Three-dimensional modeling of buildings and structures for simulation of wind effects on urban areas

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Abstract. The article describes a technique of accelerated terrain generalization for mapping wind patterns. The technique is based on the experimental research of data on digital terrain models that was carried out using special software. The developed three-dimensional parametric and polygonal terrain models can be used both for accelerated processing and generalization with special software, and for the study and calculation of aeration modes by the methods of computational hydrodynamics. DEM in studying the aeration mode of terrains is relevant due to the need for modern methods of research and verification of theoretical materials. The purpose of creating three-dimensional representations of terrain data is to accelerate the data processing, as well as to digitalize the work with three-dimensional terrain data.

1. Introduction

The most important task of urban planning is to provide healthy environment for people’s living. A set of factors that negatively affect the living environment includes the pollution of air, soil, water resources, etc. The problem of air pollution in urban areas is solved, first of all, by preventive methods, such as urban planning that takes into account the wind rose. This can minimize or completely eliminate the industrial impact on the atmosphere at the urban level, but the problem of local influence of pollution on urban development (blocks, microdistricts) requires a more thorough approach. To solve these tasks, it is necessary to consider the aeration mode of urban areas that takes into account the geometric parameters of buildings, structures, and spaces between them. Presently, this is implemented by informational numerical simulation of blowing urban areas with air flow in software complexes [1,2].

To simulate wind effects on urban areas by the methods of computational fluid dynamics, a three-dimensional mapping of urban area structures is required to assess the effect of a built-up urban area on air flows. To achieve these purposes, simplified or generalized three-dimensional terrain models should be developed. Detailed modeling of three-dimensional buildings and elaboration of facade details are inexpedient for the numerical simulation of wind effects on a built-up area, because calculations with an accuracy that would make it possible to estimate the influence of these details on the final result are irrational [3].

2. Three-dimensional terrain maps

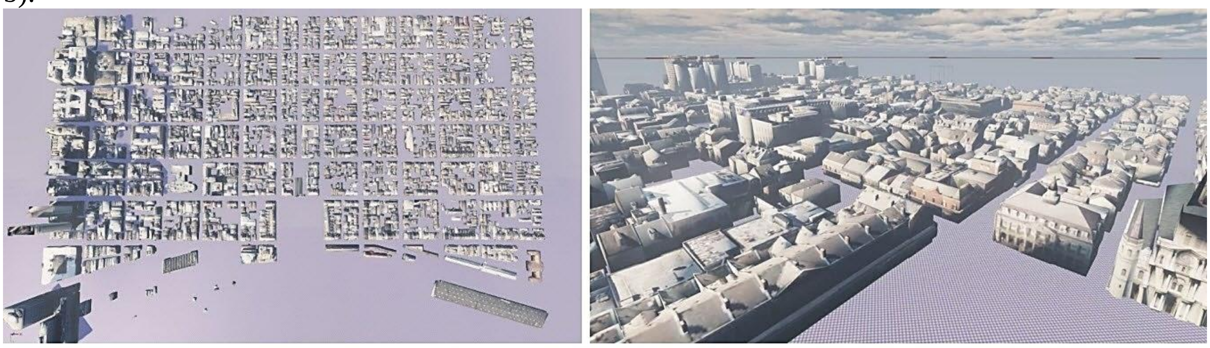
Such models can be developed by various methods, in particular, by manual extraction of building outlines on vector maps [4-6]. The height of the resulting three-dimensional "structures" represents an approximate estimation based on the data about the number of floors and the average height of a floor. The accuracy of models developed by such methods is insufficient, besides the process itself involves significant time costs.

Nowadays, there are data on three-dimensional representation of urban areas in many map services, in particular, in Google/Yandex maps, as well as in OpenStreetMap maps. However, information on geometry is stored in different ways in both services [7].

Geometric models in Google maps are separate files that contain polygonal models of structures and associative information about coordinates of buildings and other official information. These models are created in the GoogleSketchUp editor and then uploaded into the 3dwarehouse online store, which then dynamically uploads them into the map. Figure 1 shows an example of such models [8].

Figure 1. An example of geometrical models created in Google Earth.

There are several ways of creating geometrical models of buildings with this program: by capturing a 3D shot of the selected site with special software or by exporting separate available models from the 3dwarehouse service to the GoogleSketchUp editor and locating them in the map section (Figures 2a, b).



a) top view b) perspective view

Figure 2. An example of geometrical models created in googleearth.

A disadvantage of this data source is labor-intensive extraction of separate models and their subsequent integration with other structures. Moreover, there are practically no three-dimensional models of buildings in Russia except for the Moscow region, which deprives the method of universality.

3. Openstreetmap and three-dimensional data on urban areas.

There is another source of cartographic information that contains data on three-dimensional models of built-up urban areas. This source is a part of the independent project OpenStreetMap. This is a non-profit open project aimed to create a free world map by efforts of community members. Such a map comprises the whole world and contains information on three-dimensional geometry for a large number of buildings in almost all cities of the world [9,10].

The OSMBuildings portal contains a layer of a two-dimensional OSM map, as well as three-dimensional models of buildings combined with a real time map, where buildings have correct values of height and number of floors, as well as a complex shape [11,12].

In the OSM system, data on buildings is not stored as separate 3D models, but as so-called two-dimensional footprints with text parameters that define the geometric dimensions of buildings, as well as their height above and below the ground level.

By default, OSM map areas are different sets of vector lines. The areas have different tags, or parameters, the values of which define, for example, the area type.

One of these parameters is responsible for defining the area as a building, or premises. A building is a man-made structure erected by construction methods that includes premises. The difference between the definitions of "building" in OSM and Wikipedia is that OSM includes into the definition of "building", among others, underground structures with premises. Buildings also include residential buildings, industrial buildings (production departments, storage facilities), agricultural buildings for storing products and materials as well as keeping animals [13].

In the OSM system, there is also a similar category of "structures", most of which are tagged as man_made=*. Structures are man-made objects without premises, or with premises that occupy insignificantly small relative space. Examples of structures are chimneys, light towers, bridges, and tunnels. In some cases, the same object can be defined as a building and a structure.. For example, radio towers that have different indoor premises or fortress towers.

Building profiles are outlined in the OSM maps by the following methods:

- Satellite pictures (e.g., Bing) aerial photographs;
- Outdoor observations, use of sketches, or measurements;
- Going around buildings with GPS activated.

Thus, three-dimensional modeling of structures in the OSM system consists in tagging map areas as a building. Tags can also define many additional parameters to enhance the naturalness of the model, and the specification standard is always expanded. Figure 3 shows an example of tagging a complex building [14].

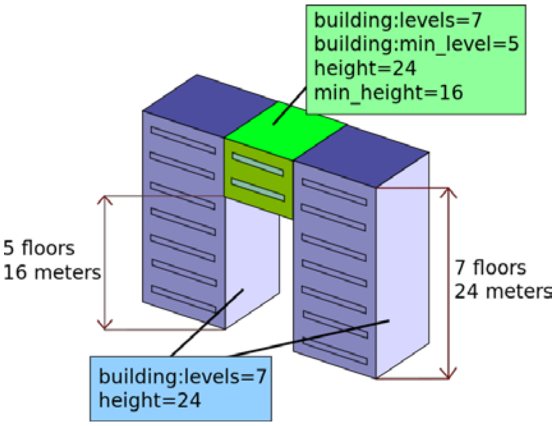


Figure 3. An example of parametrization of a structure with OSM tags and the final result.

Available data sets of building outlines are very common. Extension of the outlines makes it possible to quickly obtain three-dimensional models of buildings, which later can be used for specific purposes in any GIS editor. In many cases, the information about height can be already associated with these polygons. It can be given as a number of building floors, absolute extension height, or height above ground level. It may happen that the data on height have to be obtained from other sources to create 3D-models of buildings. If there are data from the first lidar points, either the height of a building roof, or the height of a building above ground level can be determined.

It is noteworthy that the system makes it possible to determine the building roof type with an extensive tag table. Figure 4 shows examples of some options.

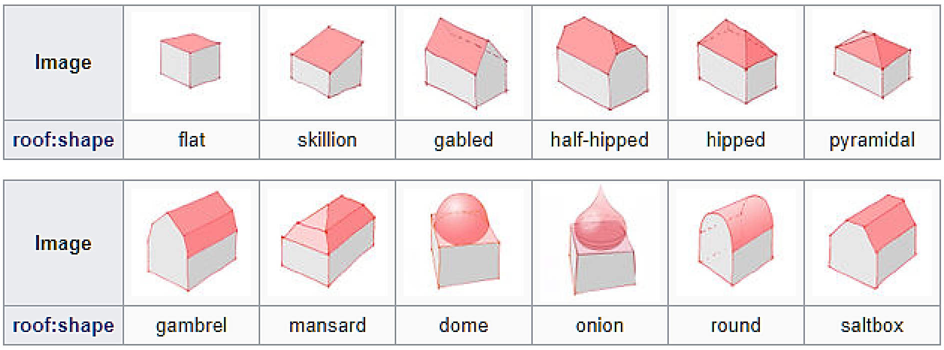


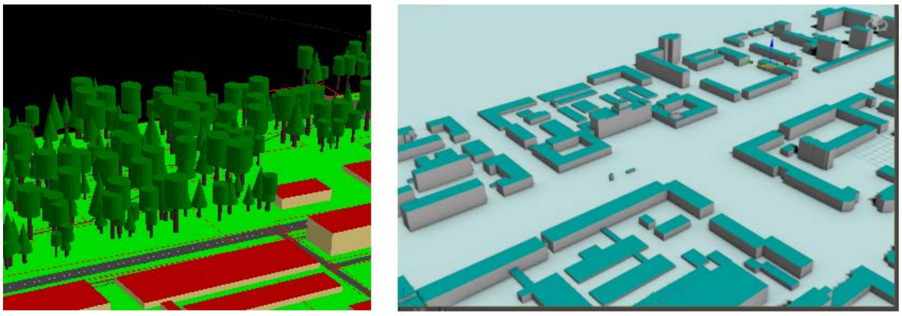
Figure 4. Building roof types and their tags.

This advantage is very important in three-dimensional modeling for calculations by CFD methods. A simple description of a roof type makes it possible to obtain not just a three-dimensional box with a flat roof, but a much more detailed architectural object with characteristic features that impact on its aerodynamic properties. This cannot but enhance the accuracy of the results obtained without additional costs. Basing on the research results, the footprints of buildings are reproduced on OSM maps with accuracy and quality within deviation limits of 4 m from the true one, which is an excellent result [15].

4. Exporting 3D data to geometric formats for further processing.

There are several services and programs for opening OSM maps and viewing 3D models of buildings. Some make it possible to export models to OBJ files (a standard polygon representation) [16].

To develop a three-dimensional model of buildings, it is necessary to download the required map section (an OSM file) from the online OSM portal. The OSM file is then uploaded into the OSM2World (Figure 5a) or 3DSMax program (Figure 5b).



a) b)

Figure 5. An example of the OSM file: a) A map section in OSM2World, b) The same map section in 3dsMax with disabled unnecessary elements.

Thus, it is not difficult to obtain simplified geometry of buildings. The difficulty consists in associating models of buildings with that of terrain. For these purposes, additional software is required that makes it possible to automatically integrate the terrain and models of buildings.

5. Methods for exporting a three-dimensional model of urban area and integrating it with DEM using BLENDER software

There are two options for integrating terrain and building models:

- Separate integration of buildings and separate integration of models with manual alignment;
- Automatic integration with the tool described below [17].

A study of foreign experience resulted in finding the best option for solving these tasks, that is, blender-osm: OpenStreetMapandterrainforBlender. This extension for the free Blender editor makes it possible to directly open OSM files of gridded map areas and visualize three-dimensional models of buildings with all currently available specification tags of roof or facade configuration (Figure 6) [18].

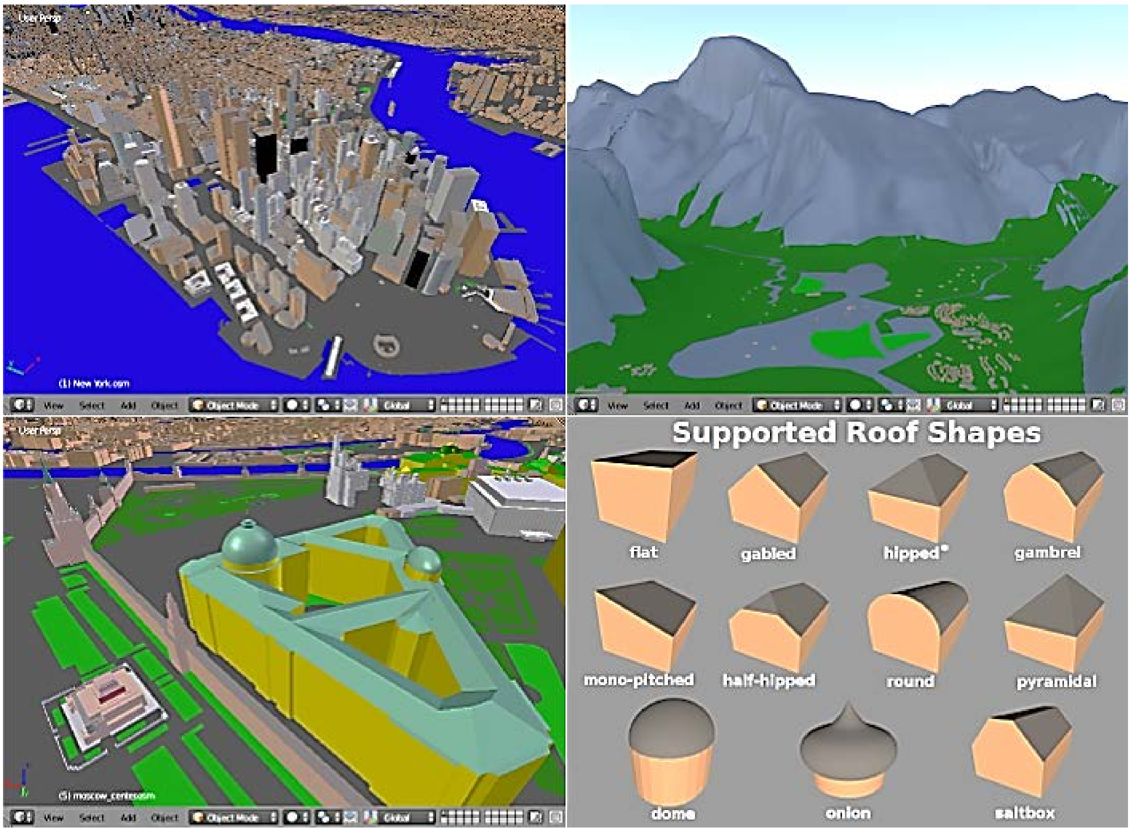


Figure 6. An example of using the blender-osm software.

The main advantages of this tool are:

- Fully automatic process of model extraction;
- Possibility of importing both a section and a whole city with buildings;
- Support of many tags that define the architecture of buildings.

The disadvantages are:

- Slightly complex operation of the Blender editor (data can be exported at once and processed in any familiar editor);
- Use of the SRTM model of height map (DEM) by default [19].

6. Conclusions

The study resulted in the development of a general technique for the semi-automatic three-dimensional modeling of buildings and structures that takes into account the urban terrain, and, in particular, for modeling wind effects on urban built-up areas. The technique is based on the use of geographic information systems and services, which provide data on the digital terrain model. There is a whole range of different software complexes for the subsequent data processing; three of them - Blender, 3DSMax, OSM2World - were chosen as the optimal ones [20].

In general, the accuracy of three-dimensional modeling of buildings makes it possible to conduct various studies related to numerical modeling (studies of aeration modes, effects of atmospheric pollution on residential area, etc.). The modeling programs and tools described in the article significantly accelerate the creation of a calculation scheme for subsequent numerical modeling.

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