BUILDING FOOTPRINT EXTRACTION FROM LIDAR POINT CLOUD DATA

Gjorgji Gjorgjiev
PhD, Associate Professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia
gorgi.gorgiev@gf.ukim.edu.mk

Vancho Gjorgjiev
PhD, Full Professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

Natasha Malijanska Andreevska
MSc, Teaching Assistant
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

In the past two decades, very intensive development has been done in the area of LiDAR technology, providing high-quality spatial data for large areas in a short time. The raw LiDAR data consists of an enormous number of points, made by reflection of the laser beam from various objects such as earth's surface, buildings, vegetation, powerlines, bridges, etc. In order to extract the geometrical characteristics of the objects many different approaches and methods have been developed. Many of these approaches have been focused on automatic feature extraction. The subject of this paper is to investigate the possibilities for automatic building footprint extraction from LiDAR data provided by the Agency for Real Estate Cadastre, available for the territory of the Republic of North Macedonia.

Keywords: LiDAR, point cloud, automatic building extraction, building footprint

1. INTRODUCTION

The need for three-dimensional spatial modeling of the terrain and objects, with details and quality that significantly exceeds traditional 2D approaches, constantly gains attention as a research topic. This need has been initiated by spatial data users and supported by the development and easier accessibility of LiDAR technology for spatial data acquisition. In this context, the 3D models of urban areas stand out, which represent a powerful foundation for various spatial analyzes and simulations in the field of cadastral systems, telecommunications, urban planning, environmental protection, tourism, navigation systems, etc. The models basically consist of a 3D geometric representation of objects of interest, such as buildings, roads, trees, etc. very often combined with high-resolution aerial or satellite images, forming a realistic model, visually and geometrically, accompanied by attribute data that complements the image of the objects being presented. Considering the potential of available data acquisition technologies, researchers in the field of geomatics are focusing on creating powerful algorithms for extraction and 3D reconstruction of objects, so the models would be as close as possible to the real objects, which consequently, will provide more accurate spatial analysis and greater power in their application. At the moment LiDAR (Light Detection and Ranging) could be pointed out as a primary technology for spatial data acquisition for 3D modeling, as an extremely fast and precise technology that provides a large amount of data in a short time. In the last decade with the development of powerful algorithms for image processing, photogrammetry took a significant part in this process. Primary objects for creating 3D models of urban areas are buildings, which in practice could have a large variety of shapes, sizes and details.

Depending on the existing data quality, such as point resolution, the 3D model can be produced with different levels of detail. The spatial data acquisition methods when the sensor is placed on an aircraft have an excellent potential for geometrical modeling of the roofs of buildings and limited potential for modeling the walls and other elements of the building that are not visually accessible from a height. In these cases, it is a kind of challenge to create a model for the areas that are not observed with a large number of points. Since the building structure is complex, their complete automatic reconstruction is not yet feasible with a high level of quality. Therefore, manual and semi-automated approaches are still widely used, although it can be said that the automatic detection of buildings, with the algorithms that are available and implemented in software, every day, achieves better results. Considering the fast dynamics for the establishing and updating of 3D models, the automatic detection of buildings and the extraction of their geometric properties are of great importance.

2. POINT CLOUD PROCESSING METHODS

The research in the area of point cloud implementation, as a data source for detailed modeling of urban areas, has revealed a point cloud large potential. In recent years, studies on the detection and reconstruction of buildings have made significant advances (Gilany, S.A.N. 2018). The need for faster, more detailed, and reliable building detection and reconstruction has led to intensive development of many algorithms based on different approaches. In general, the process of building modeling can be separated into two major steps, *building detection*, and *building reconstruction*. The first step deals with the segmentation and classification of points from a point cloud, while the second step comprises the reconstruction of the building based on the classified point cloud data.

Segmentation and classification

Segmentation of point cloud is a process where points are placed in groups with some common characteristics, for instance, geometrical or radiometric characteristics, such as ground and non-ground points. A segmented point cloud consists of points belonging to only one of many predefined segments. In the segmentation algorithms point properties such as reflectance intensity (if it is a point cloud obtained by laser scanning), the number of returns or geometric properties could be used. Typically, in laser scanning data, geometrical properties such as surface normal, gradients, and curvature in the neighborhood are used (Sapkota 2008).

The methods used in the segmentation process are several and in general could be divided as follows (Grilli, F., Menna, F., Remondino, F. 2017):

- Edge-based,
- Region growing,
- Model fitting,
- Hybrid method,
- Machine learning method.

The *edge-based* method consists of two consequent steps, the first step detects the edges that outline borders of different regions/segments and the second step groups the points within detected borders. Edges are detected by the change of a local variation beyond the provided threshold.

The *region growing* method starts from a single point and grows around neighboring points that fit well in a surface with similar characteristics as surface orientation, curvature, etc. The points that are considered as part of the same object, with similar characteristics, are placed in one segment.

The *model fitting* method tries to fit primitive shapes in point cloud data and the points that conform to the mathematical representation of the primitive shape are treated as one segment.

The *hybrid method* takes more than one of the previous methods in consideration during the process of point segmentation.

The *machine learning* method of point cloud segmentation is frequently used. This method takes into consideration successfully segmented point cloud data, learns from the provided examples, and then gained "knowledge" is implemented on other non-segmented point cloud data. This method is robust and flexible.

The second part of the first step deals with point cloud classification. The classification takes further the segmented point cloud by providing details about points and dividing them into classes such as buildings, high and low vegetation, bridges, powerlines, etc.

Building reconstruction

The second major step after building detection is building reconstruction. Depending on the needs, the reconstruction of the buildings could be done as 2D reconstruction of the building footprint or 3D modelling. Since the major focus in this paper is placed on 2D reconstruction, a short description of the process will be given.

There are a large number of algorithms for the creation of polygons that represent the footprint of the laser scanned building. The paper will briefly discuss two possible approaches to achieve this goal.

The first approach is based on the assumption that the buildings consist of straight lines and the building corners are square angles. Based on this assumption, the polygon is created by fitting many rectangular polygons that are iteratively changed, further reduced or increased in order to establish a complex polygon representing the size of the building from those small rectangular polygons.

The second approach for creating a polygon of the building footprints envisages inserting straight lines that are formed with the support of the points representing the edges of a building. By further processing, the lines are converted into polygons based on their intersections and connections.

The first method gives good results when buildings have square angles and straight sides, while the second method gives good results when the buildings have flat, straight sides, but not always square corners.

3. METHODOLOGY

The primary goal of this research is to investigate the possibilities and quality of the automatic building footprint extraction from LiDAR point cloud data available from the Agency for Real Estate Cadastre in Republic of North Macedonia.

The official data source is the database of the Agency for Real Estate Cadastre (AREC) from the LiDAR scanning activities performed in 2019. It is an airborne laser scanning with a flight altitude of approximately 1200m above the ground. Although the density of points varies, we can say that it is approximately 30 points per square meter. According to the data obtained from the quality control reports for the dataset, controlled through the height difference between the recorded points with classic surveying technics and the points from the LiDAR scanning, a mean square error of 0.025m was achieved, while the positional accuracy according to the control is within 0.06m. During quality control, it was determined that the height difference between two overlapping scanning lines is less than 0.05m.

The data processing consists of several consecutive steps tailored to achieve the highest possible quality. The process begins with the first step, which focuses on removing, i.e., classifying outliers (noise). The second step in the sequence is the segmentation of the points into ground and non-ground points. The third step uses the non-ground points and further classifies the points that represent buildings. The fourth phase refers to the extraction of the building's footprint based on the points belonging to the class "buildings", to finally perform the regularization of the created polygons, i.e., to make a kind of generalization that follows a certain tendency, for example, the expected shape of the buildings, right angles, straight sides, etc. The process is shown schematically in the following graph:

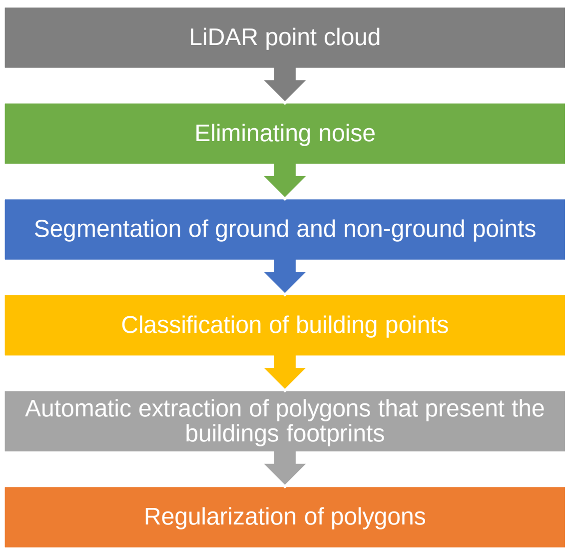

Figure 1. Methodology for automatic extraction of buildings footprints

In order to conduct a comparison of the results obtained by processing the LIDAR data with another reliable and accurate dataset, data from the registration of buildings from the cadastral system is used as reference data. This data is obtained by photogrammetric and classic surveying methods followed by many controls. The comparison is based on the assumption that the buildings analyzed in the research haven't been changed between the moment of registration in the cadastral system and the moment of LiDAR scanning.

To evaluate the quality of the automatic footprint extraction approach, a two-stage process was established. The quality control results of geometric shapes representing building footprints will be expressed in numerical values, but also narratively because the presentation of the matching between detected building footprints and registered building footprints is difficult and it can be misleading if it is only presented by numerical indicators.

The first approach to assess the quality of the detection is made by overlapping the polygons that present the detected building footprints and the polygons that present the registered buildings in the cadastral system. These two objects should be approximately the same in shape and size, but with differences arising from the different modelling approaches. The closer those two shapes are, the higher quality of automatic detection is obtained. Of course, in this research, the data obtained from the cadastral system is given priority in terms of quality.

To show the quality of the results in the first approach, two numerical indicators were used:

a) percentage of the area of the detected building footprint within the registered building footprint,
b) percentage of the area of the registered building footprint within the detected building footprint.

Considering the fact that there are newly erected buildings that have modifications that are not registered in the cadastral system, but those same buildings are detected by processing LiDAR scan, the impression of a large discrepancy between the detected and registered building footprints will be created. For those reasons, such buildings will be excluded from further data analysis. It should also be noted that in the process of automatic footprint detection, objects that are not subject to registration in the cadastral system, such as bus stops, traffic lights, small sheds, etc., will be detected by processing LiDAR scans. These objects will also be excluded from the comparative analysis.

The second approach for the quality evaluation of the building footprint detection is carried out through a visual inspection considering the matching of the two figures. Since it is based on expert opinion, there is always a possibility of subjective conclusions, but if it is done impartially and conscientiously it can be an excellent indicator of the detection quality.

3. RESEARCH RESULTS

As an area for the case study, an urban area with the presence of public, business, and residential buildings was chosen. These buildings are characterized by a large footprint and straight sides usually placed at an angle of 90°. In some parts of the area, close to the buildings, there is a significant presence of high vegetation. The research area covers 37ha, the highest building has a height of 60m, and the largest area under the building is 23200 m2. Based on the automatic building footprint extraction, a total of 105 polygons were created (Figure 2).
As a basic principle for building footprint extraction and comparison, need to be pointed out that extracted building footprints can differ from the building footprints registered at the cadastral system. This is because buildings that are sharing a wall are so close one to another that the detected polygon represents these two or more neighbouring buildings as a single building presented with a single polygon, while on the other hand, the cadastral system could register two or more buildings. This is because the cadastral system makes distinctions and sees more than one building from purely administrative reasons, and not because the geometric characteristics are showing more than one building.

Figure 2. Extracted buildings footprints in the research area (red polygons)

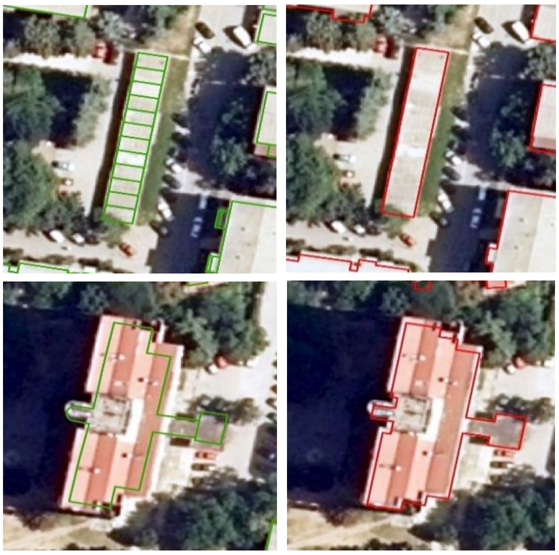

Figure 3. Building footprints registered in the cadastral system (left – green polygons), extracted building footprints based on LiDAR data (right – red polygons)

By comparison of the extracted and registered building footprints, it was calculated the first indicator, and it was found that on average 86% of the area of the polygons of the automatically extracted building footprints is within the polygons of the registered building footprints in the cadastral system. This area overlap varies from the lowest of 69% to the highest overlap of 98%.

Figure 4 shows the result of the comparison of these two datasets, where the horizontal axis shows the percentage of overlap of the extracted polygons within the registered polygons, while the vertical axis shows the number of polygons in the given interval.

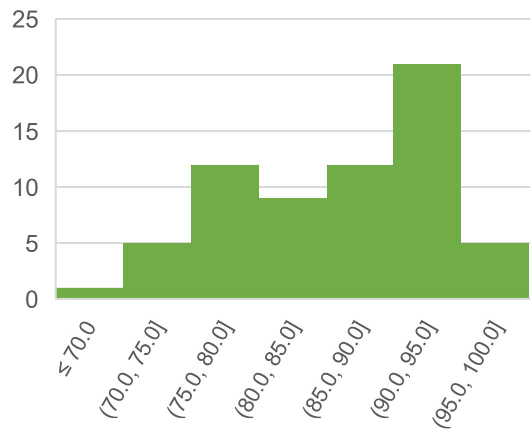

Figure 4. Percentage of overlap of the extracted polygons within the registered polygons

The second numerical indicator shows that the percentage is higher when it comes to the overlap of registered building footprints within the automatically extracted building footprints. The smallest overlap is 64% while the largest overlap is 100%. This means that the polygons from the automatically detected building footprints in a large percentage, and in some cases even completely, contain the polygons of the cadastral registration. The previous statement can be confirmed by the figure, which shows the percentage of overlap on the horizontal axis, and the number of cases in the given interval on the vertical axis. Figure 5 shows that most of the building polygons have an overlap of more than 95%, while only a small part of the building polygons have an overlap of less than 85%.

These two numerical indicators confirm a situation that can also be seen from the visual inspection, which shows that the polygons presenting the automatically extracted building footprint usually cover a larger area than the polygon presenting the registered building footprint. This conclusion is logical, maybe even expected, considering the LiDAR technology and the position of the sensor in relation to the buildings. The canopies, cantilever parts of the buildings, awnings, balconies, etc. significantly contribute these parts of buildings to be shown in an expanded form in comparison to the officially registered building footprint in the cadastral system, where we only have a presentation of the contact between the building and the ground, but not the extensions that are located on a certain height above the ground.

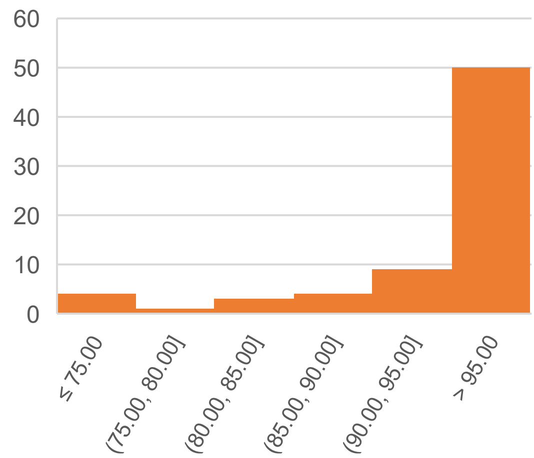

Figure 5. Percentage of overlap of the registered polygons within the extracted polygons

To present the automatic footprint extraction and interpretation of the buildings in more detail and to get an impression of the possibilities and weaknesses of this type of extraction, the results, and cases, of the extraction, will be presented. The classification of these buildings into three characteristic cases is based on their degree of overlap.

Case 1

The buildings presented in case 1 have a high percentage of overlap between the extracted and the registered polygons in the cadastral system. This type of building is characterized by a simple, rectangular shape, a height of approximately 30m, and does not have large canopies and/or consoles (Figures 6 and 7).

Figure 6. Building footprints registered in the cadastral system (green polygon), extracted building footprints based on LiDAR data (red polygon)

Figure 7. Photograph of the buildings shown in Figure 6

The percentage of overlap of the buildings with characteristics as in case 1, according to the first numerical indicator, more precisely the overlap of the extracted building footprint polygon within the registered building footprint polygon, is on average 94%. The second numerical indicator for this type of building shows an average of 99.5% overlap. The sides of the polygon produced by automatic extraction are parallel to the sides of the registered polygon, the number of vertices is approximately the same, and the polygons have an almost identical shape. The deviations of the vertices range between 20cm and 90cm.

Case 2

The buildings presented in case 2 have a complex shape, many vertices, a relatively small height, and a large area under the building. In general, these are public buildings, schools, kindergartens, shopping centres, etc.

In terms of numerical indicators, we can say that this type of building also has a high percentage of overlap. The first numerical indicator shows that the percentage of the overlap of the extracted polygon within the registered polygon is on average 94%, while the second numerical indicator shows that the percentage of overlap of the registered building footprint within the extracted building footprint is 91.5%.

Figure 8. Building footprint registered in the cadastral system (green polygon), extracted building footprint based on LiDAR data (red polygon)

Figure 9. Photograph of the canopy on the building shown in Figure 8

It could be noted that the shape of the buildings is almost the same and many details have been preserved. For this particular building it can be pointed out that there is an existing canopy and it creates a false impression that the footprint of the building is larger. This location in Figures 8 and 9 is indicated by a yellow circle. It is interesting to note that the openings in the buildings (patios) in both cases of the building presented in Figures 8 are shown without major deviations regarding the registered polygon in the cadastral system.

Figures 10, 11 and 12 show another building classified as case 2.

Figure 10. Building footprint registered in the cadastral system (green polygon), extracted building footprint based on LiDAR data (red polygon) – Skopje City Mall

Figure 11. Photograph of the building shown in Figure 10 - Skopje City Mall

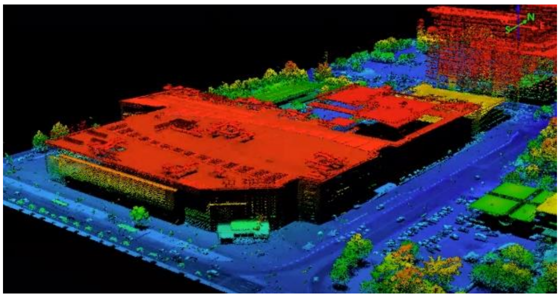

Figure 12. LiDAR point cloud of the building shown in Figure 10 - Skopje City Mall

Case 3

The buildings in case 3 have a greater difference between the polygon produced by the automatic extraction of building footprints in comparison to the polygons registered in the cadastral system. This type of building is shown in Figure 13. If we take a closer look, we can say that the larger deviations occur on the northern side of the building, which essentially represents an open terrace with a height above the ground of approximately one meter. On the other hand, if we look at the point cloud, it can be concluded that the points that present this part of the building (the terrace) are segmented as non-ground points but are not classified as building points. The reason for this situation is that, during the extraction of building footprints, a condition has been set that the points where there is a local variation in height greater than 2 meters should be classified as buildings. Since the open terrace is less than two meters high, the points are not classified as building points. The situation is the same with the points on the eastern side. Figure 14 shows the point cloud related to the specific building, where the points from the terrace are segmented as non-ground points, but not classified as building points.

Figure 13. Building footprint registered in the cadastral system (green polygon), extracted building footprint based on LiDAR data (red polygon)

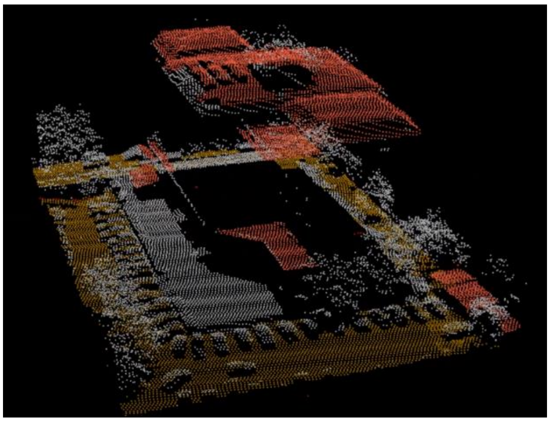

Figure 14. Classified LiDAR point cloud of the building shown in Figure 13 (red points - buildings, gray points – non-ground, brown points - ground)

Figure 15. Photograph of the building shown in Figure 13 – north side

Figure 16. Photograph of the building shown in Figure 13 – south side

The extracted building footprint given in Figure 17 has more deviations in relation to the cadastral registration. This is a characteristic situation in which the building is surrounded by urban equipment, canopies, and umbrellas which according to the law on cadastre are not subject to registration. The points obtained by the LiDAR scanning are classified as building points because those locations have urban equipment with geometric characteristics of buildings.

Figure 17. Building footprints registered in the cadastral system (green polygon), extracted building footprint based on LiDAR data (red polygon)

4. CONCLUSIONS

The first category of conclusions refers to the capability of automatic building footprint extraction based on airborne LiDAR point cloud. The analyses of the results of the automatic building footprint extraction have provided the following conclusions:

a) Building footprint extraction has higher quality in the case of large and tall buildings,
b) The presence of canopy covers creates a false impression that the building footprint is larger than it is,
c) Series of buildings connected by common sidewalls, forming a continuous group are extracted as a single building footprint,
d) Buildings surrounded by urban equipment, umbrellas, canopies, verandas, carports, etc. are creating a false impression of a larger building footprint.

The second category of conclusions focuses on the application of automatic building footprint extraction obtained by processing airborne LiDAR point cloud data. The sublimated conclusions indicated that the building footprints can be used in the following situations:

a) Detection of newly built and unregistered buildings,
b) Detection of extensions/upgrades of existing buildings,
c) Detection of removed buildings and structures.

The third category of conclusions is essentially a part of the second category, but considering its importance, it is pointed out as a separate category. It is about establishing 3D building models as an essential component in the construction of 3D city models. The production of these models is greatly facilitated and shortened on the one hand, and the quality and details are significantly improved on the other hand, if point cloud data is used. It should be noted that further increases in the quality of these models will be achieved by combining the point cloud data and cadastral registration data.

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