Using Free Lidar Data with Aerial Photogrammetry Images for Construction of 3D Building Models for Openstreetmap

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Abstract. 3D-modeling of buildings in OpenStreetMap project (OSM) is a new trend, and the level of detail (LOD) for most 3D building models still present - LOD1 without taking into account the modeling of building roofs. In addition, there are many defects and shortcomings existing in 3D building models that need to be corrected and adjusted. In this article, we propose to use the available data LiDAR (Technology of using light in the form of a pulsed laser to measure distances to objects on Earth) with free aerial photography image to build 3D models of buildings to eliminate existing defects and shortcomings and to obtain fairly accurate 3D building models for OSM. To demonstrate one of the shortcomings of 3D OSM models, we reviewed the 3D model of the building of the St. Petersburg National Research University of Information Technologies, Mechanics and Optics (ITMO) in OpenStreetMap, and, having corrected this deficiency, obtained a revised 3D model. Applying the proposed method of using LiDAR data with aerial photography, we selected a territory in the city of Christchurch in New Zealand, where there are available LiDAR data, downloaded LiDAR data point clouds from the Open Topography site and built fairly accurate 3D models of buildings that exist in this area of study with their roofs using the Global Mapper software. Accordingly, we received good and complete 3D building models with a level of detail LOD2.

1. Introduction

Currently, volunteer geographic information describes a relatively new phenomenon in geoinformatics. OpenStreetMap (OSM) is considered one of the most successful and popular VGI projects (volunteer geographic information) with global volunteer participation. Over the past ten years, user growth is an indicator of the level of attractiveness. For example, the registered number of OSM members by the beginning of 2014 amounted to 1,500,000, while on October 27, 2018, this number reached 4,977,138 [9,13] (Figure 1).

Figure 1. Number of OSM registered members until 27 October, 2018.
Due to such rapid growth in the volume of volunteer geographic information (VGI), and in particular to the OpenStreetMap project, there is an increasing interest in using VGI to build 3D city models. Therefore, the need to provide accurate 3D models of buildings for these projects is an important issue. Many maps and tools support a simple 3D building scheme. The first were the OSM-3D.org visualizer in 2009, the OSM2World visualizer and the Kendzi3D JOSM plugin in 2011. OSMBuildings launched a 2.5 D display in 2012, and then a 3D version in 2015. In 2013, F4 Map became the first visualization tool that fully supports the scheme of simple 3D buildings [5-7].

The concept of level of detail (LOD) is important in 3D modeling of cities. It is used to define a series of different representations of real-world objects. According to CityGML, there are five discrete LODs (LOD0 - LOD1 - LOD2 - LOD3 - LOD4), which are mainly characterized by the complexity of the geometry. LOD0 is a digital elevation model with building outlines, and volumes are not available. LOD1 - the building is geometrically represented as a block model with a flat roof. LOD2 - the outer shell of the building is represented geometrically in a general way. Different parts of the outer shell are semantically classified, for example, walls or roof surfaces. LOD3 - the outer shell is presented geometrically in detail. In addition to LOD2, doors and windows are identified in the outer shell and presented as separate objects. LOD4 - extension of the model LOD3 on the internal model. Textures can be added to any LOD (i.e., texture is not part of the LOD specification) [1-4]. For each level of detail (LOD0 - LOD4) there are sublevels, as shown in Figure 2.

![Figure 2. Levels of detail (LOD) with their sublevels.](image)

2. 3D data quality in OSM (Restrictions and limitations)

Some researchers studied the quality of buildings footprints data in OSM database (Fan et al., 2014). They found that building footprints data in OSM in some cities in Germany has a high degree of completeness and semantic accuracy, which shows the potential of using OSM to model building structures. Although it is difficult to directly describe 3D geometry with the current OSM data schema, in recent years some efforts have been made to solve this problem by introducing new OSM tags. Along with these efforts, a pair of OSM data schemes arose to capture internal components (for example, doors, rooms, and elevators) and their interconnections, such as IndoorOSM. Most 3D buildings in OSM are represented as multi-faceted, extruded outlines with flat roofs, so that information on the height of a number of buildings is directly taken from the building footprints attribute or converted from a number of floors, while most 3D building models have random heights. Thus, the level of detail of 3D-models of buildings in OSM can be classified as LOD1. However, there are many limitations of 3D modeling of buildings with LOD1 in OpenStreetMap. One of them is that...
most 3D-models of buildings have the same height for the entire building without taking into account changes in the level or height for each individual part in the case of their existence. To clarify this limitation, we presented an example with this limitation in OSM (3D model of the ITMO University building in OSMbuilding). The building in OSMbuilding is shown in Figure 3.

**Figure 3.** 3D model of ITMO University building in OSM.

Comparison of this model with satellite image allows you to notice that the two parts (in Figure 4 are marked in red) have the same height of adjacent parts of the building in the OSM, although, as shown in Figure 5, they have a less height.

**Figure 4.** A 3D - model of ITMO University building with two parts in red color that should be corrected.

**Figure 5.** Image from Google Earth, showing the building of the ITMO University.

Another limitation of 3D modeling of buildings in OSM with LOD1 are gaps inside building blocks, which are often not considered, and building blocks are often represented in OSM without them. This limitation is often associated with errors in creating the footprints of the building. An example of such a situation is a building block with geographic coordinates (174 46 37, 41 16 53), (Figure 7 and Figure 8).
3. Using LiDAR data to repair shortcomings in OSM 3D models

To overcome these limitations, we suggest using free aerial photographs images with free LiDAR data (light detection and ranking), where they are available for construction a 3D building models and depositing them in OSM. Although it is difficult to obtain an accurate three-dimensional model of a building depending on the available open source data, such as aerial photographs and LiDAR data, it can be considered a very good method with sufficient accuracy for many applications, such as, for example, creating 3D models of buildings for OSM. In our proposed method, we used free and effective software for extracting aerial images for areas with available LiDAR data, called Terra Incognita. This is simple software with high bandwidth. The size of the installation file is approximately 2 megabytes. Using this software, we can download images with resolutions up to (7.5 cm by 7.5 cm) from a variety of sources, such as Google satellite maps, Bing maps, ESRI ArcGIS maps [8,10-17].

We used Global Mapper for processing LiDAR data, which has many flexible tools for analyzing, processing and managing point clouds of LiDAR, as well as for classifying, obtaining and constructing all the characteristic natural features, such as (trees, land surface, rivers, ... etc) and non-natural features such as (Buildings, roads, bridges ... etc).

We applied the proposed method in a small area located in the city of Christchurch in New Zealand. This area contains a series of buildings, shown in Figure 9, with the boundaries of the study area in addition to the grid of geographical coordinates to determine the location of this area. These buildings in this area are represented in F4map (WebGL 3D Map Viewer based on OpenStreetMap data), as shown in Figure 10. To build 3D models of buildings in the Global Mapper, we downloaded LiDAR data for the city of Christchurch with the LAS extension, then downloaded it to the Global Mapper with an aerial image downloaded from Terra Incognita software from Google Satellite maps with high resolution (7.5 * 7.5 cm).
Figure 9. Studied area in Christchurch in New Zealand.

Figure 10. The area, as presented in the New Zealand F4map.

We first filtered the LiDAR data to remove noise from cloud data. This powerful filtering tool can reclassify or automatically remove any points that exceed the prescribed height or height above the ground threshold within the local area. In the next step, we created a 3D building model using the Path Profile tool in the Global Mapper. Using this tool, we can create a three-dimensional model of a building with a roof for many types of roofs. After creating the profile above the roof of the building, a window is displayed in the image of the study area, as shown in Figure 11, and you can use the buttons above the window to move along the profile. Using the button next to the “Extract lines from perpendicular profiles” buttons, we see a window (shown below in Figure 11) where we can create a building surface by drawing lines in the profile, trying to interpolate points as much as possible. Figure 12 shows a 3D model of this building, displayed in a 3D representation in the Global Mapper.

Figure 11. Creating a 3D model of the building in the Global mapper.

Figure 12. 3D building models in Global mapper.

4. Recommendations and conclusions
3D modeling in OSM is in its infancy, and much research is being done in this area. After analyzing in this article the results of using LIDAR data obtained using aerial images, we can conclude that the proposed method gives good results for improving the quality of 3D-modeling of buildings in OSM for the following reasons:

1. Using this method, we can obtain the footprints of the building with sufficient accuracy, so that we can eliminate the errors associated with the buildings footprints and correct them in OSM.

2. We can detect parts of buildings that were not modeled in OSM, so that we can model all buildings with all their parts, to recover missing or unconsidered parts if they are missing.

3. As we mentioned earlier, the level of detail in OSM for 3D building models is mainly LOD1. Using the proposed method, we can obtain models of roofs of buildings. More detailed views can be
implemented by adding roof forms and building descriptions using several parts, so in other words, we can provide 3D building models in OSM with LOD-2. This is an advantage of the proposed method.

4. In addition, as we showed earlier on the example of the building of the University ITMO, we can get 3D models of buildings with building details with level differentiations for each part, if they exist. While most 3D building models in OSM are displayed as blocks with the same height. This height is usually measured from the ground to the top of the building or the top of the roof, if it is not flat.

5. Another advantage of the proposed method is that it allows you to get a fairly accurate building height, while some building heights in OSM are not accurate, because in most cases they are calculated depending on the number of floors, and are approximate [17-20].

Summarizing all the above, we can conclude that the use of free LiDAR data with aerial images is an effective method for improving the quality of 3D-modeling of buildings in OSM and can provide reliable 3D models of objects existing on the Earth's surface with all their details with reliable and good accuracy.

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