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DATA QUALITY COMPARATIVE ANALYSIS OF PHOTOGRAMMETRIC AND LiDAR DEM

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ABSTRACT

Photogrammetry and LiDAR are best-known technologies of mass data collection. In this research, comparison of two DEMs (Digital Elevation Models), created from data collected by LiDAR and photogrammetric technology, was done. In that way it was tried to analyze these two technologies and discuss about their advantages and disadvantages. Research area was area of Petrovaradin (Novi Sad, Republic of Serbia). It was examined difference in heights between the two models, slope, minimum, maximum and mean height. Also, transversal profiles of some objects (the rampart and the tunnel) and places (terrain cover by forest and the coast), from the both models were compared. Statistics was approximately the same, but during the examination of transversal profiles some objects hadn't been detected on photogrammetric model. LiDAR model has better approximation of terrain in areas covered by forests, because of more ground points, which were detected thanks to laser beam capability to pass through tree canopy and reach the ground. Based on facts obtained during this study, LiDAR technology may be especially useful in archeology, during exploration in dense forests. Based on the performed analysis and the obtained results, in conclusion given are advantages and disadvantages of the obtained height models as well as their areas of application.

Key words: Photogrammetry, LiDAR, DEM, quality data, comparative analysis.

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1 INTRODUCTION

Considering the technology advancement in the digital terrain modeling and increasing trend of using laser scanners in collecting data and creating DEM from the same, it is of great importance to compare it with older, reliable techniques that have been used for a couple of decades in data collecting. Photogrammetry and LiDAR are today one of the best-known technologies of mass data collection. LiDAR is an active technology because it emits energy source (laser beams) rather than detects energy emitted from objects on the ground. And on the other side photogrammetry, based on images that are transformed from 2D into 3D models uses the same principle as 3D videos do (stereo photogrammetry).

The main advantage of LiDAR technology in comparasion with other techniques of remote researching is that the details on relief are directly measured, they are not gained with extra stereo restitution (Čekada, M. T., 2010). Point density of LiDAR recording affects on final result, more detailed analysis can be found in paper (Čekada, M. T. et. al. 2010). Also, LiDAR beam as an active sensor can penetrate through gaps in tree canopies and reach the terrain so it could be useful for digital terrain modeling (Buckowski, A. 2018). This fact is interesting for comparing two DEMs created from data collected by both technologies and for examination how photogrammetry approximates terrain in dense forest areas, i.e. what are the main differences in quality between these two technologies when we are talking about terrain modeling, that was done in this study.

Some researches dealt with similar topics, when we are talking about comparing these two technologies. Their subject of research was mostly focused on comparing the accuracy of forest inventory attributes estimated from high-density Airborne lasser scanning (ALS) (21.1 pulses m^{-2}) point cloud data (PCD) and PCD derived from photogrammetric methods applied to stereo satellite imagery obtained over forest in New Zealand. For mean top height ALS produced better estimates (RMSE = 1.7m) than those obtained from satellite data (RMSE = 2.1m). The satellite-derived CHM (Canopy Height Model) showed significantly lower detail than the ALS-derived CHM, reducing the usefulness of these data for tree-level metrics and delineation (Pearse et al., 2018). The comparative analaysis of photogrammetric and LiDAR data was done on flood example in Slovenia (Čekada, M. T., & Zorn, M., 2012). Analysis of LiDAR and multispectral Ikonos stereopairs on the example of DSM, revealed an overall vertical difference between the models of 8.2m, where only one third of the differences were below 3 m (Marsetič, A., & Oštir, K. 2010). With combination of LiDAR and ortophoto data, a high-quality visualization of area of interest can be obtained (Lunar, M. et. al. 2016). Laser scanning can be used for accurate characterization of forest properties (Shao et al., 2018, Shi et al., 2018a, Shi et al., 2018b, Hall et al., 2005, Naesset, 2002, Shao et al., 2018, Moran et al., 2018, Gu et al., 2018) or individual tree level (Chen et al., 2006, Holmgren and Persson, 2004, Persson et al., 2002, Roberts et al., 2005, Liu et al., 2017, Pierzchała et al., 2018, Hu et al., 2018). Study in the paper (Salekin et al., 2018) clearly shows that point density of vegetation affected on the quality of DEM. At the most demanding cases (steep downhills and urban areas), different methods for DEM creation based on concepts of mathematical morphology, result with accuracy higher than 90 % (Mongus, D. et. al., 2013).

Today is also in usage UAV - LiDAR (The Unmanned Aerial Vehicle - LiDAR), it is promising technology and attempts to be used for forest management due to its capacity to provide highly accurate estimations of three-dimensional (3D) forest structural information with lower cost than airborne LiDAR. A study in wich are evaluated the effects of UAV - LiDAR point cloud density on the derived metrics and individual tree segmentation results and evaluated the correlations of these metrics with above ground biomass (AGB) by a sensitivity analysis (Ginkgo platanation in east China). The results showed that, in general models based on both plot-level and individual-tree-summarized metrics performed better than models based on the plot-level metrics only (Liu, K. et al., 2018). Application of UAV technology during estimate of earthwork volumes determination of landfill or excavation of the building material was done in the paper (Urbančič, T. et. al. 2015).

Through few papers the comparative analysis of different methods of interpolation was done.These methods are commonly used in software packages.Some examples of these methods are: Inverse Distance Weighting (IDW), Nearest Neighbour (NN), Radial Basis Functions (RBFs), Local Polynomial or Kriging. Research in the paper (Arun, P. V., 2013). They revealed that, Kriging's method gave the smallest value of RMSE in most of cases. Besides Kringing method in paper (Szypuła, B. 2016), method NN gave good results too. On the other side, at impact of DEMs on the time which is analyzed for public transport in Warsaw, methods NN and Spline gave the worst results (Bielecka, E., & Bober, A., 2013). Conclusion that there is not optimal method of interpolation, can be found in several papers (Arun, P. V. 2013; Kienzle, S., 2004; 2000; Susetyo, C., 2016) and on the first place it depends on the focus of reserch. It is important to mention that application of visual methods has good impact on quality estimation of DEM (Asal, F. F., 2012).

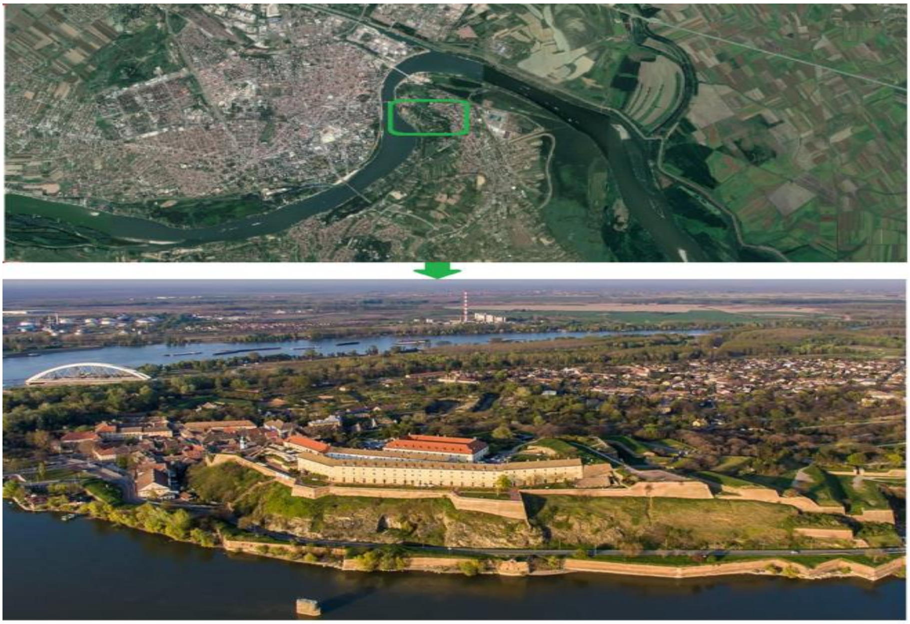

Fig. 1: *Area of interest*

In this paper, a comparison between two DEMs, created from data collected by LiDAR and photogrammetric technology, was done. On that way we tried to analyze these two technologies and discuss about their advantages and disadvantages. In some previous papers about similar topic, it was concluded that the LiDAR data were able to reflect more accurately the true ground surface in areas of dense vegetation, especially in places where the ground was invisible to photogrammetric operators (Alejandro Lorenzo Gil, 2012). Also, it was shown that LiDAR can reveal different geomorphological structures in densely vegetated regions (R.M. Landridge, 2013). That means that one of advantages of using LiDAR is detection change and measurement of large-scale geomorphological processes (Jason R. Janke, 2013). In this paper were compared models not only in forest areas but also in other places, including a general comparasion (over the entire area). The area of recording was Petrovaradin (Autonomus Province of Vojvodina, Republic of Serbia), one of two municipalities of Novi Sad (**Fig. 1**). It was built around fortress carrying the same name, during the 17th century. Research area covered the coast of the Danube river and the bed of the Danube.

2 DATA AND METHODOLOGY

Photogrammetric DEM used in analysis was obtained in its final form. Next, LiDAR DEM was created during the laser data processing step, and data were collected by the laser scanner *RIEGL LMS-Q680i*. The Number of recorded points was 66 million. Data acquisition was done by Laboratory for geoinformatics, Faculty of Technical Sciences and Italian company GEOCART S.p.A. The Scale of photogrammetric recording was 1:50 000. *Terrasolid* applications such as *TerraScan*, *TerraModeler* and *TerraPhoto*, which are specialized for laser data processing within *Microstation* software, were used.

Using different algorithms in classification process over cloud points and verification of the classification, besides other classes, class “ground” was created too and from that one, DEM was constructed within software *Microstation*. The model was exported as a lattice file in *GeoTiff* float format, with a resolution of 1 meter. To make comparison possible, it was necessary to overlap the models, i.e. to position them in the space on their real geographic location. The Positioning of the model, i.e. georeferencing and further analysis was done within *ArcGIS* software (**Fig. 2**).

Comparative analysis between two digital elevation models requires, among other things:

- slope calculation, minimum and maximum height, mean height and calculating other statistical data;
- calculating height difference and volume difference between two DEMs;
- drawing longitudinal and transversal profiles;
- visibility analysis (derivation of viewsheds)
- visualization of digital model (3D visualization and animation for better interpretation of terrain model) (Li, Z. et al., 2004);

Statistical calculations are obtained automatical for both models loaded in raster form.

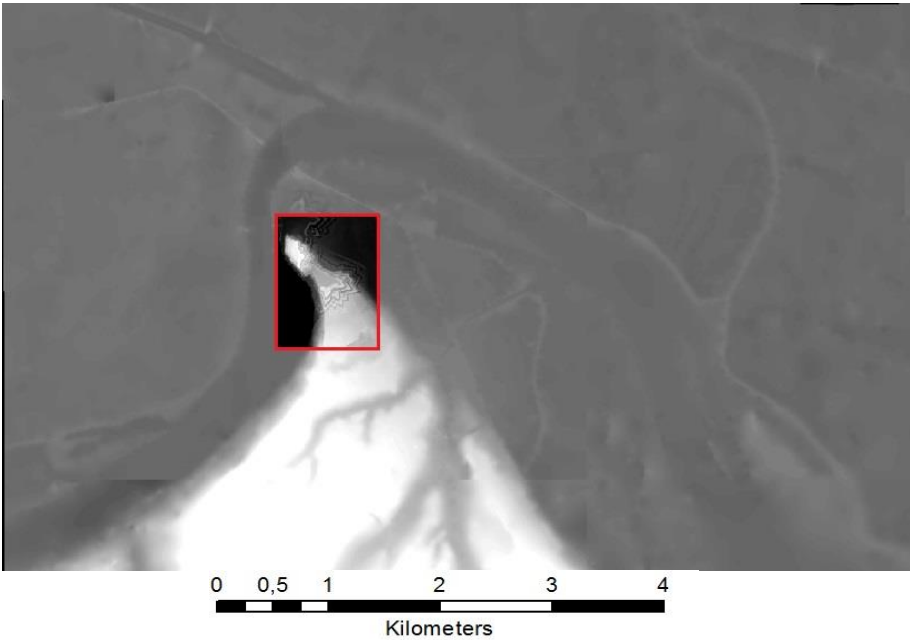

Fig. 2: *Overlap of two DEMs in raster form*

There are two opportunities for comparing two DEMs and calculating height difference between them, using an options *Cut Fill* and *Surface Difference*. Option *Cut Fill* is used for comparing two rasters. Software compares or deducts every pixel of the first image with the corresponded pixel of the second image. As a result, raster with display area where the input rasters match and where they don't, is obtained, i.e. where is one raster above or bellow the other one (Desktop.arcgis.com, 2018).

This method is commonly used during erosion examination of ground in a longer span of time in order to determinate where erosion occurred and where deposition or sedimentation occured. However, due to a more detailed analysis and better review of results, option *Surface Difference* was used because of a possibility of showing results in TIN format too (with hypsometric display of height differences), besides vector shp format(Desktop.arcgis.com, 2018). This tool requires that DEMs be displayed as surfaces, so conversion has been made from raster to TIN format before its use.

After conversion, used the tool *Surface Difference,* that works by perforimg a geometric comparison between triangles of both input surfaces. Triangles from the LiDAR DEM (**Fig. 3** Left) were classified based on checking if they were above or bellow the photogrammetric model (**Fig. 3** Right).

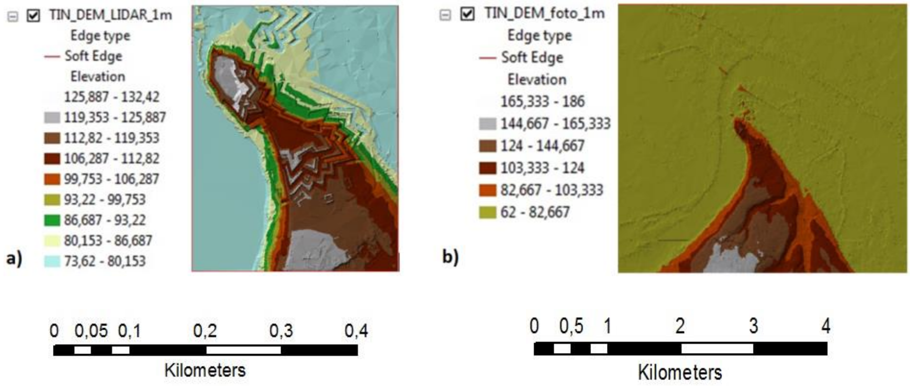

Fig 3: *Lidar DEM (a) and Photogrammetric DEM (b) after converion to TIN format with display of heights*

If intersection of one triangle from the first model with a triangle from second model is detected, then that triangle is split in smaller portions (triangles) in way that new triangles are above or bellow the second (photogrammetric) model with entire its surface, and after that, they can be classified into class “Above” or “Bellow”. Neighbouring triangles that are classified in same class are groupped into polygons, and volumes of triangles (volume space above or bellow the referent surface) are summed, creating in that way a good overview of the surfaces that are over or under the referent model. As a result, shape file is obtained in the output, with previosly defined and classified polygons and values of their surface area and volume. The difference surface is constructed using constrained Delaunay triangulation (Desktop.arcgis.com, 2018).

In order to get better review of difference between two models and find advantages of using different technologies on smaller localities, it is necessary to compare them on “local” level too, not just on global. That means that these two models should be analysed in some specific places and see which model better aproximates terrain in that specific area. For the purpose of this anaylsis as specific places we used a tunnel on right side of Kamenichki road, coast of Danube nearby (**Fig. 4** Center) and ramparts of the Petrovaradin fortress (**Fig. 4** Left). It is important to mention that ramparts of fortress that are covered in vegetation, taking into account their age and material from which they are built, were considered as an integral part of the terrain, so they were included in digital model. Also for analysis purposes, small forest area was observed (**Fig. 4** Right), on the north of the recorded area, in order to understand how presence of forest vegetation affects creation of DEM and which technology is more accurate in such cases.

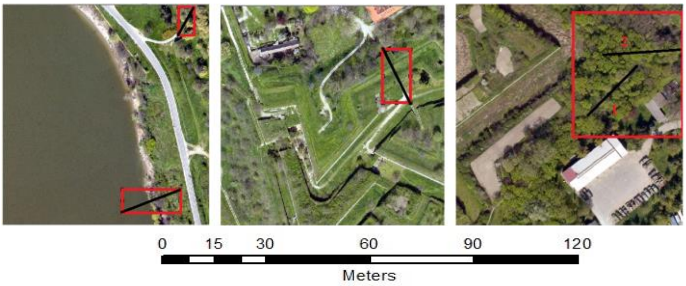

Fig. 4: *Marked profiles (areas of digitazed lines) for examination (tunnel, coast, rampart and forest*)

For this part of the task, *3D Analyst toolbar* was used with its tools for creating charts of longitudinal and transverse profiles of terrain models. Previosly, orthoimages of the tunnel, the fortress ramparts and the forest were georeferenced, in order to determine precisly the position of the tunnel and specific rampart on the model that will be analyzed. After that, using the tool *Interpolate Line*, we digitazed 3D line on the surface of that specific places. This tool allows turning off the display of the TIN model even during the digitization process, which can be particulary useful for better view and more accurate positioning of drawn objects. Also, digitization and analysis can be done on models in raster format too.

An important apsect of analysis and intepretation of digital terrain model is visibility analysis. Therefore, it was done in this paper too. Observation point was set up on the top of bulwark facing the Srem side which was detected on both models (Srem, serbian Срем/Srem is one three districts of the Autonomus Province of Vojvodina, Republic of Serbia). Tool *Observer Points* was used, that tool counts points that are visible on DEM in raster form, from the location that we specified earlier.

3 RESULTS AND DISCUSSION

Table 1 shows the statistical indicators analyzed for the area of interest (minimum and maximum height, mean height, slope calculation, and other statistical data).

Table 1:*Statistical data for both models*

	Photogrammetric model	LIDAR model
Minimum height [m]	71,00	73,62
Maximum height [m]	132,00	132,44
Mean height [m]	90,83	91,27
Standard deviation [m]	17,43	17,52
Minimum slope [˚]	0,00	0,00
Maximum slope [˚]	62,88	80,01
Mean slope [˚]	5,67	7,43

It was noticed that height range and standard deviation are aproximately same for the both models. However, value of minimum and maximum slope significantly differ, which may indicate that photogrammetric model is “smoother” than LiDAR model. Also value of the mean slope indicates that LiDAR model is more hilly than photogrammetric. Calculating height difference and difference in volume between two DEMs shows in the **Fig. 5**.

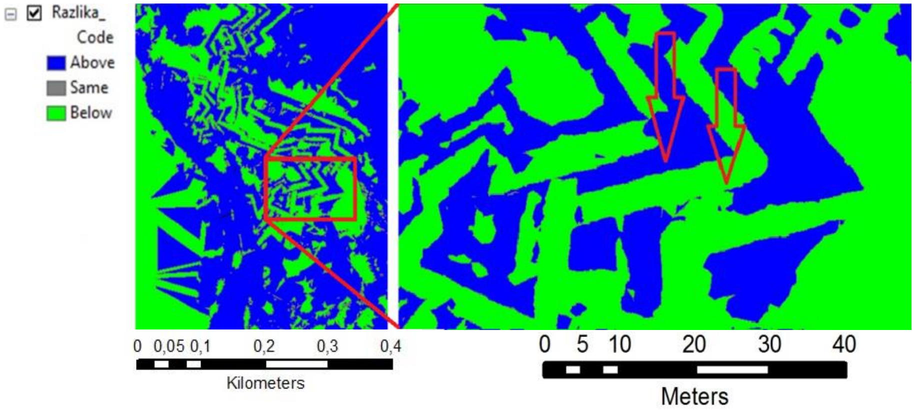

Fig. 5: *Feature class of differences with drawn polygons with example of height difference between rampart and the interspace between ramparts*

It is clear that the walls of the fortress are above the photogrammetric terrain model, while interspace is between them (green surface) lower than same space on the photogrammetric model (**Fig. 5**). It can be concluded that height differences between the top and the bottom of the wall are much bigger on the LiDAR model. The space on the northwest, that is inhabited, is mostly above, while the surface of the Danube is mostly bellow the photogrammetric model.

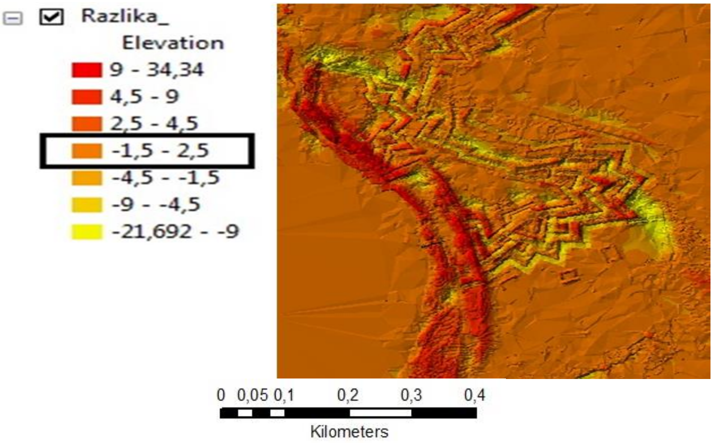

Fig. 6: *Model TIN with hipsometric display of height differences*

The value range of height difference classes was determined manually. Biggest differences according to the image above (**Fig. 6**) are on the west, along the coast of the Danube, on the right side, where differences are from 9m to 34m and near the southeast part of the fortress where they are from -21 to -9m. Considering that, accuracy of photogrammetric process of recording is 5m and accuracy of classification, it can be concluded, with certain degree of caution, that an “error/mistake” has occurred on the edges of Petrovaradin near the Danube and on the southeast. The height differences in other areas are in normal range and it can be noticed that models differ on biggest part of their surface, in a range from -1,5m to 2,5m. Sign minus suggests that in LiDAR DEM is lower than photogrammetric model in that region.

Based on graph profiles (**Fig. 7**), it was concluded that the tunnel is quite well detected on LiDAR DEM, compared to the photogrammetric model, where it was not detected. Such results justify a slight rise of the road before entering the tunnel, which corresponds to the actual situation on the ground.

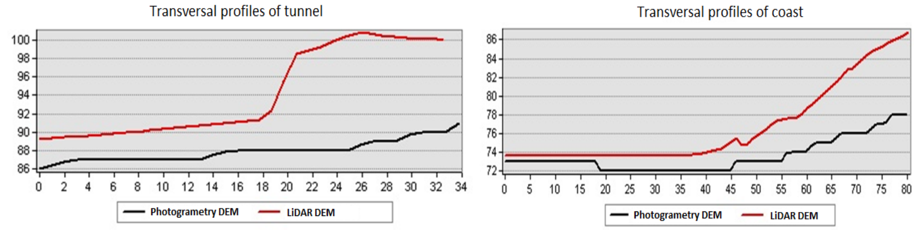

Fig. 7: *Transversal profiles of tunnel and coast*

It should be taken into account that the accuracy of photogrammetric model is 5m, so it is quite possible that the object on this model doesn't even exist. Profile of the coast (**Fig. 8**) is especially interesting for this study. Height differences between two graphs are not significant, and on 30-35m from the beginning , tilt change can be seen (border between water and the coast) on both profiles. The main difference is that on the LiDAR model, water height is fixed on constant value (it was done before creating the LiDAR DEM, within Microstation software, during the laser data processing step). So we can see a clear boundary in coastal area between the water and ground, and that is not case with the photogrammetric model.

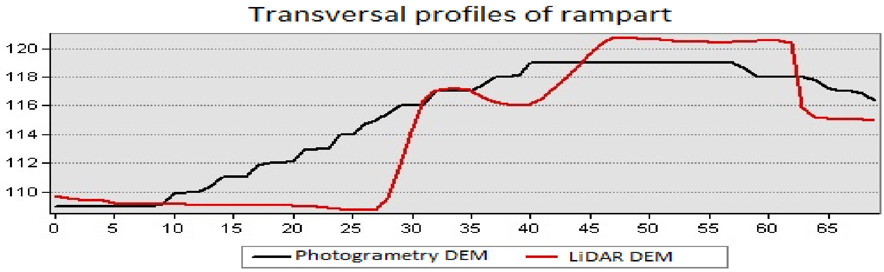

Fig. 8: *Transversal profile of the rampart*

On the transversal profile of rampart (**Fig. 8**), differences in height between these two models are in a range from few centimeters to 3m at the end of graphs. Similar change of altitude (height)on both graphs is noticeable, but with a different slope. Also we noticed that this slope is much more realistic (considering a fact that this is the transversal profile of rampart) on LiDAR model. The existance of the hillock and hollow (udoline) before the rampart, between 30th and 40th m indicate on interspace (path between the fence and rampart), where former austrian guards were passing during the time (Petrovaradin fortress was orginally built for military purposes as a fortification on Danube, during the austrian rule). The hillock, that is 1m high from the ground (hollow) and that is located near the "interpsace" or path, played the rule of protetective fence or wall, but in time it is collapsed and overgrown with vegetation.

Such structure of rampart on Petrovaradin, are confirmed by the ramparts near the Danube that are not overgrown with vegetation and that are preserved in a perfect condition. Finaly, it can be noticed that these profiles are not matching completely, based on the height change at the begging and at the end of the profile, that happens around 63rd m on the LiDAR model, and around 59rd m on the photogrammetric model. However, the structure of the terrain in this area on both graphs, despite the height difference, is similar, so it can be said that rampart was detected on both models.

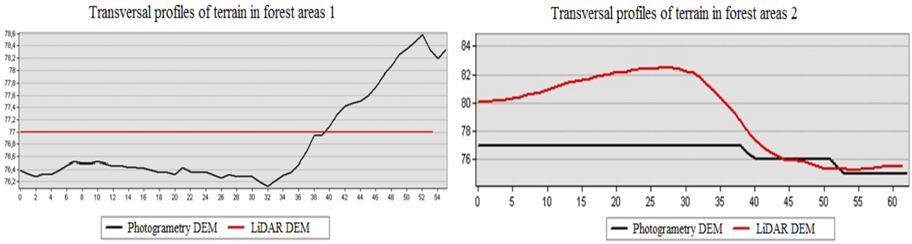

Fig. 9: *Transversal profiles of terrain in forest areas*

On these two profile graphs (**Fig. 9**) it can be easly noticed that, the height on the photogrammetric model does not vary significantly, it's even constant on the first profile graph and on the second it reminds on discrete function. That fact tell us about a small number of recorded points that represent a model in this area, collected by the photogrammetric technology. This indicates the impossibility to detect points in areas covered by dense forest vegetation. Unlike the photogrammetric method, laser beams easly pass through the vegetation reaching the ground, so based on few reflections tree canopy and terrain are detected (Rising, J. 2018).

3.1 Visibility analysis

It has been concluded that visibility on both models is similar (**Fig. 10**), but it's more clearly defined on LiDAR model. Still, it should be taken into consideration that these models couldn't be perfectly matched, so eventual divergence in visibility is possible from some other observation points which are not discovered in this research.

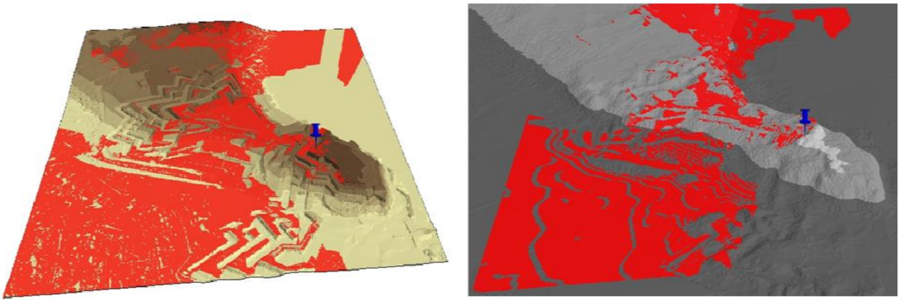

Fig. 10: *Visible surface from observation point on the LiDAR DEM (left) and on the photogrammetric DEM (right)*

4 CONCLUSION

Using different algorithms in classification process of cloud points in this paper and verification of the same, besides other classes, class “ground” was created too and from that one Digital elevation model was constructed within software *Microstation*. Such a model was exported as a lattice file in *GeoTiff* float format with a resolution of 1m. The lattice file unlike the raster one, represent a surface using a square net of points, of which, each keeps its original Z value (in this case its elevation)(Blogs.ubc.ca, 2018). This information is particulary significant during export to raster file. Scaling range of pixels was done, based on the whole area taking into account possible gaps that occurred during classification.

Considering that the goal was comparing two DEMs, export in the form of lattice file was used, to make the analysis more credible, by corresponding to real differences between models. Furthermore, the photogrammetric model contains surface of Danube river too, with mean value of 74m, the surface of the Danube is included in LiDAR model as well. Previously, the mean height on the surface of river was calculated, as the average Z value of 20 000 points, classified as water during classification. Calculating the mean height was necessary, as the height of the river surface varied at different places, due to the appearance of waves caused by wind and passing ships. Based on the calculated data, the height on the surface of Danube is fixed as 73,62m.

To make comparison possible, it was necessary to overlap the models, i.e. to position them in the space on their real geographic location. Positioning of model, i.e. georeferencing and further analysis were done within *ArcGIS* software. Georeferenced raster image is usually liable to distorsion, i.e. it loses data on its edges, due to fitting into coordinate system. The value of pixel on these places is null, so the height differences would be enormous on the edges, between two DEMs. In order to avoid this phenomenon, *Elevation Void Fill* function was used (**Fig. 11**). This function creates pixels in the elevation models, on regions where gaps with no data exists. Gaps i.e. holes appear due to the lack of points (in this case on the edges) within the surface that are represented in raster form. Function uses Plane Fitting/IDW (*Inverse Distance Weight*) method that estimates the value of created pixel or cell, that is based on the average value of neighbouring cells(Desktop.arcgis.com, 2018). Before execution this function we used *Mask* function that specifies areas (regions without data) over which function *Elevation Void Fill* should be executed (Desktop.arcgis.com, 2018).

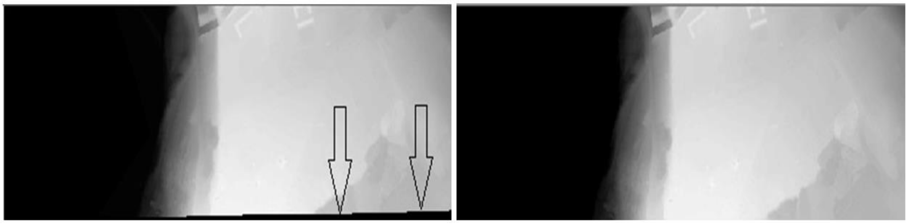

Fig. 11: *Before and after the using the function Elevation Void Fill*

After georeferencing of DEM and defining the spatial reference, filling “gaps (areas with no data)” caused by distortion during georeferencing, changing the resolution of photogrammetric DEM, valid overlap of two models is provided, and it is accurate enough so the comparason could be done.

Differences between two models are not latge in the majority of areas. The smallest differences were noticed on areas without vegetation that have the smallest slope. Increasing of the slope and appearance of dense forest vegetation caused increase in height differences. Based on these presented facts, it can be concluded that photogrammetric model gave quite solid results on majority of places, representing the ground in accordance with its accuracy. However, during the analysis of the transverse profiles, we noticed that some anomalies of the ground are not detected on photogrammetric model. This indicates a bad aproximation of terrain in these regions, comparing to DEM created from LiDAR data. The advantage of between these two technologies in areas with dense forest vegetation is given to the LiDAR technology because of the possibility for better terrain detecting, and that estimation was given, during the study of these transversal profiles of terrain in forest areas. Also this technology, based on examination of terrain model in forests in this paper, can be useful in archeology during discovering ancient cities and places in regions such as Amazon, equator and other areas covered by dense vegetation.

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