Exploratory Analysis of LiDAR Data in Urban Areas

The Case of Faro Island in Southern Portugal

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Keywords: Airborne Laser Scanning, point cloud, building extraction, roofs, height data

Introduction

The LiDAR (Light Detection And Ranging) technology, also known as Airborne Laser Scanning (ALS), unlike traditional methods such as photogrammetry, enables us to swiftly collect direct elevation data over a vast area. The basic principle of LiDAR is to collect a georeferenced and dense 3D point cloud from laser scanning. Data acquisition during the flight is performed by three components: Laser sensor, GPS (Global Positioning System), and INS (Inertial Navigation System). The laser sensor transmits laser light pulses to the Earth’s surface, GPS gives the position of aircraft, and INS gives the sensor’s attitude (roll, pitch and yaw) for each laser beam. 3D point data are very useful to generate: Digital Terrain Model (DTM), i.e., bare earth surface; Digital Surface Model (DSM) of the visible terrain surface as well as such objects; and 3D feature models (buildings, trees, and other urban objects). Currently, the photogrammetric stereorestitution is the usual method to collect 3D data. The comparison between LiDAR and photogrammetry has been discussed by Baltsavias [1]. The disadvantage of using photogrammetry stereo measurements for building reconstruction is the fact that it is costly and time-consuming. The main advantage of LiDAR is its high vertical accuracy. However, its planimetric accuracy is 2-6 times less accurate than its vertical accuracy, while photogrammetry is typically 1/3 more accurate [1].
Over the past years, 2D and 3D building extractions using LiDAR data have been studied by several authors, such as [2], [3], [4], and [5].The development of algorithms for automated building extraction in urban areas is of great importance for the 3D reconstruction of buildings. The major application of these 3D urban

models would be in urban planning regulations [5] and visualization for public discussion.

This work presents an experimental study on building extraction from LiDAR data. In this context the main objectives were to extract: i) building roofs; ii) building height; and iii) roof types.

Study Area and Data Collection

The study area is located in the Faro Island. The selected geographic area has an extension of 190m×82m (Figure 1). This area is characterized by water bodies, a main avenue, scattered trees along the area (palm trees, deciduous and coniferous trees), and sand. The buildings are single-family and multi-family houses. In this study area there are 22 buildings, almost all of them with irregular shapes. The roofs are flat, multiple-level flat, pitched and complex (roofs with different slopes).

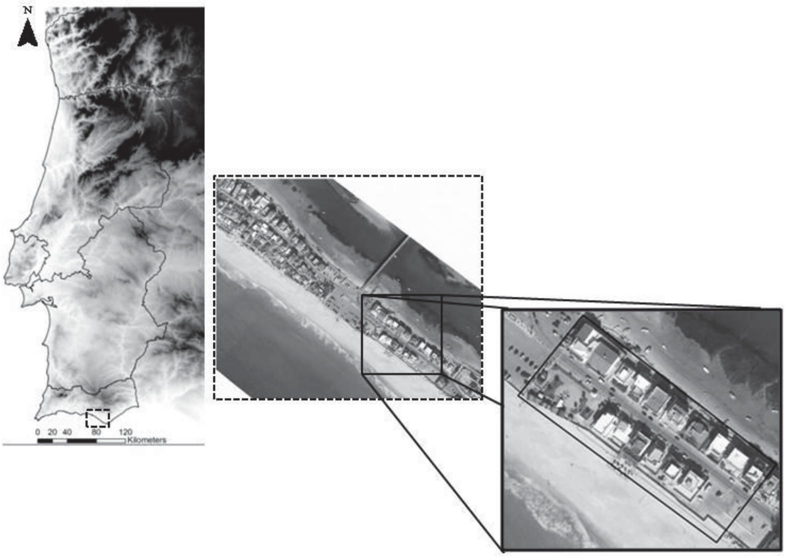

Figure 1: Study area of Faro Island, Southern Portugal.

LiDAR point data were collected in November 7, 2009. The LiDAR system used for this task was TopEye MK IIB. The density of the point cloud depends on height LiDAR flight. In this case, LiDAR flight is of about 500m height, resulting in a density of 5-9 points/m^2, according to metadata. Such density corresponds to a distance between points of less than one meter. The distribution of points is elliptical due to the type of laser scanning (Figure 2).

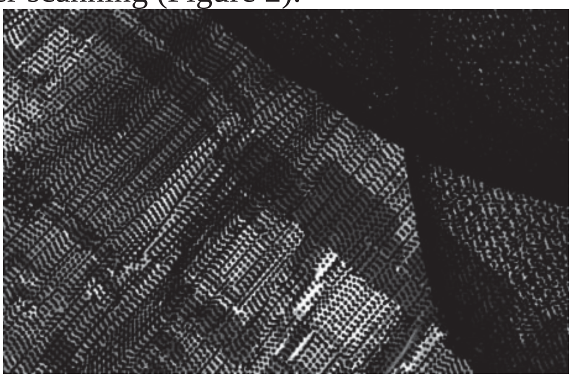

Figure 2: LiDAR point cloud.

The range capture recorded two returns per pulse laser (first and last returns). Eachlaser return results in a point data with x, y and z coordinates and the value of intensity (or reflection of objects on the surface) for each point. The characteristics of LiDAR data (area marked in Figure 1) can be seen in Table 1.

Total Points	1^{st} Return Points	Last Return Points	Point Spacing
84927	80587	4340	0.70 m

Table 1. LiDAR point data information of study area.

According to the flight planning report, the point cloud has a vertical accuracy of 10 cm.
Before extracting the buildings, it is important to assess the quality of pre-processing data and the conditions of the LiDAR flight. The LiDAR data used in this work are accompanied by a report that describes the whole quality control process, including georeferencing and calibration of the flight lines of 3D points based on GPS/INS data. The ground control points used in coordinate transformation from WGS84 to the local coordinate system Datum 73 are also known.
Furthermore, orthoimages of the same area were also used in this study for visual inspection of building roofs. This dataset was produced by aerial images captured at the same time as LiDAR data. The ground sample distance of these images is 9cm/pixel.

Methodology

The automatic acquisition of buildings from point cloud can be done in three steps: 1) interpolation from point cloud (first and last return) to raster DSM; 2) creating raster DTM from DSM, using last return points or first and last return points; and 3) extracting building features based on DSM, DTM, and a set of extraction parameters.
The flowchart of this automatic processing is shown in Figure 3. The methodology included two different approaches. In the first approach (Test 1) buildings were extracted using default parameters of the LIDAR Analyst software. The second approach (Test 2) was designed to improve the results of the first one by the introduction of two steps in a workflow: refining DSM and customizing the extraction parameters.

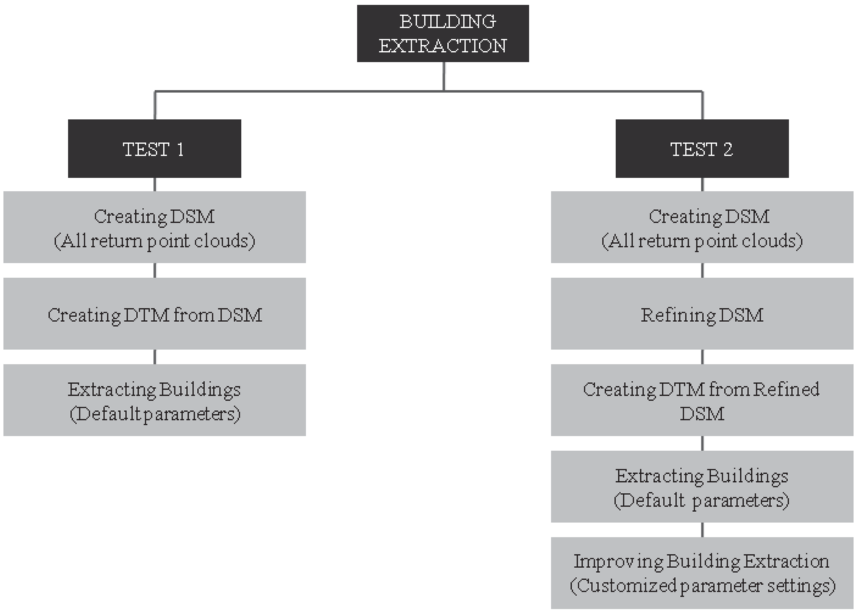

Figure 3: Two methodological approaches for building extraction based on LiDAR point cloud.

When performing building extraction, it is necessary to ensure a good quality of the DSM and DTM. While for Test 1, the DSM and DTM were built using the default parameters, for Test 2 the refining process for DTM was carried out by editing the DSM with the removal of objects near the buildings (e.g. cars). The extraction parameters for buildings were then manipulated with a combination of parameter values. Firstly, the parameters used to define the boundaries of buildings were changed by the minimum and maximum slope values of building roofs. Then, this combination was repeated with two additionally changed parameters: minimum building height and smoothing tolerance. The latter parameter defines the maximum distance a point can move in relation to its neighboring vertices. Another parameter used in the extraction was the texture variance to differentiate between trees and buildings [6].
Parameter values adopted for Test 1 and Test 2 can be seen in Table 2.

Parameters	Test 1	Test 2
Do Not Remove Buildings with area between	30-35000m^2	30-35000m^2
Slope for building roofs (minimum-maximum)	15-40º	30-70º
Texture Variance Trees	80%	80%
Remove Buildings with Height Less Than	2.2 m	1 m
Smoothing Tolerance	2 m	1 m

Table 2. Parameters for extracting buildings (Test 1 by default and Test 2 customized).

Test 2 represents the best combination of parameter settings within the set of tests.

Results

The first Test automatically extracted 15 isolated buildings (Figure 4a). However, in this Test, most building roof areas did not match the highest elevation values visible in DSM ('white shaded areas' in Figure 4a). The 3D model of these buildings can be seen in Figure 4d. This model (without roof details) was obtained from building boundaries and an extrude function by attribute *average height* of building. If the reconstruction of the buildings is created with original LiDAR data (without processing), the results will be as presented in Figure 4c.

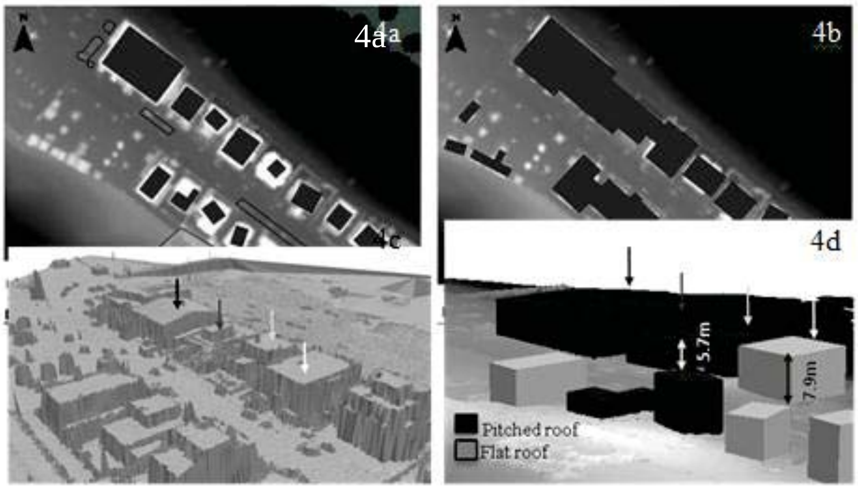

Figure 4: Visualization of buildings extracted from Test 1 and Test 2. 4a) Buildings extracted by default and polygons that identified the objects removed in Test 2; 4b) Buildings extracted by Test 2 with Refine DSM; 4c) TIN (Triangulated Irregular Network) model from LiDAR data; and 4d) 3D model buildings of Test 1.

The buildings extracted from Test 2 (Figure 4b) have better orientation and the geometry is more consistent with the DSM.
Building roofs were classified into three types: complex, flat and pitched (Figure 5c). The results of this automatic classification can be seen in Figures 5a and 5b. The values of roof slopes were taken into consideration during the extraction process.

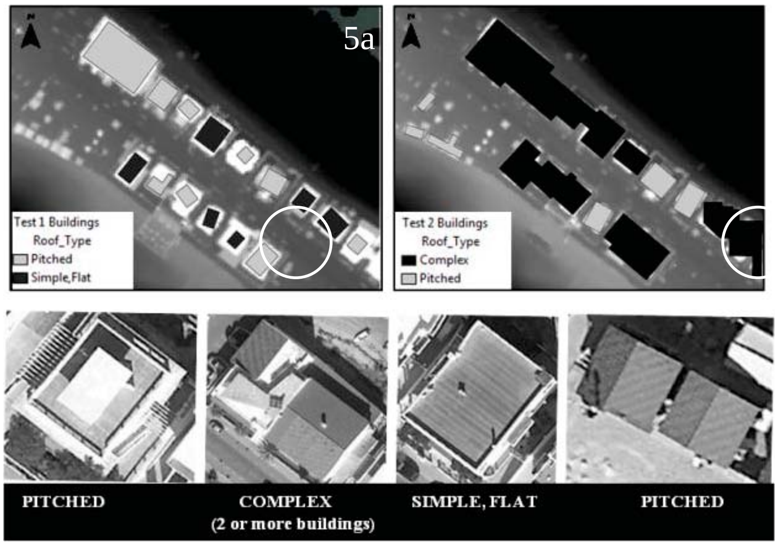

Figure 5: Visualization of types of roofs extracted. 5a) Classification of building roofs on Test 1; 5b) Classification of building roofs on Test 2; and 5c) Classification of roof types.

In Figure 6 it is possible to compare one single building (circled in Figures 5a e 5b) acquired from stereorestitution (building roof boundaries) and the automatic feature extraction from point cloud, with a density of 12 points/m^2 in the building roof areas.

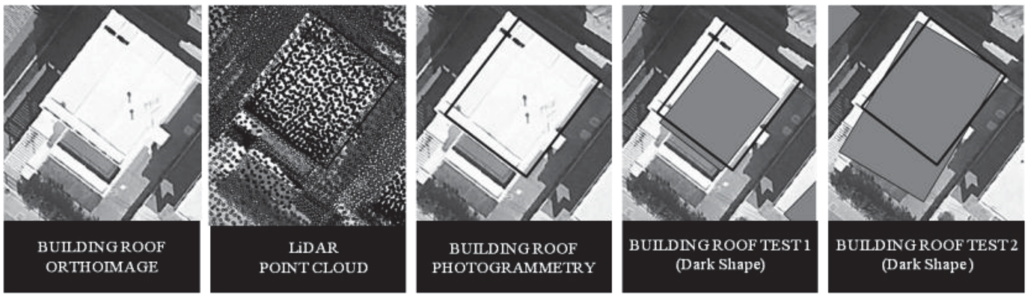

Figure 6: Comparison between the building roofs extracted by stereorestitution and LiDAR data. Influence of the building roofs extracted in the classification of roof types.

The building extracted in Test 1 (marked in Figure 5a) had the same orientation as the building extracted by stereo photogrammetry. The roof of this building was classified differently according to each approach because of the automatic extraction process. When the building extracted was characterized by higher slopes, the roof was classified as pitched (Test 2) and when the slope was low, the roof was classified as flat (Test 1).
The difference between building height obtained by photogrammetry (6.46 m) and building height extracted from LiDAR (6.61 m) is on the order of centimeters.

Concluding Remarks

This first approach to the use of LiDAR data in urban areas revealed potential use in the delimitation of built-up areas or block buildings in an urban area.
The automatic extraction of building height from LiDAR data shows a small difference (on the order of centimeters) regarding the height value obtained by photogrammetric restitution. On the other hand, the results show that it is difficult to extract building roofs with irregular size and heterogeneous surface structures.
Future work includes refining the DSM and DTM with vector data acquired by photogrammetric stereo-restitution. The vertical accuracy of LiDAR data in determining urban parameters, building height and building volume will be investigated and error sources quantified.
Future tests performed with LiDAR data will be essential to assess the accuracy of 3D building modeling. This modeling process may represent an important step towards the operationalization of data processing methodologies for the virtual reconstruction of towns.

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Acknowledgments

This work was partially supported by PROTEC program (SFRH/PROTEC/67481/2010) in the context of e-GEO, FCSH-UNL. The LiDAR data was kindly provided by Micore project FP7 Framework. The authors would like to thank Professor João Catalão Fernandes of the Faculty of Sciences (University of Lisbon) and Master Student Célia Sousa for providing the building’s footprint. We would also like to thank Teresa Santos and Sérgio Freire for their helpful comments.