FROM POINT CLOUD TO 3D BUILDING MODEL

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3D City Models are virtual representations of urban environments integrating geospatial data like buildings, terrain, landmarks, infrastructure landscapes and vegetation. 3D City Models positively influence urban planning, offer environmental analyses, can help manage risk and leads to better decision-making. Due to the rapid change in urban environments, there is a growing need for more efficient methods for spatial data acquisition as well as processing methods, which will meet the needs of 3D City Models in terms of accuracy, details, but also in terms of time and cost.

In this paper methods for spatial data acquisition and data processing are presented, theoretically and practically, in order to obtain 3D Building Models as the most important component of the 3D City Models. The main goal of the paper is to explore the possibilities of modelling 3D buildings by processing point cloud data generated from photos produced by Unmanned Aerial Vehicle (UAV), as one of the most convenient, fast and cheap ways for spatial data acquisition. The practical example presented in this paper, point out the power of this kind of data as an input for obtaining 3D building models.

Key words: 3D City Model, 3D Building Model, Point Cloud.

1. INTRODUCTION

Ever since the modelling of spatial object has started there is an ongoing tendency for increasing the level of details and the level of quality (spatial or nonspatial). It is an ongoing battle and most probably will continue in the future. Typical representation of the buildings and the objects in the traditional way ware presented/projected on the horizontal plane, where presentation of the characteristics of the buildings is done with symbols. Even though for some applications this way of presenting the spatial phenomenon is still sufficient, there is a strong market request for more detailed and more comprehensive modelling of real world. On the other hand, increasing the level of details creates a need for faster and low-cost data acquisition, data processing and data modelling.

The geospatial industry has developed significantly in this area and today we have many solutions, products, systems, applications where models are far from simple 2D representations of the objects. One of the big movements in the urban area modelling are 3D city models. Introduction of the third spatial component is not new and it was done in the past also, but with surfaces modelling which today is known as 2.5D representation. In this 2.5D models on one known location (Y,X) the model represents only one value (Z), which is not sufficient to present complex urban situations. These needs have driven the science to develop more detailed full 3D model of urban areas, which has resulted with 3D City Models.

3D City Model is a representation of urban environment with 3D geometry of common urban objects and structures, with buildings as most prominent feature (Biljecki, Filip, et al, 2015). These models have constant development process and in general two phases can be distinguished. The first phase where models ware developed and had purpose of visualization urban areas without serious possibilities for spatial analysis and in the second phase, applications of 3D models has been seriously developed. Today we have wide range of implementation of 3D models in a different area of research, planning, protection, prediction, decision making and many other processes.

The application of these models highly depends of the details of the model and the quality of the model in general. The amount of detail that is captured in a 3D model, both in terms of geometry and attributes, is collectively referred to as the level of detail (LOD), indicating how thoroughly a spatial extent has been modelled. As a result, the LOD is an essential concept in geographical information science (GIS) and 3D city modelling (Biljecki, Filip, 2017).

Figure 1. 3D City model level of details

Based on CityGML classifications, there are five level of details, starting from LOD0 to LOD4. The standard for LOD represents the necessary features of the buildings that need to be presented/modelled. Developed models with different LOD gives a different possibilities in exploitation phase of the model but also more detailed 3D city models require more labour and entail a reduced degree of automation (Jokela J, 2016).

Spatial data acquisition for development of 3D City Model is a hard and long process.

2. MOST COMMONLY USED TECHNOLOGY FOR 3D CITY MODELLING

Technology for spatial data acquisition is in a constant development, striving toward more precise, detailed and faster data acquisition. Other very important tendency is related with cost of data production.

3D city models are based on a large data quantity gathered in order building models to be as close as possible to the actual appearance, texture and geometrical shape. The process of data collection is not only focusing on spatial but also nonspatial data. Data acquisition technologies can be divided by many criteria, in this paper three are discussed.

The first classification is based on data acquisition technologies. In general, there are three major technologies which provide a satisfactory result in 3D city modelling and those are as follows:

- Classic approach (total stations)
- Photogrammetry
- Laser scanning

Classic approach of modelling buildings has long tradition of implementation and still it is usable method. It is a method of collection of spatial data without high degree of automation but a great level of control. This method is very much time consuming and not very reach with details of the modelled object. It is in general manual data acquisition, that means the number of surveyed points is not very high and has significant influence of the process of creation of the model where intensive labour needs to be invested.

Photogrammetry methods are very much exploited in the last decade. Development of new camera caring platforms like drones, cars or long telescopic poles, together with new software and techniques like Structure from Motion (SfM) has made photogrammetry one of the top technologies for modelling complex objects. The models are produced based on a large number of photography's taken from different positions with overlapping of about 80% which are further processed and point cloud is extracted. Development on the building models are created from the generated point cloud. This method is characterised with high degree of details, depending of the distance between camera and objects, fast data acquisition, low cost of production, and possibility of high accuracy. Many positive sides that photogrammetry has in context of 3D City Modelling has made photogrammetry as one of the technologies most commonly used in 3D City Modelling (Kobayashi Y., 2006). The photogrammetry has gained even more popular when regular digital cameras started to be used in order to obtain images for building spatial products through photogrammetry methods. In the past it was expensive to use airborne images for small scale projects, today with introduction of drone as a camera carrier it is one of the most convenient and cheap ways for spatial data acquisition.

Third technology widely used for data acquisition is laser scanning. It is a powerful technology which has characteristics that are in favour of building precise models accompanied with a lot of details. Laser scanners can be terrestrial or can be scanning from the air. Terrestrial scanners can be static or mounted on a moving vehicle and airborne lidar can be done with sensor mounted on an airplane, helicopter or drone. In the last several years mounting lidar scanner on drones has become very popular for small scale projects. By evaluating the explicit height information contained in laser scanning data together with cues such as surface roughness or laser intensity, objects such as buildings and trees can be extracted automatically (Rottensteiner, F, Trinder J, Clode S, 2005). Lidar data has high accuracy and it has fast data collection period.

There are many academics discussions about better and more suitable method for data acquisition and many researches have been conducted to resolve the dilemma. Bottom line answer is: depends, laser scanning technology requires more preparation and it is more time consuming while image-based point cloud production it takes faster time to acquire images and equipment is rather cheaper. In comparing laser scanning to image-based method, for small and medium size objects and distance image-based method have an advantage in terms of methodology and speed, but on large scale objects laser scanning is better in terms of quality and processing time.

Creating sufficient data quantity for 3D modelling of objects can lead to combination of all previous technologies in providing data that is going to be used in establishing or updating the model. Each of these technologies, due to complexity of objects, could be insufficient source of data, so additional data can be provided with other available technologies for data acquisition or most probably combination of terrestrial and observation from the sky.

Concerning modelling processes, we could categorize modelling methods in three categories: automatic, semi-automatic and manual. The automatic approach is basically modelling of existing buildings, structures, based on point cloud data by using technologies for pattern recognition. The semi-automatic approach is to model a building based on the point cloud data and algorithms for detecting characteristic features of the building, like walls, roofs with some interventions of the operator. The manual building modelling is conducted in classic CAD software by creating each building element manually form the collected data. These three modelling methods are very dependant of the available data type, way of data is collected, accuracy of the data and objects and surroundings that are being modelled. Also, each method is error-prone, so this component it needs to be taken in consideration as well.

3. EXPERIMENTAL RESULTS

The research has been conducted on a test area, which has been selected in order to be an adequate test polygon for the purpose of this research. A flight campaign was conducted in June 2018 using a drone DJI Phantom 4. The flight had an altitude of 50m above ground level. The test area covered approximately 4 ha where ground control points were marked and surveyed. The observed settlement is with densely built houses, with various types of roof constructions, but not so dense built areas are also present in order to see the impact of neighbouring characteristics on the buildings during building extraction process. Vegetation is also present with different heights within observation area.

Figure 2. Orthophoto of the study area

The dense point cloud generated for the study area was made of more than 15 million points. The model is georeferenced by 7 ground control points and the position error after georeferencing the model is 4.4 cm. The point cloud as a result is shown in the next figure.

Figure 3. Point cloud data of the study area

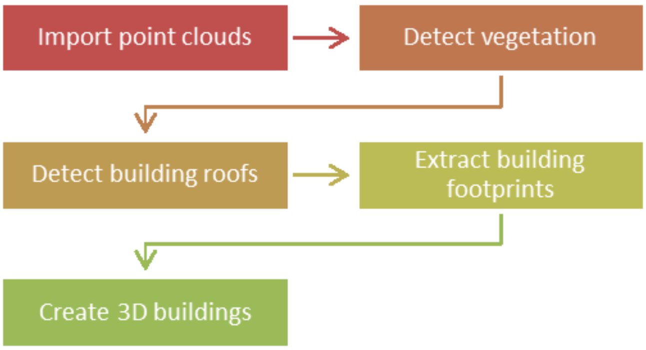
4. PROCESS DESCRIPTION

In this research an automatic and semi-automatic method for feature extraction was used. The focus are roofs of the buildings, and the buildings as a whole, having in mind that buildings are the most important part of the 3D City Models. The buildings are created of planar surfaces as a best approximation of the created point cloud and the composition of the building is consisted of walls and roofs.

Data processing of created point cloud starts with importing the point cloud in the software, manual removing of unwanted points accompanied with automatic point filtering based on a given parameters. Vegetation detection is the next step and it should be made in order to differentiate vegetation points from the points that represent the rest of the objects. The software for classification of point cloud data offers the possibility of defining different parameters for detecting points from vegetation and points form building for more effective automatic classification. After the detection of points which represent vegetation, the next step is the detection of points from buildings roofs. A choice of parameters for automatic detection of the points that represent roofs of the objects can be made. These parameters refer to the minimum height of the roof construction, the maximum slope of the roof construction, the minimum and the maximum number of points per roof construction, etc.

As mentioned earlier, two methods were used, automatic and semiautomatic building modelling. In both methods creation of the model is based on definition of planar surfaces as a best fit to the point cloud. In the manual modelling process, borders of the roofs are delaminated and best fit plains are created, also similar process is used for a wall modelling.

A basic processing workflow for automatic creation of 3D building form point cloud is shown below:



If automatic modelling of buildings is conducted, the next step is extraction of building footprints and creation of 3D models of buildings from classified point cloud data. 3D buildings can be modelled at a different level of detail as mentioned earlier in the paper. In this research an automatic modelling method was applied and two 3D building models were created with different level of details, LOD1 and LOD2. Results are presented at Figure 4, a) LOD1 and b) LOD2. The LOD1 presents buildings as objects with flat roof, while LOD2 presents the buildings with geometry which is close to the actual geometry of the roof but without details about some additional elements of the roof like chimneys.

Automatic extraction of 3D buildings will be successful if a good classification of the point cloud data has been previously made. Under conditions where buildings are rare and the vegetation around the buildings is not dense, the automatic classification and extraction of 3D buildings yields good results. But in conditions of dense construction and the presence of dense vegetation it is necessary to make corrections to the automatic classification and extraction of building elements semi-automatically in order to obtain good results. Automatic 3D modelling is sufficient to get a 3D City Model at a lower level of detail. In order to get a 3D model at a LOD3 or LOD4, more efforts and application of semi-automatic or manual processing of point cloud data should be done. For this purpose, we use mathematical algorithms in order to extract planes from a point cloud data. In this process, it can be chosen different planes as well as contours of those planes from which a model of 3D objects can be created. The following figure represents model of different types of roof constructions by extracting plains a) without and b) with defined boundary.

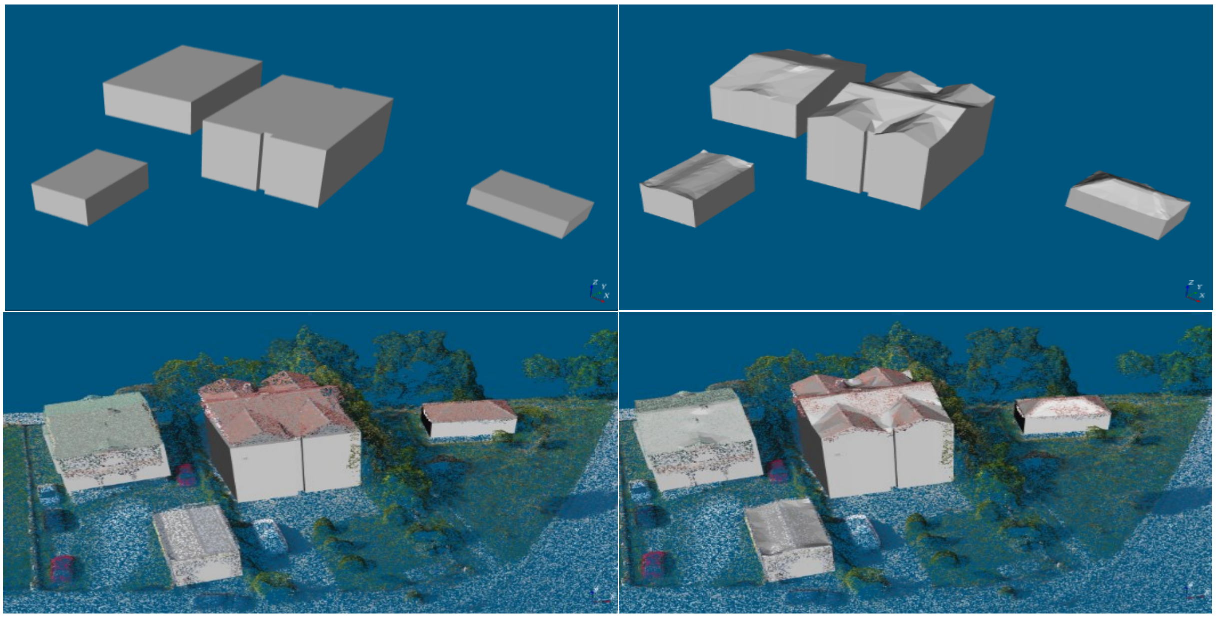


Figure 4. a) Buildings at LOD1; b) Buildings at LOD2

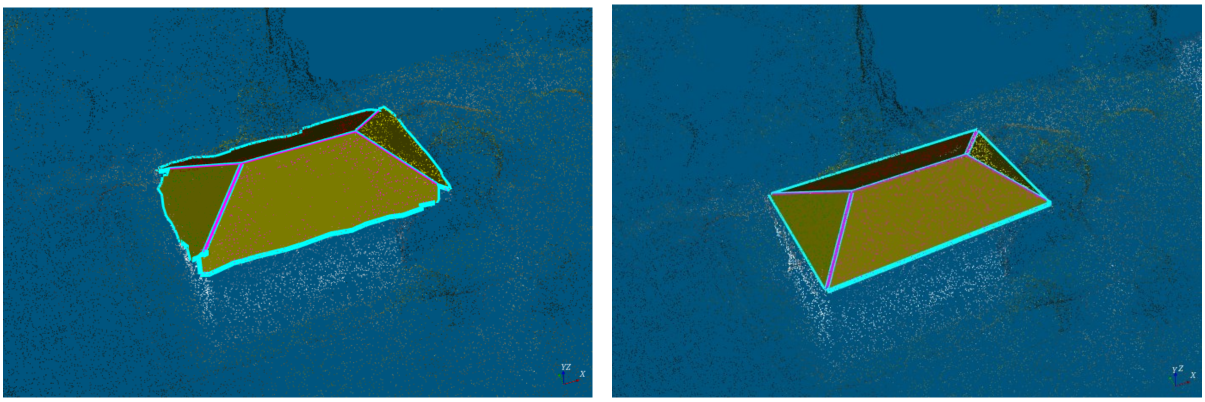


Figure 5. a) Extraction of plain without defined boundary; b) Extraction of plain with defined boundary

This procedure can be used to model other elements of 3D objects and not only the roofs. The Figure 6 shows model of the object at a LOD3 created with semi-automatic extraction by extracting planes which represent roofs and walls of the building.

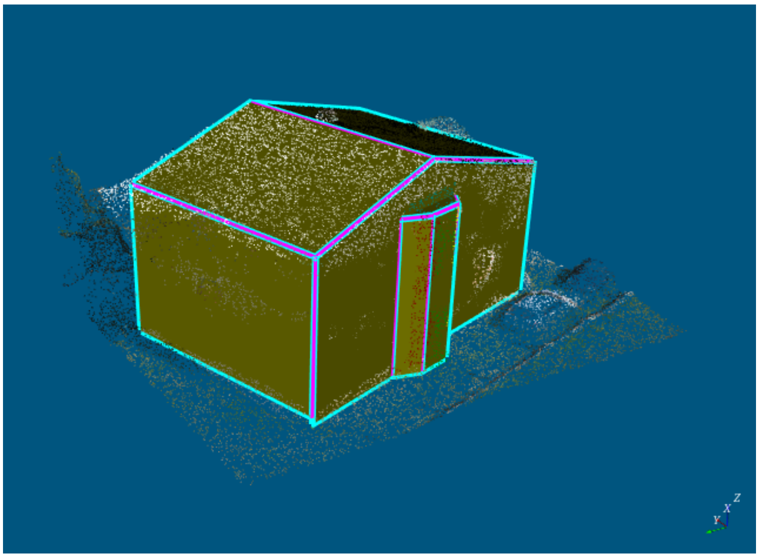


Figure 6. 3D building modelled by extraction of plains

5. CONCLUSION

The industry together with researchers are in a constant struggle for development of a new technologies for data acquisition and data processing where 3D City Models are going to be produced in faster and more efficient manner. For small and middle size projects, UAV together with image processing algorithms have made a small revolution in 3D modelling. Point clouds have become standard data source for feature extraction at mass data collection projects and models produced in this way are becoming more and more competitive with other technologies such as laser scanning. However, Image based point cloud data has its limitations, particularly in the areas where dense vegetation is present and algorithms for automatic data extraction shows their downsides. Aerial photos are producing good results for roof modelling but walls of the buildings especially in a densely build areas are not modelled very well, in this case and oblique image need to be taken. Very often a manual intervention is necessary in order a better-quality model to be created. If higher level of details is requested, bigger manual interventions are going to be needed in order to produce a higher quality result.

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