonable, and it has abundant advantages for the various applications.

3. RESULTS AND DISCUSSION

3.1 Process of the study

The case study of terrain and non-terrain using terrestrial laser scanning system is Lim mountain, Lim pagoda, and Phuc Hau temple in the Lim town of the Tien Du district, Bac Ninh province, Vietnam. Tiên Du is a rural district of Bac Ninh province in the Red River Delta region of Vietnam. The district capital lies at Lim. The Lim town covers an area of about 4.88 km².

The process of the research which has six main steps, is built in the Figure 3. The first step is the field work for the first surveying the objects. The second step is proposing the technical and economic project. There are several plans need to be calculated and prepared, such as station set options, target set options, coordinate network, lights and equipment. The third step is collecting data for the field work. The scanners will be set in the optimal stations. The targets and the lights are also set in the field. Back sight and foresight methods is used in this step. The fourth step is directly checking the data in the field. The noise and the colours will be checked. After that, the office-work step is conducted. The data will be processed in the computers by the experts. The accuracy will be assessed in this step. The final step is extracting the productions. The products will be used in different applications.

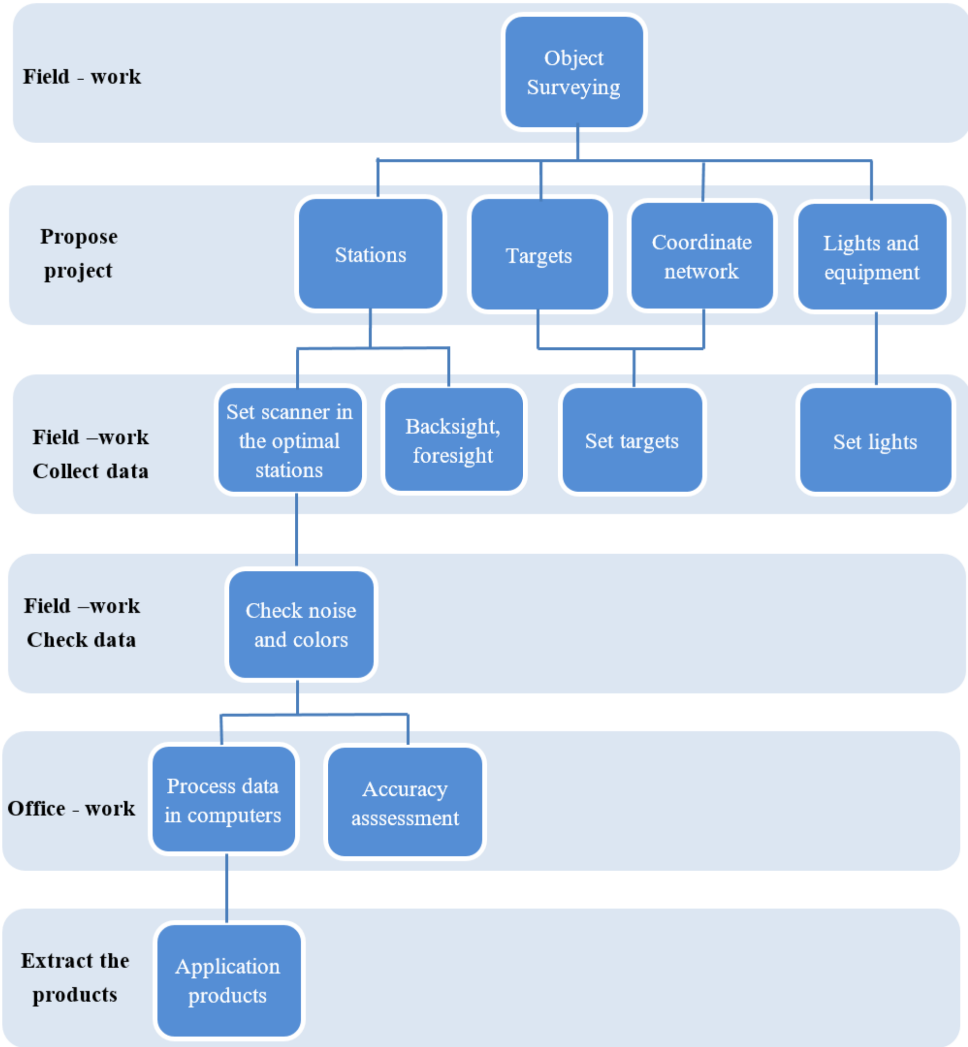

Figure 3. The process for terrain and non-terrain objects using the terrestrial laser scanning

3.2 Comparison results

The applications of 3D terrestrial laser scanning technology in the terrain field include the topographic map establishment, terrain digital model building, volume measurement, topographic change monitoring and evaluating, and others. The 3D terrestrial laser scanning technology in the non-terrain field has various applications such as architecture, construction and design, archaeology, cultural heritage, oil and gas, medicine, forecasting and eliminating dangerous incidents, and others.

After conducting the study, the results of the application of 3D terrestrial laser scanning technology in the terrain and non-terrain objects is compared in these following aspects (Table 1):

1. Comparison of technical equipment:
* Similarities: + Both are required the compact devices to be able to move with a long distance and with only one person. + The devices with the highest possible point cloud accuracy are needed (1-2 mm). + The objects could not be scanned through by scanners, even trees or glasses. + UAV may need to support.
* Differences: - *For the topographic survey*: + The equipment is required measuring with the long distance (> 300 m) in order to limit the number of stations. + The devices require the special targets. In addition, the coordinate targets are monitored with the high accuracy using GPS RTK or total stations (Leica). It is possible to use devices with mirrors to measure the coordinates of the location of the scanning stations for pairing (Leica/Faro). Besides, the devices with sensors to capture the exact coordinates of the scanner stations (Trimble) may be used. + The devices do not need high-resolution cameras as well as good image quality. It does not also need the

technologies to help photos with good brightness (HDR). It is also possible not to use the object photography function in terms of the topographic survey application.

- *For the cultural heritage conservation*:

+ The devices with the moderate distance measurement are need (< 150 m)

+ The devices needs to be compact (< 5 kg). They need to have the suitable targets, easy to move because of high density scanning.

+ The devices need the high-resolution cameras with nice and bright color quality and with HDR support for the best possible color.

2. Comparison of the process:

* Similarities: Both basically follow the process of Figure 3.

* Differences:

- *For the topographic survey*: The products are shown in Figure 4, Figure 5, Figure 6.

+ Location coordinates and targets with moderate accuracy are needed (10 – 50 cm)

+ Scanning stations have a distance from 50 to 100 m per station

+ The product is a digital terrain model. Therefore, there is no need for colors, or the colors do not need to be so beautiful.

+ The products include DTM, DSM, DTM, and topographic maps.

- *For cultural heritage conservation*: The products are shown in Figure 7, Figure 8, Figure 9.

+ Location coordinates and targets with high accuracy are needed (< 1 cm).

+ Scanning stations have a short distance from 10 to 20 m per station.

+ Various products include ortho-rectified maps (the need of UAV supporting), heritage point cloud model (use for digitization, conservation and restoration), 3D mesh model (use for restoration or advertising). Therefore, it is necessary to require cameras or an integration of cameras with high resolution as well as high image quality.

Figure 4. Digital Surface Model of Lim mountain case study (Bac Ninh province, Vietnam)

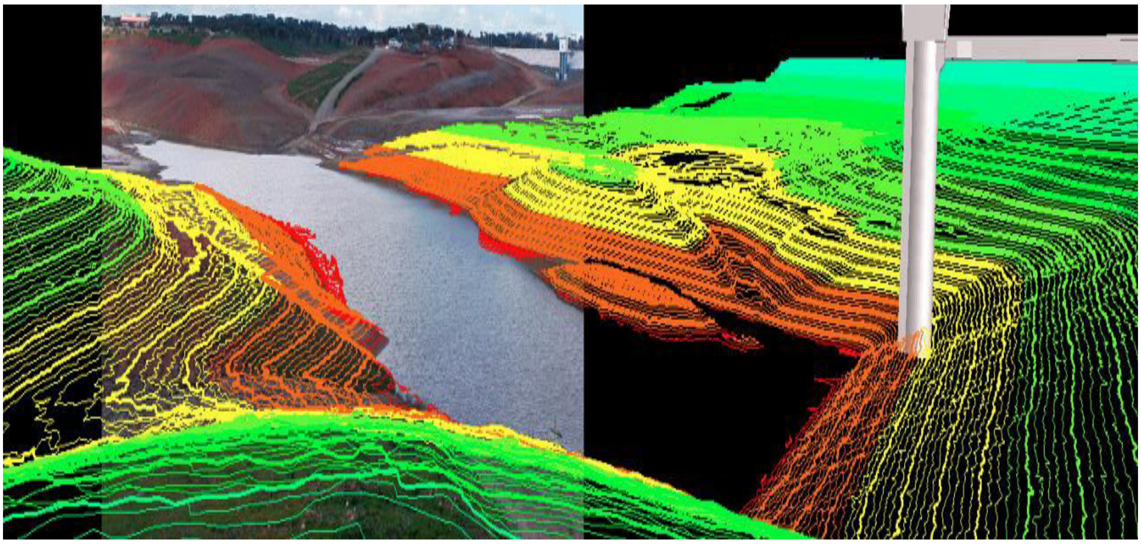

Figure 5. Digital Terrain Model of Lim mountain case study (Bac Ninh province, Vietnam)

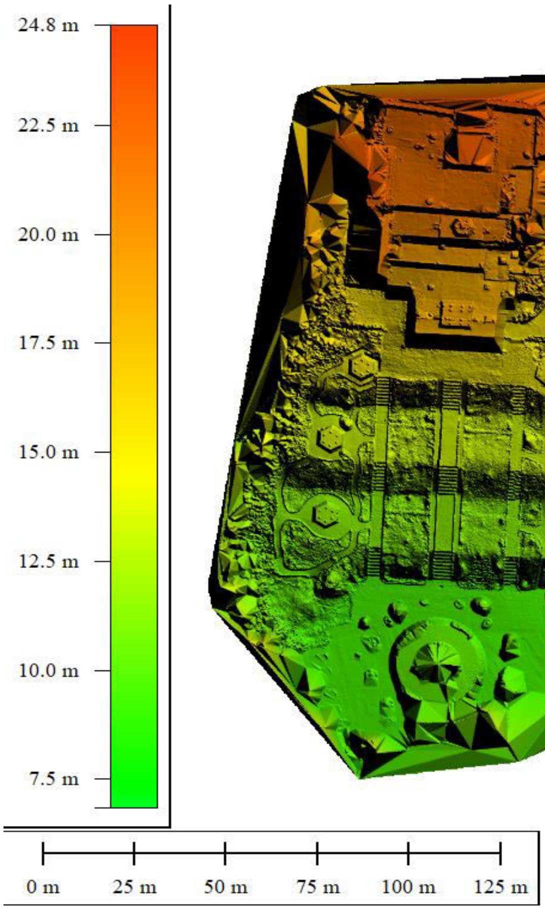

Figure 6. Digital Elevation Model of Lim mountain case study (Bac Ninh province, Vietnam)

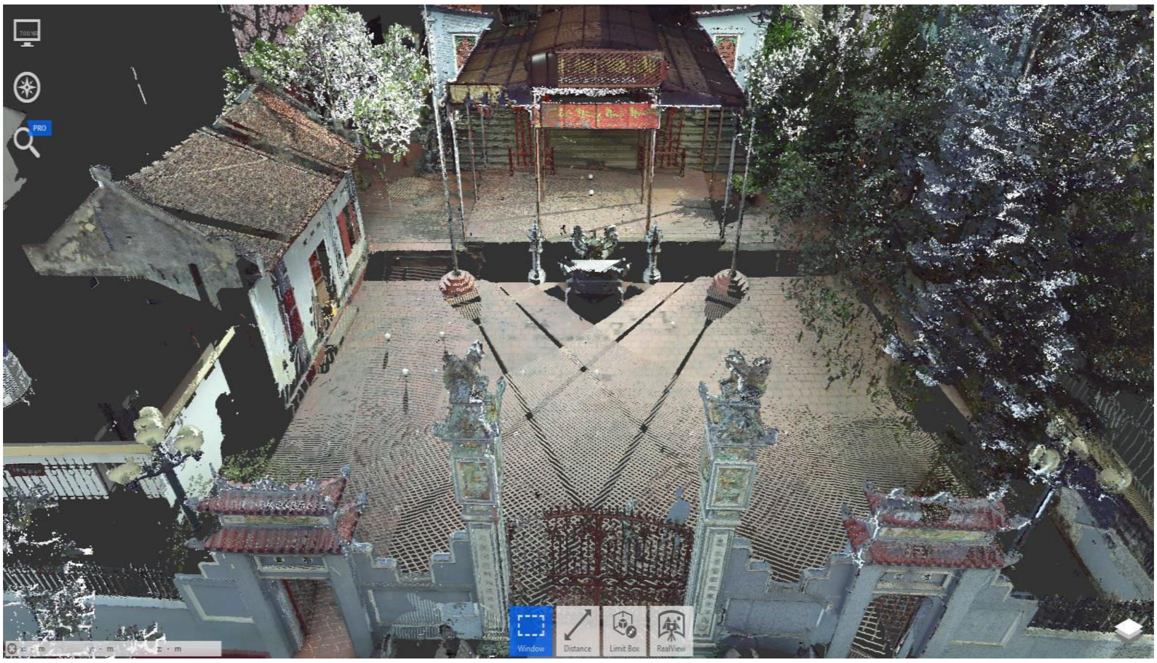

Figure 7. Point cloud model of the Phuc Hau temple (Bac Ninh province)

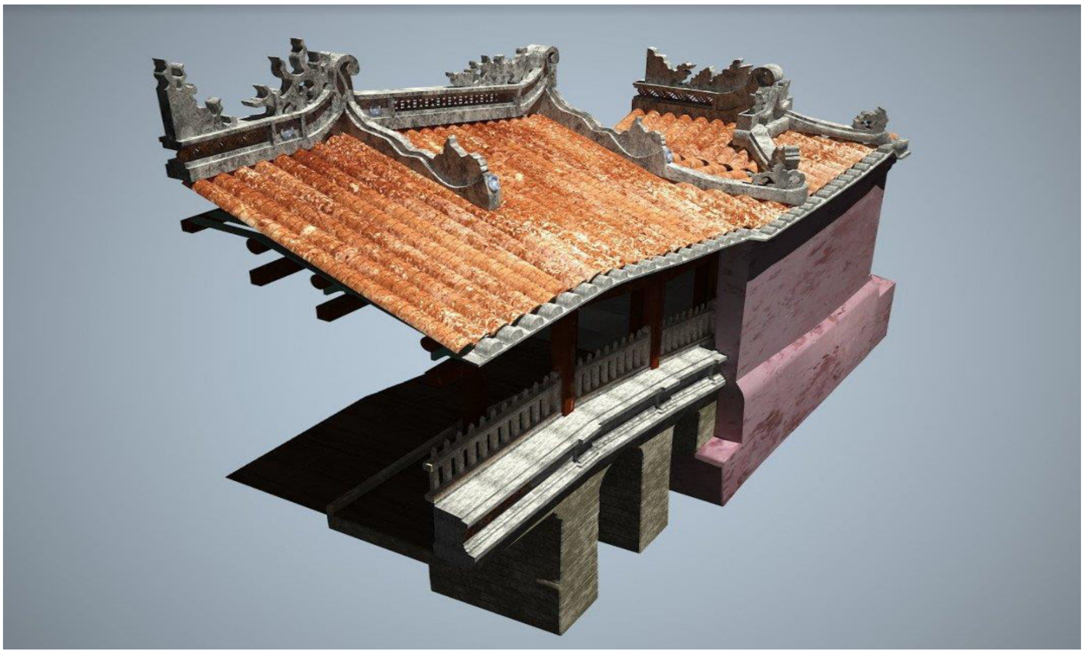

Figure 8. Solid model of the Phuc Hau temple (Bac Ninh province)

Figure 9. 3D terrestrial laser scanning product of a cultural heritage - Buddha with thousands of eyes and thousands of hands in But Thap pagoda (Bac Ninh province)

These figures above are the products of the terrain and non-terrain fields using the 3D terrestrial laser scanning. The Figure 4, Figure 5, and Figure 6 are the DSM, DTM, DEM of the Lim region in Bac Ninh province. Figure 7, Figure 8, and Figure 9 are the different models of the cultural heritage in Phuc Hau temple and But Thap pagoda in Bac Ninh province.

Regard to the terrain models, the obtained point cloud models are corrected and merged into the overall model. Then, the non-terrain objects are filtered in order to produce the surface topographic point cloud. After processing the point cloud model of the terrain in the scanning area, the software is used to interpolate the digital elevation model of the area. With a thick density of points, the digital elevation models are interpolated much more details than the traditional methods.

In terms of the point cloud model in this study, the scanned model has a high resolution with a scanning speed of 488,000 points per second. This is the average level to get a qualified product to establish a 3D model of the object. Depending on the type of products, the appropriate software to import data for the typical 3D modeling are used. For example, the Autodesk recap software was used for point cloud of the Phuc Hau temple. The parameters are directly measured in order to convert the 3D point cloud models to other 3D models such as HBIM models, 3D solid models, and 3D Mesh models.

The accuracy of these products (terrain and non-terrain objects) using the 3D terrestrial laser scanning meets the regulations of Vietnam conditions. The methods of the accuracy assessment of these two objects are different.

- Terrain objects: The absolute errors of the DEM are evaluated through the test points in the field. The mean square errors of the height of the test points set between the measured elevation and the interpolated one from the DEM should not exceed the allowable errors of the final DEM. The limit errors should not exceed two times the mean square errors. The deviations of the test points should not exceed the limit errors. The number of points should be in the range from 70% to 100%. The limit errors should not exceed 10%.

The data are examined in details. The DEM test points in the field are measured by the angle traverse method or the reverse intersection method. The electronic total stations, the static GNSS measurement technology, or the dynamic GNSS measurement technique with the elevation station base which is taken from the points of the second level or higher measuring framework are used.

- Non – terrain objects: The non – terrain product accuracy is assessed by using direct measurement of the area to be tested for accuracy with a tape measure. It is in order to compare with the products and evaluate relatively the accuracy. The location accuracy of the feature points is checked by direct measurement in the field using the electronic total stations or high-precision GPS-RTK.

4. CONCLUSIONS

The 3D terrestrial laser scanning technology is suitable for collecting the terrain data in the small areas. In addition, it also meets the need for data collection of non – terrain objects which have the high details. Each application for terrain or non – terrain objects using terrestrial laser scanning technology has its benefits or drawbacks in terms of technical equipment, process, or the accuracy.

When the 3D digital models of different terrain and non-terrain objects are built, it is necessary to have different solutions to provide the appropriate and flexible technical process in order to achieve the high efficiency in production. Some other types of terrestrial laser scanners, the various terrain and non – terrain objects, and the different case studies should be researched in the future.

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