Analysis performed using LIDAR mobile mapping

Jan Hovad, Pavel Sedlak, Jitka Komarkova, Adam Duchac

Abstract - Light detection and Ranging technology (LIDAR), becomes one of the most popular tool used for terrain spatial analysis. Usually its used for creation of digital elevation or terrain models (DEM/DTM). This article shows the complex way how to use raw LIDAR data sets in geoinformatics in the way of preparing and processing data. Scanned data points are noisy, with many intersecting areas and large data files. Their raw form must be carefully adjusted for further usage. This article also shows how to use the LIDAR outputs for purposes of disabled persons in case of performing network analysis or barrier free maps. Final part consists of pros and cons of point to polygon conversion which can be useful for 3D model creation.

Keywords - scanner, LIDAR, laser, disabled person, network analysis, GIS, visualization, object, identification

I. INTRODUCTION

People studied the environment they lived in since ancient times whether in the form of hand-drawn maps, paintings on the cave walls or in the form of detailed statues and portraits. They were actually the first people who tried to record and store as detailed information about surroundings as they could. The requirements for such information rapidly increased several thousand years later. Society cannot longer use hand-drawn maps or portraits for many purposes as before but it benefits from fast growth of technological age.

Old techniques were replaced by digital maps, photographs or high resolution photo-realistic models created by computers. As the useful tool which allows to handle the tasks above can be a laser scanning - LIDAR technology [1].

This article will briefly explain the principles

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of technology, emphasizing the important parameters for scanning and storing large amounts of data. Included will be an example of raw LIDAR data and photographs with high resolution. The first part will be devoted to a data point formats and their corrections. During the process will be presented the whole portfolio of applications that allow to work with point data. That includes AutodeskMAP 3D/3Ds Max, Global Mapper, VRMesh, Pointools, Leios2 or application made by Geomagic, Studio and Wrap.

Data will be used as basis for network analysis and object passportisation in application from ESRI, ArcGIS. Two practical examples will show usage of LIDAR in practical situations.

For the further use there will be an example of converting the points to a mesh including the possible complications and their solutions as mesh repair. Mobile scanned LIDAR data are not as good in density as a static scans. Even in this case, there is a possibility to show necessary steps for another use of repaired mesh - for example for half-automated creation of town models for GPS navigation etc. [2].

II. PROBLEM FORMULATION

LIDAR is a technology which functionality is based on the measuring the distance of objects by means of electromagnetic radiation - light and its reflection from the surface. Variety of data formats and scanner properties limits the usage and processing of data cloud. This article will show the possible way to use low resolution LIDAR data in various cases.

LIDAR Technology

The whole device consists of several parts, the first is the laser itself (Fig. 1). During the illumination of objects by laser/rotating mirror, different specific wavelength is used. For example, the first range is limited from 650 - 1000 nm. In this interval, device does not achieve such a high performance because of eye protection. The human eye is able to detect radiation somewhere beyond 700 nm. Another option is to use larger wavelength band around 1000 or 1500 nm, where the radiation is already beyond human perception limits and there is no damage or risk. Laser performance is in this case higher and extends the applicability to particular disciplines that work with large distances and do not require high spatial resolution [3].
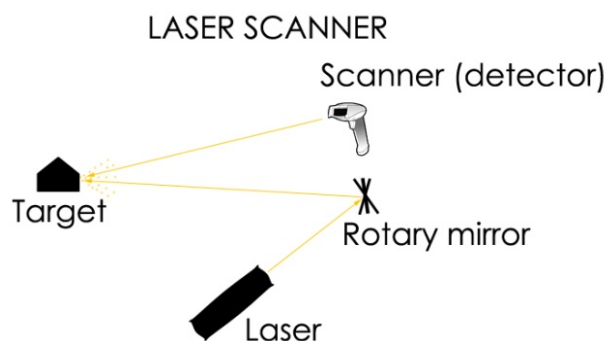
LASER SCANNER

Fig. 1 - Laser scanner (Source: authors)

The reflection of the light is recorded by the scanner device. It works with the backscatter of light. That means that the part of light is reflected in the direction where it came from and detected by the scanner. It's the opposite as the mirror function which is pure glossy and all the signal is reflected directly in the same angle. Scanner affects the read-out speed, total time needed for one point-cloud frame. Optical device like a lens indicates the angular coverage of the scanned area and spatial resolution. The last, very important system is the electronic and navigation device that ensures the control of the device position and orientation of a sensor.

To obtain a digital image records it is necessary to integrate digital cameras or cam coders as a mobile mapping devices and ensures an accurate synchronization. In the current mobile mapping systems are most often used imaging devices that are equipped with multiple lenses and can shoot in the panoramic and spherical angle (360°). This approach allows to capture each point more than one time in many images from different angles [4].

In the mobile scanning, tens of parallel scanning units that are targeted to all sides are used in modern systems. Because of this there is a good chance to eliminate any uncovered area and significantly increase amount of scanned points which lead to better accuracy of model. For example, one of the most advanced current LIDAR systems from company NAVTEQ is able to capture more than 1.5 million points per second using 64 parallel scanning units. Such precision allows for very detailed coverage of the surface and objects up to 120 m from the scanner even at higher speeds (NAVTEQ, 2010).

The use of LIDAR technology can be divided into 3 main areas. The first one is the plane scanning. Device is connected to the body of the plane with the scanning unit heading towards the ground. The result is a cloud of points, a dense model made by rotary mirror, mostly captured in the lines, from which a digital terrain model (DTM) can be created. The application of this type can be found in the Geology in the analysis of the coast areas and creating a very accurate digital elevation model (DEM, which is used to monitor the changes in the earth's surface). Then also in agriculture (sun exposure areas), archaeology (search for structures under vegetation) or astronomy (laser mapping of distant objects).

The second type is the mobile scanning/mapping. LIDAR is located on the roof of the mobile device, e.g. a car. While driving through the place of interest, the surroundings is immediately scanned. Because the information from this type of laser scanning is used in this article, it is necessary to mention at last the basic factors that affect the final quality of the output. The most important are: scan and read-out speed, selected angle which affect the spatial resolution, density of points and points coverage – minimization of empty places where no data were measured (e.g. behind the cars, surfaces hidden from the laser field of view, etc.)

Third one is the static scanning used for building scans, isolated objects or large areas of interests. The most suitable use can be found in the analysis of engineering surfaces, realistic modeling of engineering parts or in architecture for realistic creation of house models. There is even more possibilities how to use the LIDAR as the distance detection for cars or analyzes of the construction of solar and wind power plants and many others.

GPS unit

In case of both, terrain and plane systems of mobile mapping, the final image (point cloud) is created by shifting the laser beam in direction of movement. The geometry of such data is very complicated and its necessary to register detailed position of the scanner unit, its angle and acceleration. To get right coordinates for each point the reference point must be always in the focus. Position is derived by two basic devices. Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU). Typical satellite unit doesn't work enough because it's able to refresh position only once per second and it has some interference with urban area environment. In the modeled example, the device moves in average speed of 40 km/h, travels 11 meters each second. Therefore the GPS unit refreshes position every 11 meters which is not sufficient to get nice data structure. In this case the IMU unit helps the situation and provides side and front tilt extended with rotation information. To store coordination for each point correctly there are two parameters Alfa and Beta. Both for measuring the direction of laser beam. Distance of object is then calculated by the difference of both times, send/receive.

III. PROBLEM SOLUTION

Laser data which served as the basis for most analyses were supplied by company GEODIS. GEODIS is one of the few companies dealing with terrestrial mobile scanning in Czech Republic. Cut out of several streets in town Hradec Kralove (100 000 inhabitants, 2012) was selected as an area of interest. There were two data packets, the first one was about 850 MB large and the other one had 1500 MB.

Both of them in LAS file format (Log ASCII Standard). Included were also orthophoto images with a resolution of 30 Megapixels. The main applications are in the condition survey but in this work were used for demonstration of data correction and subsequent use for other purposes like recognizing the shape of buildings in urban areas [5].

Formats and hardware requirements

Laser scanning basically stores large volumes of data. To handle such a volume can be hardware and time consuming process and it should be taken on mind that the process will require powerful hardware. Especially important is to buy enough memory (16 GB in this case) and because of this acquire suitable bit version of software. During the analysis and creation of this article were used only 64-bit versions because some 32-bit applications were not able to handle large data packets even for read purposes.

Each measured point carries mandatory information about the position which is represented in the coordinate system XYZ. This is necessary information which can also be represented as latitude, longitude and elevation. A simple example of creating XYZ file can be demonstrated by ordinary cube shape (Fig. 2).
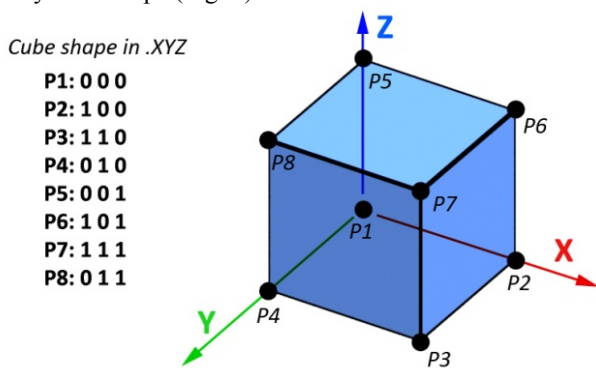

Fig. 2 - Cube shape in .XYZ (Source: Authors)

Any shape form can be reconstructed in this way. It is possible to add other attributes than basic XYZ. The main ones are the intensity (i – intensity is different for example for sand and water), amount of reflected pulses (n), classification (c – vegetation, buildings, roads, …), scanning angle, normals for each axis coordinate system (nx, ny, nz – point orientation to the sensor) or information about the object color (Fig. 3).
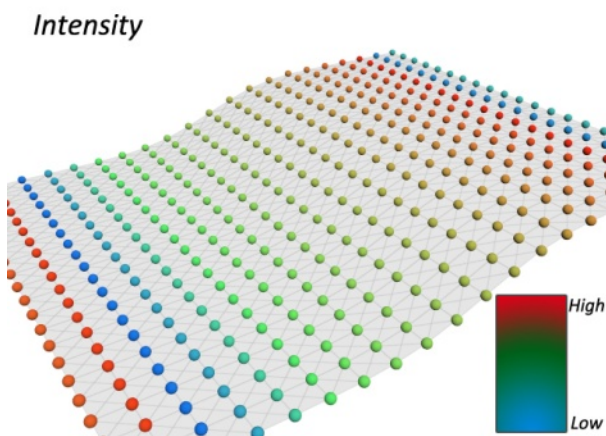

Fig. 3 - Reflected intensity (Source: Authors)

Due to the many opportunities and requirements, there are a variety of data formats, which include the activities necessary to create complex transitions between them. The most popular in use are LAS, XYZ, TXT. Because of given size of the area of interest it was necessary to reduce the number of captured points. In the raw file there were several millions of them and it was needed to reduce this amount to couple of objects. For this purpose was used Global Mapper softwar that allows visualisation of raw data in two modes.

Preview mode loads only every 10th point – saves memory and point cloud can be viewed on machines with less memory. The second mode is the full view of all points. The application allows the creation of the DEM, including exports, cut functions and subsequent export to many vector file formats. As was said, the export and crop functions were one of most required oparations which led to a substantial reduction of computing time at each step of processing.

Besides raw LAS file format, the XYZ was used after crop operation which is compatible with many applications. As an alternative, Pointools Pro (import of point cloud, cut and export) can be used as well. The other option is to use freeware application MeshLab.

IV. BARRIER FREE ACCESSIBILITY USING LIDAR POINT CLOUD

PanoramaGIS software is used to work with databases of digital panoramic images and laser point clouds. It allows positioning and distance measurements, projection of 3D layers, creation of condition survey and photographic documentation (GEODIS Brno, 2011). The basic input data is a database of panoramic images in the file format PAN (Panorama Database File) with stored information about the internal and external orientation of the camera.

Another part of the input data are laser points in LAS format. AS a basis to allow easier manipulation serves ortophotographic vector map (DGN, JPG, SHP, TIFF). Project data consist of several individual layers, typically a laser points, panoramic images, the underlying layer and the geometry of the measured points. (Fig. 4)
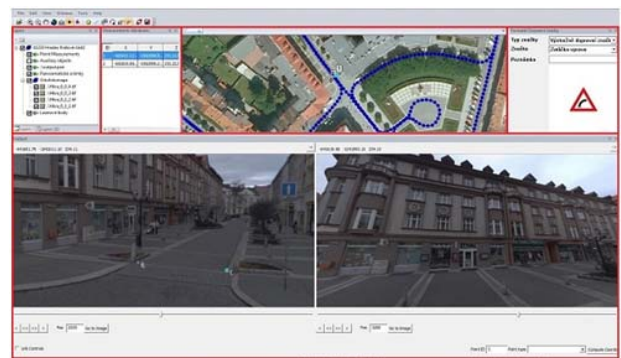

Fig 4 – PanoramaGIS (Source: Authors)

The basic options of using data to determine the geometry of objects is the passportization, database creation and use of barrier-free points along in further analysis.

Determination of geometry shapes

The application can quickly and easily obtain basic information about the geometry of objects. The following example shows the selected pedestrian crossing and its application as an instrument for measuring distances. (Fig. 5)

Fig. 5 - Crosswalk (Source: [11])

Error in such measurements depends on the quality of data and spatial resolution. From the panorama image there is also a chance to determine the object's surface and its condition. In the sample of pedestrian crossing is the surface formed from cobblestones. No major gaps are apparent and the crossing is equipped with a guide lines.

This element is in good condition with no obvious deficiencies. Another convenient feature is the ability to define crossings or any other measurable objects by point or line shapes. These elements can be exported in the SHP file format and can be used in other applications. From exported points or lines a polygon structure can be created. There is a lot of operations polygons are useful for. Very useful can be measuring of area size or an integration of these objects into the maps or any other documents.

Object condition survey

The output of passportisation process is single database providing information about the all objects of that type in the area of interest.

The information should consist of a precise position, technical condition and photographs. In the case of barrier free research an inventory of pedestrian crossings, parking places for disabled persons, entrances to buildings and traffic signs can be made.

The first step in creating passports in PanoramaGIS is marking the objects and calculating their exact positions. More accurate data are obtained if the object is identified from two different angles. Each object is then measured in the attribute table created with the coordinates and other data. Information in the table can be easily exported into formats SHP, DGN, MES or TXT.

Possibility to easily create barrier free databases is the most important benefit of mobile mapping in the barrier free environment. The main sense of this process is to create a database of all monitored objects in a given area and its attribute storage. Effective and easy creation of databases, including their export to many geographical information

systems is possible with this tool. The main difference against the passportisation lies in the recording different attributes and in the subsequent analysis.

The following figure presents identification of the object which represents a barrier. In this case a type of barrier was recorded (light pole) and information about whether it permits to move around or not. This information is determined using the distance measurement. The remaining width of the sidewalk is greater than requirements stated by a law which is 150 cm (Fig. 6). Attribute of barrier-free receives a value of "True". Reported data are entered into the table.
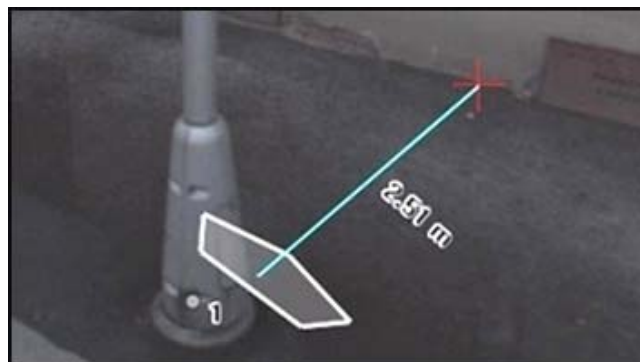

Fig. 6 - Distance (Source: [11])

From the same image information about the sidewalk can be extracted. Visibly consists of asphalt surface and it is in good condition which determines the surface attributes and status. The barrier-free attributed is in this case set to „True" as well. The sidewalk's slope is less than required, surface is not slippery and the width is bigger than 150 cm. A similar procedure is followed in the measurement of other objects.

Another practical option is to make network data analysis. Layer of sidewalks and crosswalks must be created beforehand. These layers are converted into a network graph which allows to perform these analyses.

The following figure 7 is determined from the wheelchair accessible route which connects an object which is barrier free to another object. The route goes in the shortest barrier-free path in which no barrier occurs. Network analysis allows to find the optimal path between given points. The calculated route can be further analyzed, for example in terms of length, number of sections etc. In this sample, the way is 215 m long and leads over two pedestrian crossings equipped with light markings. There is an option to find the surface state and condition of each segment in atribute table. Authors used software ArcGIS Desktop 10 which is user friendly and allows all basic operations to be performed. For the special processes an extension of choosen type can be installed additionally.

Fig. 7 - Network analysis (Source: [11])

Fig. 8 - Barrier free city center (Source: [11])

When the barrier-free points are created, it's possible to make cartographical outputs or use them as the base for other purposes. ArcGIS Desktop and PanoramaGIS applications are compatible which means that the database created by one application can be loaded into the other one. Example of map output which is adapted to the requirements of disabled people can be seen on Fig. 8.
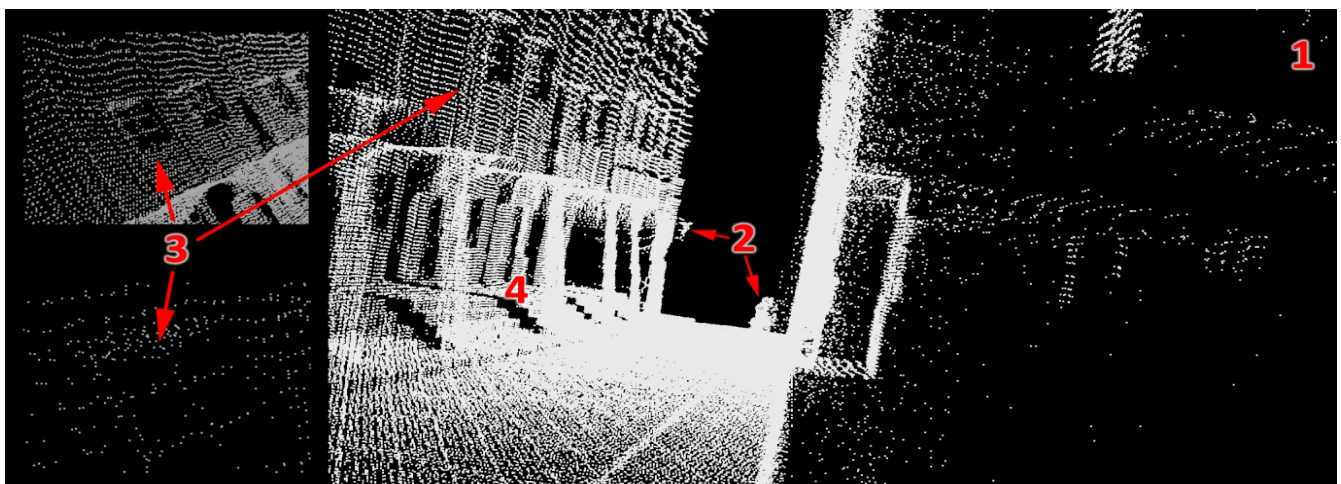

Fig. 9 - Point cloud failures (Source: Authors)

V. PREPARING POINT CLOUD

In this section, the work will be focused on the functionality of each application for pre-processing point clouds using the selected algorithms. Diagram in Fig. 10 shows the steps applied in the pre-processing phase.

Fig. 10 - Preprocessing scheme (Source: Authors)

Short look on the area of interest in the form of points shows a number of aspects that need to be corrected (Fig. 9). The most obvious are the outlying points that do not belong to the houses in the street. They were captured either by reflection from distant areas (trees, but also atmospheric conditions such as a snow/rain) or from materials embedded behind the glass of houses and their windows. Usage of LIDAR for measuring atmospheric conditions can be seen in practice too [6].

They are actually parts of interiors (Point 1). Next, for this moment parasitic information, are the people who were captured by mobile mapping device. Along with them also small objects for which the density and spatial resolution is not good enough to reconstruct a shape. Density and spatial resolution decreases rapidly with increasing distance of object and thus is a major problem capturing any more detail in these areas. Changes in the laser technical parameters would be necessary and it would make a data processing of such a large area even harder (hardware requirements). This issue can be seen, where a greater distance makes a model richer in detail but upon a closer look and examination of captured points the viewer recognizes that there are not enough points. For example, the windows of the houses are made up of only a few points that just fitted the angular spacing of the individual point series. The gaps and shadows pose another problem. There's no captured information at all (Point 4).

Most of these facts which were shown can be corrected. Before the pre-processing phase where data corrections occur there is a possibility to register individual data packets together. Registration process functions works in the way it combines multiple point clouds into one. Therefore its needed to find transformation equations for relations between data and model. This problem is fundamental in 3D scanning but its use can be found in other fields. Used data structure is even in this state very large and because of this connection of the second data set would be practically impossible to handle (Fig. 11).
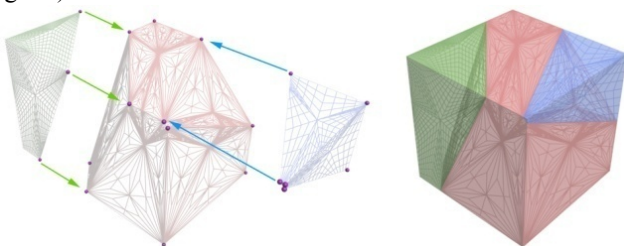

Fig. 11 - Registration of point clouds (Source: Authors)

Then it is needed to crop the whole point cloud to the area of interest. This is necessary because of the high hardware requirements. Partial operations would require the processing time in several hours, if not even tens of hours with mentioned hardware setup. For this work were available two data packets of selected parts of Hradec Kralove. The smaller size of 800 MB contained 41 378 117 points. This number was necessary to be reduced and only certain houses were selected (Fig. 12).

Certain applications can handle the entire process, but some sub-steps in them are very complicated and much comfortable and easy to solve with other software. For the view and crop the Global Mapper and Pointools Pro were selected. Both are available in trial version and both allow to import data obtained directly from the scanner unit as a LAS data file. Export can be made in any native point file format as described above (XYZ). User may expect some problem with trial versions which are frequently un-limited in processing operations but limited in export and in use for other purposes.
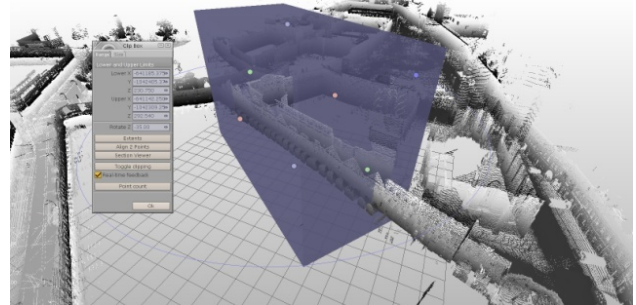

Fig. 12 - Point cloud isolation in Pointview Pro (Source: Authors)

Selection is done either by using the methods in the form of universal select tools or restriction in the form of boundary box and its main attributes (radius, height and width). When the points are exported to a smaller file, the attributes can be limited - such as information about the intensity of reflection, colour and position of normals. Application of a simple filter while exporting can also restrict the density of points [7]. This usage must be considered by the user because it can bring some problems into the scene lately.

Most of man-made objects belonging to the urban area have a regular shape with lots of sharp edges. For the best data reconstruction it is necessary to de-noise the whole dataset by any of the selected algorithms. The biggest difference is apparent in areas with high spatial resolution, i.e. nearby the vehicle. Increased distance means that the total amount of scanned points falls down rapidly and algorithm loses its power. An advance noise algorithm which is provided by the VRmesh software was used in this case. There were only two inputs. The first one is the weight attribute and second one is iteration counter. The output can be seen on Fig. 13 where the left part contains noise and the right part is denoised. Points in the uncorrected images have much larger standard deviation in all of three axes.
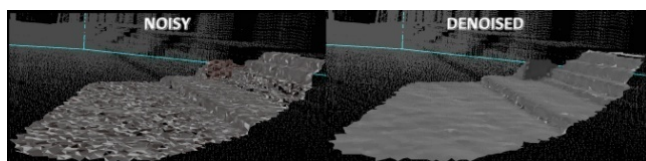
Fig. 13 - Denoised part of image (Source: Authors)

Other modifications include the removal of isolated distant points. When they stay in the dataset, the irregular geometry shapes would be created after point to polygon conversion. In case of application VRMesh single parameter is used and that is the point cluster distance. In the similar way are removed the points captured in several scans - redundancy. Curve weight is then added as an additional parameter to the distance which was used in the first case. For data where the spatial resolution is sufficient and the total amount of points reaches the limit needed for the reconstruction of the models it is recommended to reduce their volume on a percentage basis. This operation is performed either by simply using the percentage limit or it is based on the curvature of the surface – flat areas contain fewer points than curved surfaces. Hardware requirements are lowered but also the total simplification leads to a low-polygon model. For the case that even after the application of these procedures the point cloud seems to be unclear it is advisable, if time possible, to use tools like the lasso and removed a spurious object manually. In this case it is a removal of scanned inhabitants of the town, shop signs or scanned interiors. These objects are directly linked to their surroundings and their distance is not sufficient to be automatically deleted by the batch processes and algorithms. Another option is to locate near clusters of points and unite them to achieve the same effect as in the elimination of points. (Fig. 14) [8].
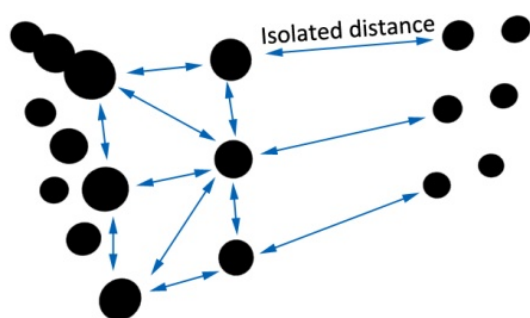

Fig. 14 - Isolated points (Source: Authors)

The greatest variety of algorithms from all analysed applications provided VRMesh. It offers, besides an individual steps, also a batch pre-processing of points in which its possible to set all necessary parameters at once and proceed the whole data. Slight disadvantage is the inability to user friendly preview. This problem is solved well in the application Geomagic Wrap and Studio. Although many do not offer repair options as its competitors but allows the entire process, including operation with polygons, which is undoubtedly an advantage especially in the area where it is

needed to export various data formats. It is a data (in) compatibility which causes the main aspects of the problematic part with LIDAR data. Geomagic products are mainly focused on denoising which means that it flattens the points and reduce them on the surface curvature based parameters. It offers more in case of polygonal model corrections. Leios 2 was very close to it, allowing a very quick preview in case the parameters of algorithms were changed. The work was because of this a much more effective than in case of VRMesh. Wide, probably the largest range of repairs allowed MeshLab. The disadvantage was the fact that the application constantly crashed even on the high speed machines. The second problem was the lack of documentation for this software. It is hard for the user to use all the benefits of this software without a technical support. Crashes weren't fixed even by reinstalling the software to other machines. Another build or bit version of software didn't help either. It was necessary to seek description of algorithms throughout the internet or books. Very powerful tool was damaged by this fact.

In the area of point cloud processing there is very interesting project for those who like programming. It is called PointCloudLibrary (PCL) where the largest companies provide a support and are included in the development. It allows filtering, registration, segmentation, visualization and includes transparency of source libraries. User is also able to compile its own version on different platforms. Great advantage is precisely made technical documentation [9].

VI. 3D MODEL RECONSTRUCTION

First idea to convert the point cloud to 3D model which could be based on polygons or triangles was halted by technical parameters of LIDAR scan. As mentioned above, the spatial resolution of city and its object was rapidly decreasing with distance from the scanner (car). Points were scanned more likely in lines which distance from each other continuously increased. This fact caused the situation, that the small objects like frame windows, signs, wall sculptures and historical extrusions faded away without any chance to reconstruct its original and complicated shape. In this phase a more detailed scan would be needed to get better details in distant areas. Even though the more detailed scan would require invention of specialized algorithm to precisely detect edges and curves which go beyond the limits of this article.
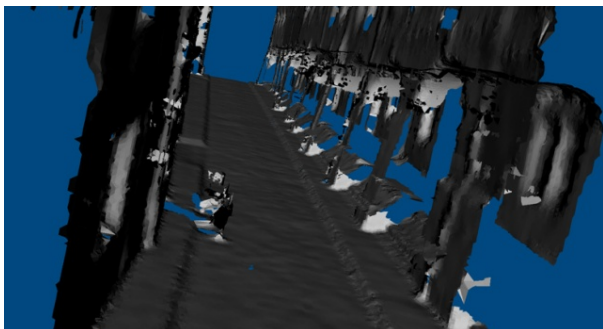
Fig. 15 - Polygonal model of the street (Source: Authors)

Fig. 15 represents what happened when the basic algorithms for converting vertices to polygons were applied. Model looks smooth and contains even smaller details close to the scanner. Street and sidewalks are modelled correctly. Precision decreases as the distance between each point line grows. That means that sometimes there are faint details on the facades but there is no data point to reconstruct the model. One line lays a few cm above and second line below from selected object. The result contains a flat wall or even bumpy flat plane because of some unremoved noise. What is even worse is that there are areas which contain no signal at all. Mostly hidden places in the historical buildings. These gaps are hard to reconstruct even manually. It would be necessary to speculate and it won't be representing the reality.

To use such high polygonal structure in application like GPS navigation requires a lot of computing power. There is one more option to use and that is the reference modeling. Each vertex can be used as reference in low polygon modeling and provides a good and easy to use template. 3DS Max was used for common operations but any other modeling software can be used as well. In the basis, only common elements like box, cylinder, plane were used along with couple of helper objects which were represented by points or dummy boxes (Fig.16).
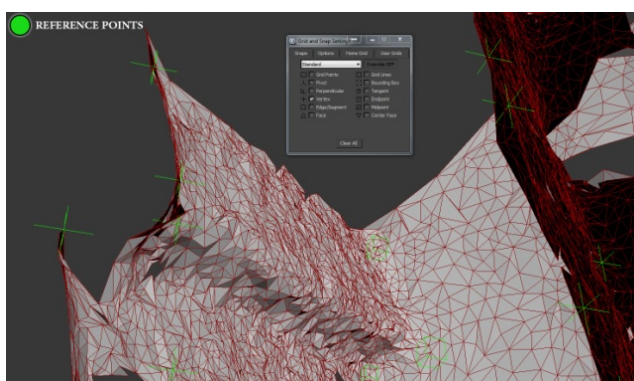

Fig. 16 - Reference points (Source: Authors)

With help of references, the basic shapes were created and converted to edit polygons. These standard primitives were connected by bridge technique which requires open edges which can be dragged and extended to selected coordinates.

Corresponding vertices were welded and detached as separate objects (walls, sidewalks, entrances etc.). Fig. 17 shows the composition of point cloud and low polygonal model of the house basic shape. This process can be performed as well with automatic reconstruction algorithms which were used by authors Shorter, Kasparis [10].
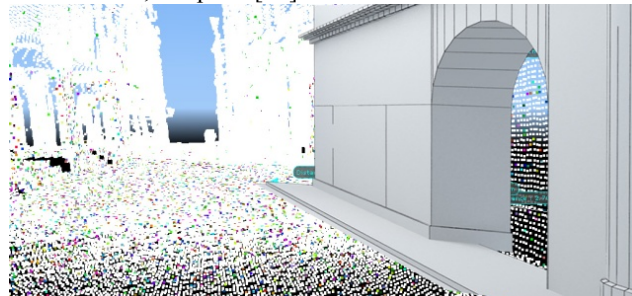

Fig. 17 - Model created by reference points (Source: Authors)

VII. CONCLUSION

LIDAR technology is very popular throughout many branches. This paper shows only one possible workflow and usability based on GIS raw data of town Hradec Kralove in the Czech Republic. First few chapters explained how LIDAR technology works and showed the basic problems with point cloud data sets. The most important factors were hardware requirements and wide variety of LIDAR data formats. Both of these factors were explained in detail with description of individual attributes. Further actions required full pre-processing stage to be completed. Raw data were cleared by separate steps, registered and saved as an output point cloud which could be used for vertex to polygon conversions. As it was explained in the paper, the spatial resolution of data cloud was not good enough. This fact caused the biggest problems and therefore the whole data set did not allow as much possibilities as it could provide because some of faint details were un-captured and some places were totally „deaf".

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