# Title:
# Creation of thematic maps and 3D models of objects using UAV and LiDAR technology

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**Level of study or work:** Master

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## Area of interest

Building footprints is important information in many types of applications, such as urban planning and reconstruction, disaster monitoring, urban dynamic monitoring, 3D city modelling etc. High-resolution UAV images and deep learning algorithms have become essential in large-scale building information collection. However, the results of extracted footprints usually represent rooftop outlines with overhangs rather than true building footprints. In addition to creating an orthophoto, UAV survey has several additional products such as dens point cloud, 3D mash models, DSM, and DTM. This paper presents the methodology for the optimization of extracted building footprints by using additional data, which is based on the extraction of a cross-section of a 3D building model at an optimal height.

## Approach to the problem

The comprehensive extraction algorithm utilizes software tools for creating 3D models, DEM and DSM, Convolutional Neural Networks for identifying building footprints, Python for calculating appropriate optimal heights and extracting sections, and software for simplifying the geometry of the extracted sections.

The workflow consists of four main steps: data acquisition, pre-processing, processing, and accuracy assessment (Figure 1).

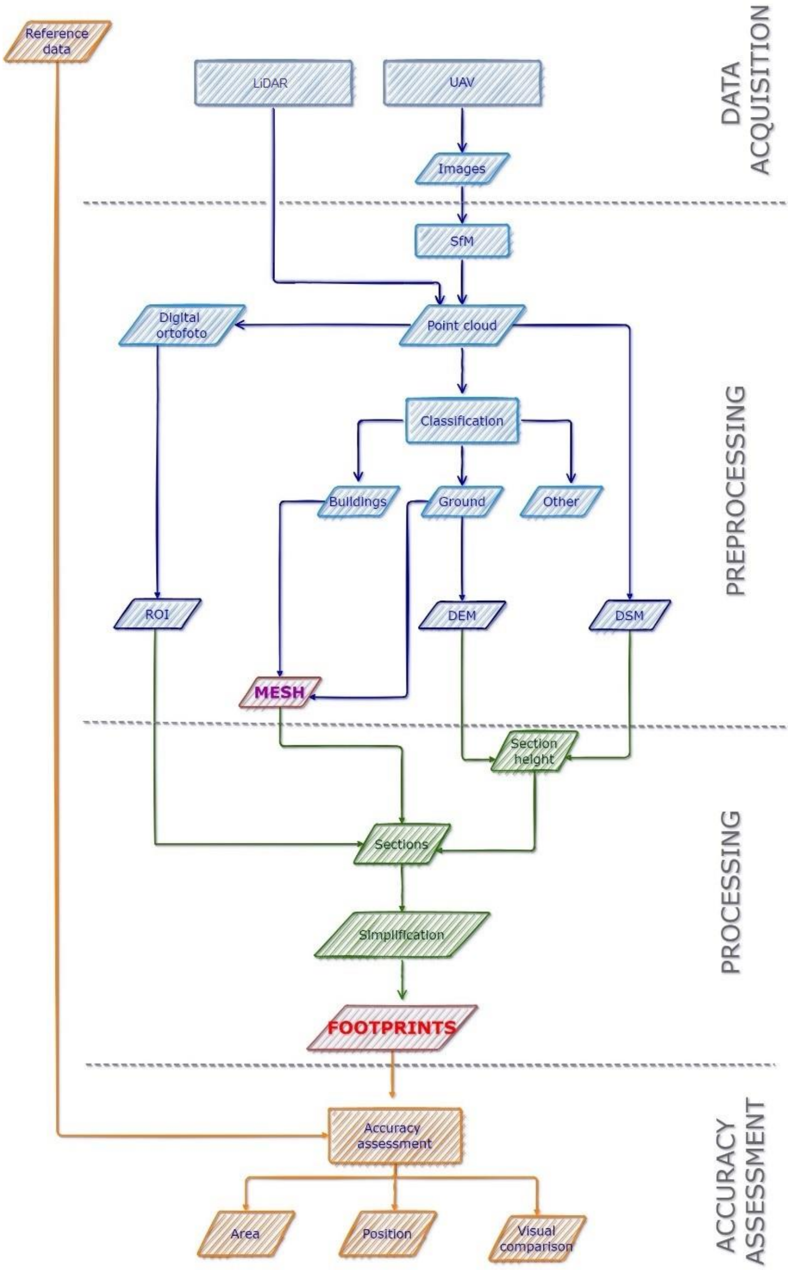

*Figure 1Workflow*

**Data acquisition.** The DJI Phantom 4 Pro drone with RGB camera was used for data collected in this study. In addition to UAV, the generalization abilities of the proposed methodology were also tested on LiDAR data.

**Pre-processing.** The Structure from Motion (*SfM*) algorithm was applied to the collected images to generate a dense point cloud. Based on both generated point clouds (one derived using photogrammetry and other derived using LiDAR technology), high-resolution DEM and DSM as well as an orthophoto are created. Using the point clouds as a basis, 3D mesh building models were generated. The CNN deep learning algorithm was utilized to extract building footprints (i.e. regions of interest (ROIs)) of each object presented in the orthophotos.

**Processing.** The model used in this study to detect real building footprints without roof overhangs was based on a cross-section of a 3D mesh model at a suitable height (Figure 2).

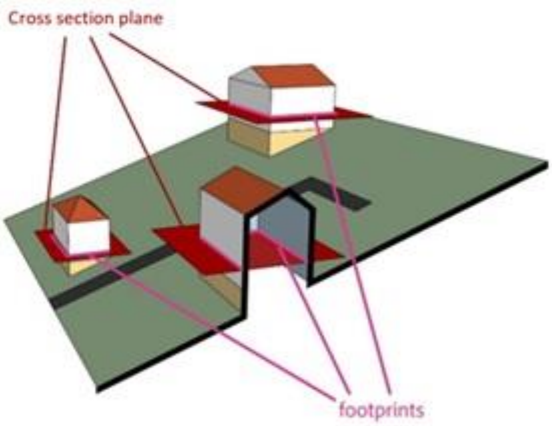

*Figure 2 . Proposed methodology for extraction of building footprints in 3D space*

The optimal height of the cross-section was determined by extracting the minimum and maximum values of DEM in ROI determined by using the *zonal_stats* function which is available in the *rasterstat* library in Python programming language. The maximum height within ROI should represent the optimal height of the cross-section. However, the dense point cloud wasn't uniformly dense. Due to dead angles, shadows etc. the holes are presented in 3D point clouds mostly in areas under overhangs and near the ground. Taking that into account, during mesh creation the interpolation was used to create triangles in those areas (figure 3, left). Consequently, creating a cross-section at the maximum height of DEM within ROI would result in a larger building footprint. Taking that into account, the optimal height of the cross section was determined by introducing the bias Δh. Bias was calculated based on building height, which represents the difference between the maximum value of the DSM and the minimum value of DEM within the ROI (Figure 3, right). The optimal height of the cross-section was defined using a tested expression:

$$H_{ROI} = H_{DEM}^{max} + \Delta h$$

where Δh = 0.5 if the building height is less than 2.35 m and Δh = 1.5 m if the building height is greater than 2.35 m.

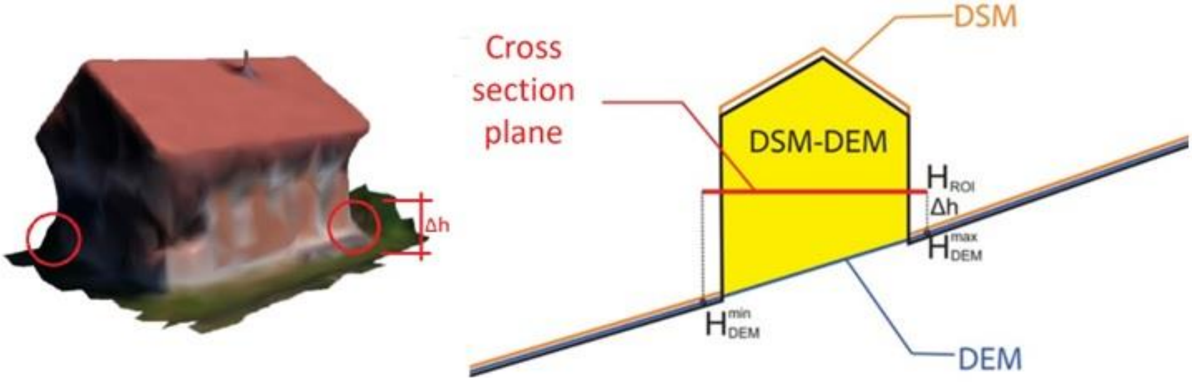

*Figure 3 Determining the optimum height of the cross-section*

The cross-section of the mesh model with ROI at optimal height was implemented by using *trimesh* library.

Buildings mostly have regular boundaries that consist of straight lines, while the created cross-sections, due to the triangle mesh structure, result in buildings footprints with irregular outlines and redundant vertices (Figure 4, left). Therefore, in order to provide optimization of building footprints it is necessary to perform generalization of extracted outlines, force several geometrical rules such as diagonal length equality, forcing right angles, etc. The generalization of extracted building footprints is performed in ArcGIS software by using Regularize Building Footprint tool (Figure 4).

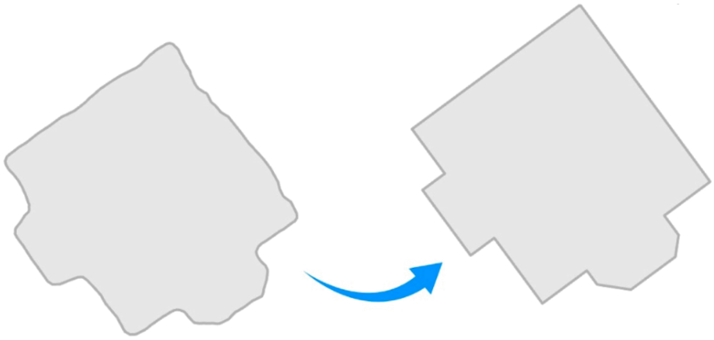

*Figure 4 Left: Building footprint derived from mesh model, right: Building footprint after generalization*

## Results, conclusions and next steps

The reference dataset contains 2D representations of buildings and surrounding objects collected through classical surveying methods with a horizontal error not exceeding 10 cm. The study performs a quantitative analysis of the results (Figure 5), including investigating the positional accuracy of building footprints. The study finds that the performance of the proposed workflow depends on the building's surroundings, and the algorithm produces lower accuracy in environments where several buildings are located near neighbourhoods. The proposed methodology provides an area improvement of 5.2% compared to OSM data. The study also finds that the average positional error for the UAV data was 0.69 m compared with reference data, while data generated using LiDAR technology had an average positional error of 1.4 m, mostly caused by low point cloud density. The proposed methodology can significantly improve the accuracy of CNN-extracted building footprints and optimize OSM footprints. However, the model's performance is highly limited by building neighbourhoods, and future research should analyse the extraction of building footprints from the point cloud.

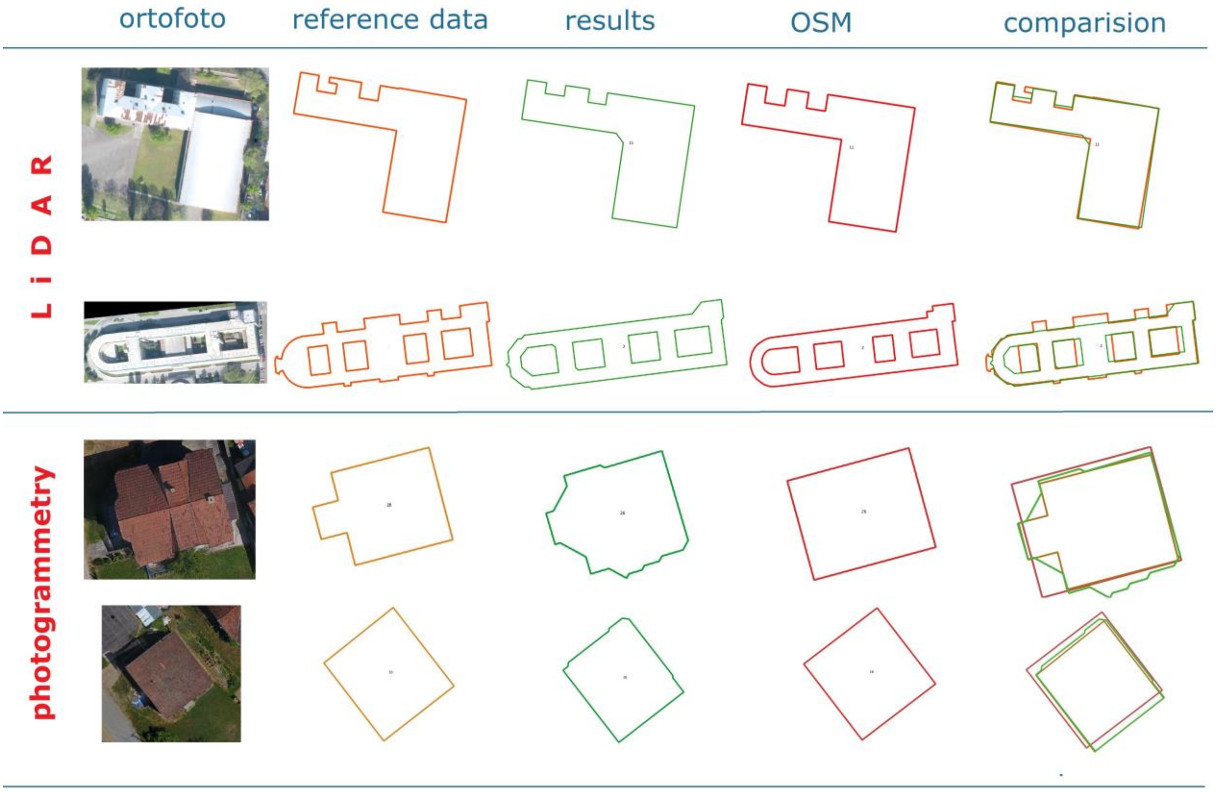

*Figure 5 Visual comparison of results*

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