http://dx.doi.org/10.15576/GLL/2017.2.21

GLL
Geomatics, Landmanagement and Landscape No. 2 • 2017, 21–35

CYCLE PATHS DESIGN BASED ON AERIAL LASER SCAN DATA

Stanisław Bacior, Jacek Gniadek, Izabela Piech, Joanna Stachowicz

Summary

Development of cycle routes in Poland is a frequently discussed topic. This type of infrastructure may be designed using a variety of methods. Manual planning of new cycle paths based on aerial laser scan data is relatively quick and also precise. The ALS technique can provide the required accuracy of design map in terms of elevation measurements. It is worth noting that only a few years ago studies indicated that elevation measurements were less accurate when using this particular technique [Hejmanowska, Warchoł 2010]. The designer has a detailed insight into the studied area. He may easily assess the terrain and choose the optimal location for the given object. Planning the route course and its elevation variability is simple when using a Digital Terrain Model.
The first stage of the present study analyses the rules that apply to bicycle route design and the area covered by the study. The course of the new cycle path was planned in such a way as to connect the most important places in towns as well as places of tourist interest. The resultant route is 1.8 km long and runs along the main road. Development of DTM and its visualizations were performed mainly on the basis of two point clouds provided by the Geodetic and Cartographic Documentation Center. The initial works were performed in MicroStation PowerDraft V8i software. In the next stage, a 3D visualization of the model was generated with the use of Surfer 11 program. Based on that, a longitudinal profile of the route was created.

Keywords

aerial laser scanning • Digital Terrain Model • cycle paths • cycle routes • longitudinal profile

1. Introduction

One of the latest and also most time-efficient methods of obtaining object data is aerial laser scanning. This technology, called LiDAR or ALS still continues to develop. Currently, this particular technique finds its application in many new fields. Visualization of spatial information regarding tourist trails offers huge possibilities not only at the stage of planning, but it also makes it possible to promote the existing trails more effectively. The spatial data obtained from aerial laser scanning (ALS) undoubtedly introduced new quality standards to the 3D-type spatial analyses, especially topographic and environmental analyses. This results from the fact, that ALS data are characterized by dense sampling of the area, allowing to obtain a cloud of points of known coordinates (X, Y, Z) [Chrustek 2015]. The ALS technology is widely applied in a large area of studies due to the data quality and the speed of its acquisition. The data then facilitates assessment of the condition of forest stands and the height of individual trees [Wężyk, Solecki, 2008]. Thanks to this method, the time required to plan complex road networks for large areas decreased significantly. These are just a few exemplary applications of the LiDAR system, which is highly competitive compared to other methods. Its applications range from the development of Digital Terrain Model and Digital Surface Model, to the creation of detailed models of individual objects, such as buildings [Podręcznik… 2015].

Designing cycle paths has recently become a much-discussed topic. An increasing number of people, especially in the cities, demand well-developed cycling infrastructure. New cycle paths are planned in Kraków for the year 2017. The cycle paths' network development program started this year, and it is meant to be continued until 2020. It is focused mostly on recreational cyclists. The routes will connect interesting places in Małopolska and will not require large effort. The cycle paths will largely run along rivers. They will also use disused railway embankments and the existing infrastructure. Eventually, the network will cover more than 1000 kilometres [Drath 2016]. There is an extensive legal aspect related to the buyout or expropriation of land plots for cycle path construction. If the owners object, the planned course has to be modified. This study focuses purely on the practical application of the LiDAR for design purposes, without taking into consideration the legal aspects. An ALS based analysis allows us to determine the optimal course of newly designed bicycle routes, connecting the existing terrain elements, i.e. embankments, slopes or ditches.

The aim of the study was to design safe cycle paths, separated from motorized traffic, in the village of Kasinka Mała, based on the assessment of natural values and conditions, terrain topography, DSM and aerial laser scan data. In order to make a logical decision regarding the course of the route, the village was thoroughly analysed. The detailed rules of design were brought up as a basis for further works. The final analysis involved generating a Digital Terrain Model along with its 3D visualization. The project was implemented in accordance with the applicable standards [Rozporządzenie... 1998]. The end result shows the course of the cycle path against the selected part of the area with layers of buildings, rivers and roads.

2. Subject and methods of the study

Kasinka Mała is located in the Małopolskie Voivodeship, county of Limanowa, Mszana Dolna municipality, at provincial road No. 968. The village is located in the northwestern part of the municipality (Figure 1) on the western edge of Beskid Wyspowy mountain range, near the Kasiczanka river mouth to the Raba river. Its elevation ranges from 370 to 440 metres. The village is surrounded by three peaks of the Beskid Wyspowy: Szczebel, Lubogoszcz and Kiczora.

Source: Google Maps

Fig. 1. Location of Kasinka Mała

2.1. Rules for the design of tourist cycle routes

In Małopolska there are three classes of tourist cycle routes: 'main', 'other' and 'cooperating'. They are complemented by all kinds of routes: recreational, extreme, sports routes and other [Podręcznik do projektowania… 2013]. Their design is based on the "backbone and fish bones" rule. All other and cooperating routes have to be directly connected to the main routes. It is not allowed to design isolated loops. The fundamental principle of tourist route design is an access to a railway. A route (especially a main route) has to begin in the centre of town, preferably by a railway station, where the cyclists can use maps, buy a guide and find all the information they need. The basic function of a main route is to handle transit traffic and to connect adjacent regions. Other routes are complementary and can serve as alternate routes of various difficulty levels. The main purpose of cooperating routes is the service of travel points [Ziebura 2013].

Design of bicycle infrastructure is based on the so-called five criteria of the Dutch standardization organization called CROW [www.crow.nl]:

- Consistency
- Directness

- Comfort
- Safety
- Attractiveness

These have been published in a design manual for cycle-friendly infrastructure “Sign up for the Bike” [Postaw na rower… 1999].

2.2. Technical parameters

Each bicycle route class has to meet certain standards. They determine various parameters, such as design speed and minimum width of the routes. Detailed technical parameters are shown in Table 1.

Table 1. Bicycle route classes and their parameters

Technical parameters	Class		
	Main	**Other**	**Cooperating**
Design speed	min. 30 km/h	desired 30 km/h	desired 20 km/h
Minimum width of one-way route	1.5 m	1.5 m	1.0 m
Minimum width of two-way route	2.0 m	2.0 m	1.5 m
Minimum width of two-way pedestrian-bicycle route	3.0 m	2.5 m	2.5 m
Horizontal gauge	0.5 m	0.2 m	0.2 m
Delay coefficient for 1km of route	15 sec	15 sec	undetermined
Maximum elongation coefficient	1.3° *	1.5°	undetermined
Minimum radius of horizontal curve	20	20	undetermined
Slope for main routes	6% **	10% ***	undetermined

* greater elongation coefficient is acceptable as long as it eliminates excessive slope for longer sections and results from natural conditions, such as meandering of river valleys

** value greater than 6% should be avoided for sections longer than 250 m; the 6% threshold may be exceeded and reach even 15% for small elevation differences (up to 1.5 m)

*** should not exceed 10% for sections longer than 250 m

Source: [*Podręcznik do projektowania…* 2013]

The most attractive bicycle route in all of Małopolska runs in the west – east direction (Figure 2). It is classified as “other” due to the exceeded 6% slope for a distance longer than 250 m. It was intended to be a main route for VeloBeskid. Unfortunately this is currently impossible, as the Limanowa District authorities did not approve for the route to be led on a disused railway line, which meets the criteria for main routes. It is 198.1 km long.

Source: [Podręcznik do projektowania… 2013]

Fig. 2. VeloBeskid bicycle route (Małopolskie Voivodeship)

2.3. VeloRaba

The main route of Małopolska, 125 km long, runs in the south-north direction along the attractive area of Raba Valley (Figure 3). It begins in the village of Chabówka and ends in Uście Solne. This route is not yet fully adjusted to the applicable requirements.

2.4. The designed cycle path

The course of VeloRaba route in the analysed area runs along provincial road No. 968 (class G). In this case, it is recommended to segregate bicycle and motor traffic. Moreover, according to the Regulation of the Minister of Transport and Marine Economy [Rozporządzenie… 1998] for special cases, justified by local conditions, as well as for reconstructions or renovations of streets, mentioned in paragraph 1, it is acceptable for the sidewalk to be adjacent to the carriageway, although for S and GP class roads it is necessary for the sidewalk to be separated from the carriageway by a fence, or other equipment that will grant safety of traffic.

Source: [Podręcznik do projektowania… 2013]

Fig. 3. VeloRaba bicycle route (Małopolskie Voivodeship)

The designed cycle path begins at the intersection of provincial road No. 968 (Krakowska) and local road by the graveyard. It then runs southwards, along road No. 968 to the border of the village, where the black trail leading to Szczebel begins. The aim of the project is to design a new, two-way cycle route, meeting the requirements of a main route with the width of 2.0 m. The route not only has a tourist function, but it also connects the centre of Kasinka Mała with important institutions, such as the school, church, or fire station (Figure 4).

Legend

A – beginning of the designed cycle path
B – graveyard
C – Church of the Visitation of the Blessed Virgin Mary
D – elementary school No. 1
E – Volunteer Fire Department
F – wayside shrine
G – end of the designed cycle path/village border
H – beginning of the black trail leading to Szczebel
I – road leading to a holiday resort

Source: J. Stachowicz study with the use of orthophotomap

Fig. 4. Course of the designed cycle path in Kasinka Mała

2.5. Obtained materials

The data for the analysis were acquired from the Geodetic and Cartographic Documentation Centre. The point clouds were obtained from an aerial laser scan, and they cover the area of Kasinka Mała. The selected clouds were: M-34-77-C-c-3-2-1 and M-34-77-C-c-3-1-2 from part 4, and also M-34-77-C-c-3-2-3 and M-34-77-C-c-3-2-4. The main analysis is based on clouds M-34-77-C-c-3-2-1 and M-34-77-C-c-3-2-3. The remaining two: M-34-77-C-c-3-1-2 and M-34-77-C-c-3-2-4 were used to give geometric shape to the analysed surface. The cloud classification was performed with precision of no less than 95%. The density of points ranges between 4 and 12 points/m^2, and the average elevation error does not exceed 0.2 m. The point clouds are oriented in the 1992 coordinate system, while the elevations are based on the Kronstadt 86 system [http://www.codgik.gov.pl].

The analysed point cloud, according to the LAS and ASPRS formats, contained the following classes:

1 – points processed, but unclassified,

2 – points located on the ground surface,

3 – points representing low vegetation, i.e. from 0 to 0.40 m,

4 – points representing medium vegetation, i.e. from 0.40 to 2.00 m,

5 – points representing tall vegetation, i.e. taller than 2.00 m,

6 – points representing buildings, structures and engineering structures,

7 – noise,

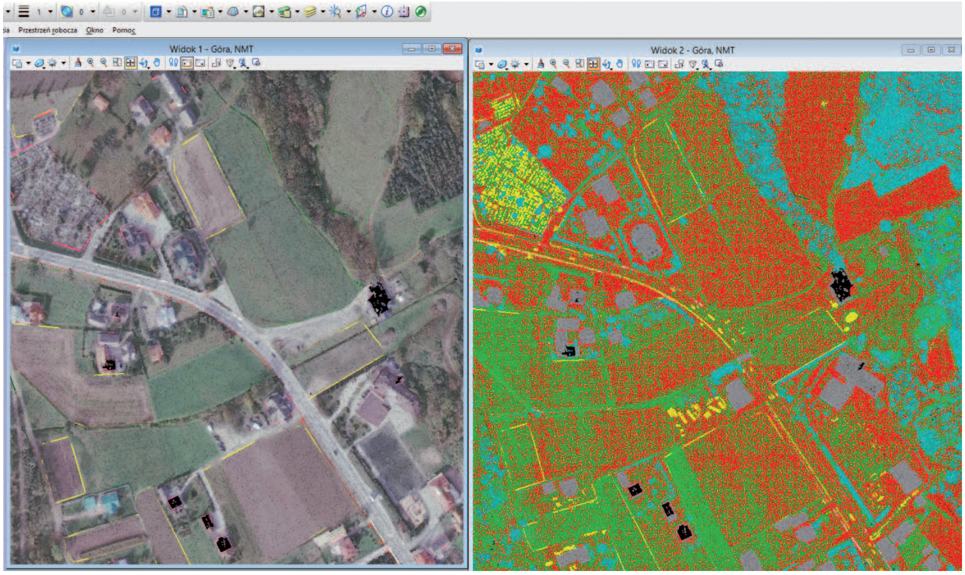
8 – points representing water surfaces [www.codgik.gov.pl].

The selected relevant point clouds were then processed in the Microstation PowerDraft V8i software by Bentley. After the data was loaded, the point cloud was trimmed and adjusted to fit the needs of the work, and layers were prepared for the purpose of creating a Digital Terrain Model. Such elaborations are usually thorough and long lasting. The work involved creating a model based on the selected layers by assigning them the following colours: meadows and grasslands – bright green, forests – dark green, asphalt roads – white, water – blue, dirt roads – brown, arable lands – yellow, designed cycle path – red.

The contours of the objects located on each layer were outlined along the points lying on the ground (points classified as ground). In order to obtain the most faithful model, efforts were made to use as many points as possible. However, there were limitations in certain places resulting from insufficient point cloud density. By connecting two points, a vector of known XYZ coordinates was obtained. Meadows, grasslands and arable lands were the easiest to define. In the RGB view they could be easily assigned to relevant layers. Problems occurred in the close proximity of forests. Trees often obscure the view and make it difficult to properly define the border of an area. The Microstation software allows for a free rotation of the point cloud. This option makes it possible to properly select a point in areas of diverse terrain cover.

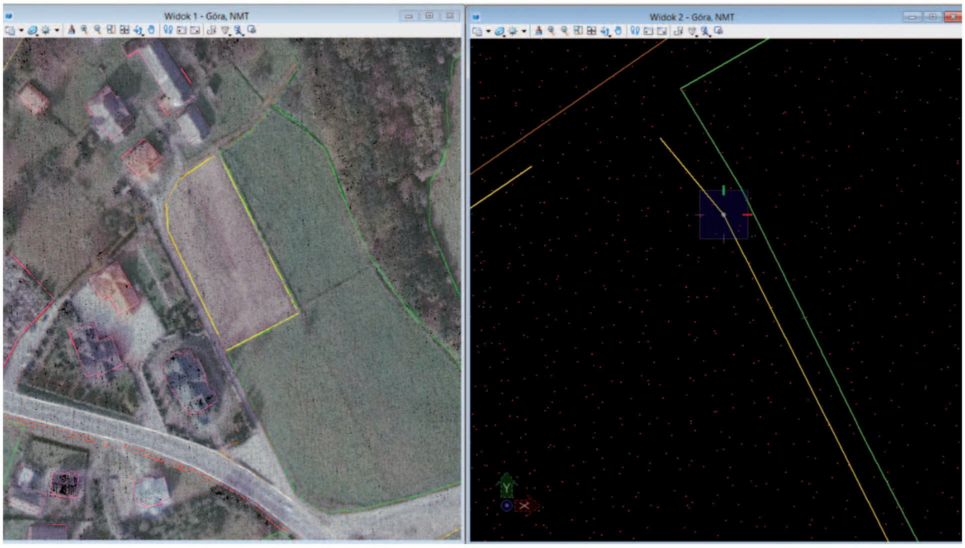
Vectorization was performed with the use of point cloud, because the aim of the study was to design cycle paths based on the data from aerial scan.

In order to properly select the points, the screen was split into two views for the purposes of drawing. In the case of terrain that was flat, easy to define and not covered with vegetation, a top-down view was used. The left side of the screen displayed the RGB view while the right side showed the classification mode view. The RGB view facilitates a proper definition of the boundaries of an area, and the classification view makes it possible to select the appropriate point of the ground. The drawing was performed in classification mode with an RGB preview (Figures 5 and 6).



Source: J. Stachowicz study based on the data obtained from GCDC

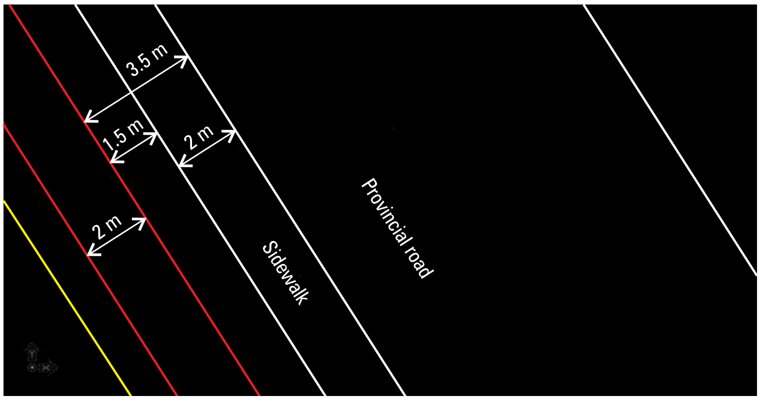
Fig. 5. Split screen view in Microstation software



Source: J. Stachowicz study based on the data obtained from GCDC

Fig. 6. Arable land outline

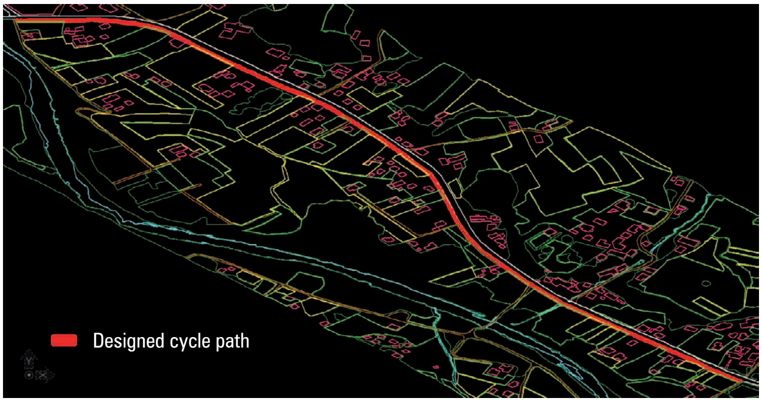
The designed cycle path, marked in red, runs along the provincial road (in white). The layer contains the road itself and 2-metre wide sidewalks. In order to meet the design requirements, the borders of the cycle paths were drawn 1.5 metres from the edge of the sidewalk. In Summary, the designed cycle path remains within the acceptable 3.5 metres of distance from the carriageway edge (Figure 7).



Source: Joanna Stachowicz, Microstation software

Fig. 7. Position of the designed cycle path

The last stage of the works was the verification of the drawn layers with the view to selecting the appropriate points of the cloud. Corrections involved e.g. moving points from trees or other tall vegetation that obscured the ground. This was done without changing the original outline shape. As a result, a Digital Surface Model visualization, shown in Figure 8 was created.



Source: J. Stachowicz study

Fig. 8. The course of the designed cycle path shown on the Digital Surface Model visualization

2.6. The stages of terrain model development

Digital Terrain Model visualization was performed using the Surfer 11 software. Surfer is one of the most popular programs used for versatile visualization of XYZ data. It is used to create maps as well as in terrain surface modelling. The program can quickly generate a model based on a data table or a function. The operation is based on gridding procedures and algorithms for creating a regular grid of values for functions of two variables. Based on a finite number of points with XYZ coordinates, a z = f (x, y) function is created. Surfer uses this method for visualization, while the density is set by the user. Based on irregularly distributed XYZ points, it calculates the function values for the nodes of a rectangular grid of defined geometry [www.surfer.net.pl].

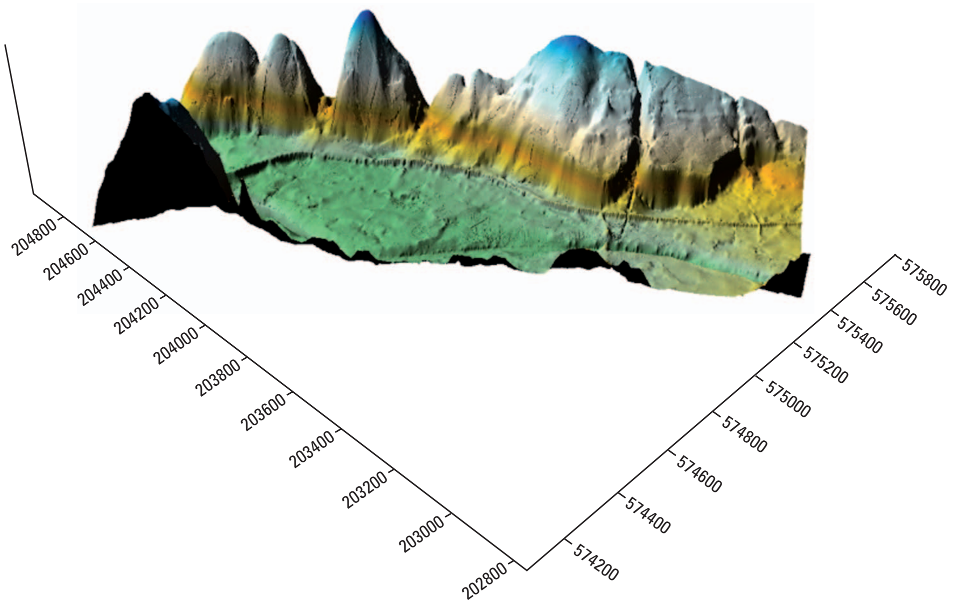
Once the grid is created, the program automatically generates a report, which includes minimum, average and maximum values of input data. These parameters for elevations are shown below:

Z_{min} = 353.43 m a.s.l. (above the sea level),

Z_{avg} = 376.42 m a.s.l.,

Z_{max} = 426.85 m a.s.l.

The obtained model is automatically generated by the software, based on the selected parameters. Therefore, the terrain appears to be mountainous, while in fact its elevation ranges from 360 to 425 metres (Figure 9).

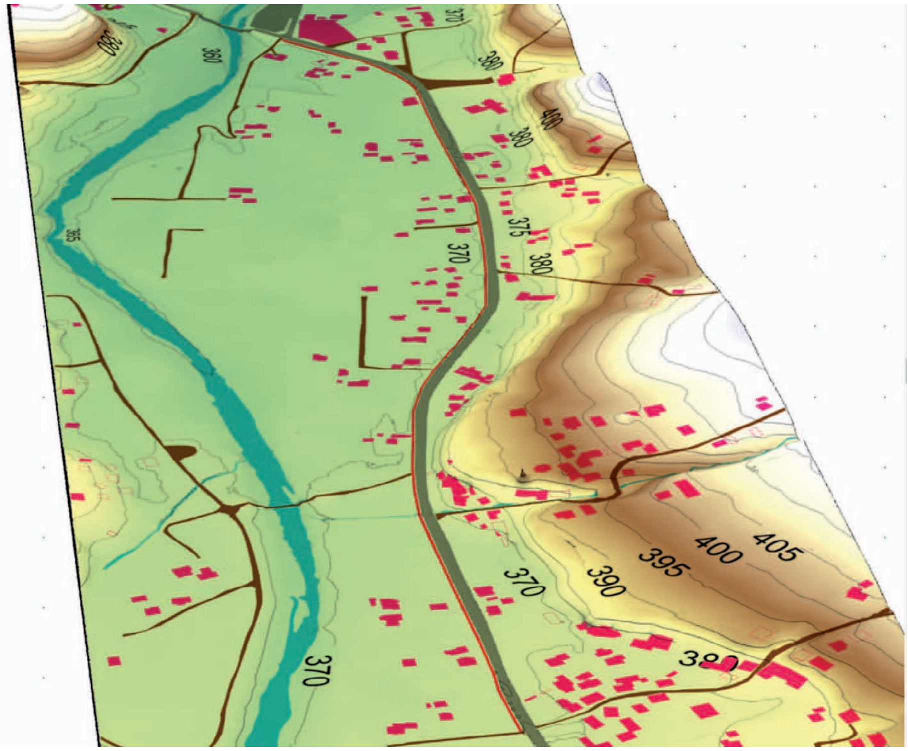


Source: J. Stachowicz study

Fig. 9. Automatically generated terrain model in Surfer 11 software

To properly visualize the area, the scales of X, Y and Z axes were adjusted, and the model was presented in a perspective view. The colors and their scales were also readjusted, to reflect the changes in elevation. The next stage was to create a raster, containing contour lines, buildings, waters and roads. The Surfer software has created an isoline map with a 5 m contour cut on the basis of the previously created grid. It was then exported to *.dxf format in order to make it compatible with the Microstation software. The contour lines were adjusted to the scale and fit to the DTM using the extreme point coordinates. The completed raster, containing the edited contour lines and DTM layers filled with colour, was loaded into the Surfer program as the "Base Map". The raster was then combined with the 3D surface, and after the proper modeling, the visualization of the area was obtained.

The model generated in Surfer software (Figure 10) is based on 37 thousand points. The analysis could not have been done with use of point clouds (the data contained over 49 million points) due to lack of proper hardware and software. Moreover, Microstation does not allow for separating and exporting only the coordinates required for DTM generation. For this purpose, other, special software would be required.



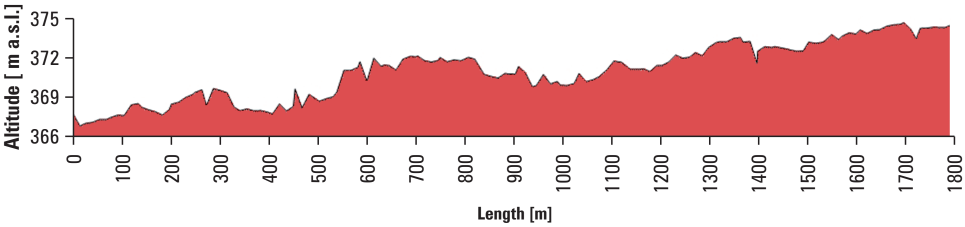
Source: J. Stachowicz study

Fig. 10. Visualization of the designed cycle path

2.7. Analysis of the designed cycle path

The aim of the project was to design a cycle path, based on the data obtained from an aerial laser scan. The final stage involved development of a Digital Surface Model and its 3D visualization. The research was performed in areas very diverse in terms of topography.

In order to present the course of the cycle path with respect to elevation, a profile was made (Figure 11).



Source: Joanna Stachowicz study

Fig. 11. Profile of the designed cycle path

The designed cycle path begins at the elevation of 367.5 m. At the length of 300 m it reaches the elevation of 370. Then it descends and gradually climbs again to 373 m at the length of 800 m. At the next section it descends to 300 m above sea level and at the length of 1700 m it reaches its maximum elevation of 375 m. The elongation coefficient is the ratio of the distance travelled between two points along the road and the distance in a straight line. The elongation coefficient itself does not have a significant meaning. It has to be referenced to the distance. High elongation coefficient is much more disadvantageous in the case of long distances than for short routes, as the total additional distance is much longer [Podręcznik do projektowania… 2013].

In the analysed case, the elongation coefficient equals 1.06, which means 60 metres of elongation for 1000 m of the distance in a straight line. The profile allows for a precise calculation of the slope for any section of the cycle path. In order to achieve the smooth shape of the road grade line, it is recommended for the distances between peaks of the longitudinal profile to be greater than:

- 300 m for the design speed of 70 km/h,
- 250 m for the design speed of 60 km/h,
- for the design speeds below 60 km/h the value is not determined.
- The average slope in this case equals 0.8% for 250 m [Rozporządzenie… 1998].

The designed cycle path is a part of the main route of Małopolska – VeloRaba, which unfortunately does not meet all the requirements as yet. The cycle path runs along the provincial road No. 968. It is a two-way route, 2 metres wide, positioned according to the rules: 1.5 m from the sidewalk edge. The proximity of mountain landscape and of the Raba river significantly increases the attractiveness of the route. Moreover, the route will also be perfectly suitable to serve the local inhabitants as a safe traffic route between important places in the village.

3. Conclusions

The selection of the designed cycle path's location was based on the thorough analysis of the village of Kasinka Mała. The surroundings, including Beskid Wyspowy and the rivers of Kasinczanka and Raba, have a significant influence on the route's attractiveness for the tourists, both cyclists and pedestrians. The error of the input data on which the model was based, does not exceed 15 cm for situation and 20 cm for elevation. The model itself slightly deviates from these values, which is caused by the smaller number of points and technical limitations of the hardware and software. Performing the scan at a lower altitude would improve the visibility of carriageway edges as well corners of buildings. It should also be noted that there is a possibility of generating a digital terrain model based directly on a classified point cloud, which significantly speeds up the process. However, it requires ALS data processing software.

The designed cycle path runs on a relatively flat terrain. The elevation varies between 367.5 and 375 m for the length of 1.8 km. The profile shows every single bend, which allows for a proper preparation of the construction works. The 1.5 metre-wide section between the road and the cycle path should be managed as a green strip. Moreover, aside from the route itself, bicycle parking or other elements of bicycle infrastructure can be planned. The planned course is just an example of how the ALS database could serve as a basis for such project. The point cloud coordinates can also make it possible to calculate the distance, the height or even the volume of earthworks.

As it has been mentioned before, the construction of cycle routes in Poland has been undergoing intensive development. There are about 17 kilometres of new cycle paths planned for the year 2017 in the city Kraków alone. The presented project could serve a starting point for further planning and improvement of VeloRaba route. Moreover, with bicycle infrastructure developing so rapidly, it is worth thinking about which design method is the most efficient, and considering the use of ALS databases for future projects.

References

Borówka D. 2014. Rowerem przez powiat limanowski i Dolny Kubin. Najciekawsze trasy rowerowe w Beskidzie Wyspowym, Gorcach, Magurze Orawskiej, Małej Fatrze i okolicach. Przewodnik turystyczny. Euro Pilot Sp. z o.o., Warszawa.

Chrustek P. 2015. Podręcznik dla uczestników szkolenia z wykorzystania produktów LiDAR, Warszawa, 208-215.

Drath J. 2016. Rowerem po Małopolsce. W 2017 ponad 200 km nowych ścieżek. Życie miasta, http://lovekrakow.pl/aktualnosci/rowerem-po-malopolsce-w-2017-ponad-200-km-nowych-sciezek_18122.html.

Hejmanowska B., Warchoł A. 2010. Analiza porównawcza wysokości terenu uzyskanej za pomocą lotniczego skaningu laserowego, pomiaru GPS oraz pomiaru na modelu stereoskopowym z kamery ADS 40. Acta Sci. Pol., Geod. Descr. Terr., 9(3), 13–24.

Kopta T. 2015. Standardy dla dróg rowerowych – dobre i złe rozwiązania. Departament Studiów GDDKiA, Kraków.

Podręcznik dla uczestników szkolenia z wykorzystania produktów LiDAR, Główny Urząd Geodezji i Kartografii, Warszawa.

Podręcznik do projektowania tras rowerowych. 2013. Urząd Marszałkowski Województwa Małopolskiego. Departament Turystyki, Sportu i Promocji, Kraków.

Postaw na rower. Podręcznik projektowania przyjaznej dla rowerów infrastruktury. 1999. C.R.O.W. oraz ZG PKE – „Miasta dla rowerów", Kraków.

Rozporządzenie Ministra Transportu i Gospodarki Morskiej z dnia 10 września 1998 r. w sprawie warunków technicznych, jakim powinny odpowiadać drogi publiczne i ich usytuowanie (Dz. U. z 1999 r. Nr 43). Wytyczne projektowania dróg III, IV i V klasy technicznej. GDDP 1995.

Wężyk P., Solecki K. 2008. Określanie wysokości drzewostanów nadleśnictwa Chojna w oparciu o lotniczy skaning laserowy (ALS). Arch. Fotogram. Kartogr. Teledet., 18, 2008, 663–672.

Ziebura J. 2013. Podręcznik do projektowania tras rowerowych, Kraków NEUTENO.

Ustawa z dnia 1 kwietnia 2011 r. o zmianie ustawy – Prawo o ruchu drogowym oraz ustawy o kierujących pojazdami (Dz. U. z 2011 r. Nr 92, poz. 530).

Internet sources

www.codgik.gov.pl
www.crow.nl
www.surfer.net.pl.
http://www.google.pl/intl/pl/earth

Dr inż. Stanisław Bacior
Uniwersytet Rolniczy w Krakowie
Katedra Geodezji Rolnej, Katastru i Fotogrametrii
30-149 Kraków, ul Balicka 253a
e-mail: rmbacior@cyf-kr.edu.pl

Dr inż. Jacek Gniadek
Uniwersytet Rolniczy w Krakowie
Katedra Geodezji Rolnej, Katastru i Fotogrametrii
30-149 Kraków, ul Balicka 253a
e-mail: rmgniade@cyf-kr.edu.pl

Dr inż. Izabela Piech
Uniwersytet Rolniczy w Krakowie
Katedra Geodezji Rolnej, Katastru i Fotogrametrii
30-149 Kraków, ul Balicka 253a
e-mail: rmpiech@cyf-kr.edu.pl

Mgr inż. Joanna Stachowicz
Absolwentka Uniwersytetu Rolniczego w Krakowie
e-mail: aska.ona@wp.pl