Urban Perspectives: A Raster-Based Approach to 3D Generalization of Groups of Buildings

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***Abstract*—The suggested method for 3D generalization of groups of buildings is based on rasterization of 2D footprints of the 3D buildings. The rasterization is processed within quarters, which are automatically defined by using Digital Elevation Model (DEM), water objects and roads. The 3D urban perspective is computed based on separate levels of generalization of each quarter as a function of its distance from a pre-defined view point.**

Keywords-Generalization; 3D urban model; Groups of buildings.

I. INTRODUCTION

3D generalization of the urban model is a fast-growing topic. The main types of objects in the 3D city model are buildings. Nowadays, 3D models are used in many disciplines [18]: GPS navigation, desktop and mobile city viewers, geo-simulation, architecture, and many others. The two common problems which usually arise in any discipline are: (1) huge computer resources are required for drawing 3D models based on the original, non-simplified buildings, and (2) 3D models based on the original non-simplified buildings are very detailed and often appear unreadable and overly complex. To resolve both problems we have to generalize the buildings. There are two different tasks in the building generalization process: (1) simplification of a single building, and (2) generalization of groups of buildings. The topic "simplification of a single building" is a widely researched topic [2][9][10][20]; we can describe several different approaches of generalization, all of them valid. In contrast, "generalization of a group of buildings" has been treated, so far, on a very limited level. There are several very close approaches, largely based on the Delaunay Triangulation (DT) [22]. We propose, in concept, another approach for the generalization of groups of buildings, based on rasterization and vectorization operations, which are carried out by sub-dividing the urban neighborhood into quarters.

This paper is structured as follows: the related work is considered in section two, the source data are described in section three, the raster based algorithms of quarter calculations and generalization are considered in sections four and five, the results are evaluated in section sixe, and finally, in the last section the conclusions are detailed.

II. RELATED WORK

One of the most holistic approaches for the 3D generalization of buildings was described by Xie et al. [22]. The main idea supposes that, within a threshold (distance from a view point), we will generate objects which contain the results of simplification of single buildings, whereas outside of the threshold we will generate objects containing the results of groupings of buildings and simplification of groups of buildings as a single building. An approach of "converting 3D generalization tasks into 2D issues via buildings footprints" was described in [6].

The generalization of 3D building data approach [2], based on scale-space theory from image analysis, allows simplifying all orthogonal building structures in one single process. Another approach [20] considers buildings in terms of Constructive Solid Geometry (CSG). In [22], an approach was proposed which realized 3D single building simplification in 5 consecutive steps: building footprint correction, special structure removal, roof simplification, oblique facade rectification and facade shifting. A very interesting approach was proposed in [9] and [10]. In this approach, geometric simplification was realized by remodeling the object by means of a process similar to half-space modeling. Approximating planes are determined from the polygonal faces of the original model, which are then used as space dividing primitives to create facade and roof structures of simpler shapes.

The second aspect of 3D generalization of an urban environment is the generalization of groups of buildings. 3D generalization of groups of buildings is mentioned in several publications (e.g., [3][5][6][21]). These papers describe different approaches of 3D grouping and group generalization: grouping of building models (using the infrastructure network) and replacing them with cell blocks, while preserving local landmarks [3]; "express different aspects of the aggregation of building models in the form of Mixed Integer Programming problems" [5]; and, grouping of building models "with a minor height difference and the other with a major height difference" [6].

2D building generalization algorithms should also be considered as being used by researchers for a 3D building group generalization. A holistic and automated generalization method based on a pseudo-physical model was considered in [8]. An approach based on Delaunay triangulation, Graph and Gestalt theory was described by Li et al. [16].In the above-mentioned publications, different approaches were considered, but we can identify some common ideas which are important for most research in this area.

In most cases it is very useful to generate levels-of-detail (LOD); normally, researchers use 3 or 4 LODs ([1], [17] and [20]). LODs are widely used in 3D video games, usually for detailed objects; more simplified objects are created for saving processor load and virtual memory [17]. Usually a detailed object has references to several simplified versions (at different levels of simplification), so that if the object stays near the view point, the most detailed version of the object is used, and as the object is located further from the view point the more simplified object is used.

It is very popular to use CityGML standard for 3D urban models ([4], [7], [11], [12], [13], [14], [15] and [19]). This format supports many useful possibilities, which are very important for working with 3D urban models (e.g., LODs, topology, semantics etc.).

III. SOURCE DATA

For implementing and testing our approach, the free geodata of the city of Trento, Italy was used. The buildings (with individual heights), water objects and land relief (DEM) were downloaded from the website of Trento Municipality [23]; roads were downloaded from the OpenStreetMap website [24]. On the map of Trento (see Figure 1) the buildings are depicted as gray areas; the extent of the maps in Figure. 2, Figure 3 and Figure 4 are marked with a blue square; the extent of the map on Figure 8 as a red square, and the view point and view direction of Figure 9 as an orange circle and arrow.

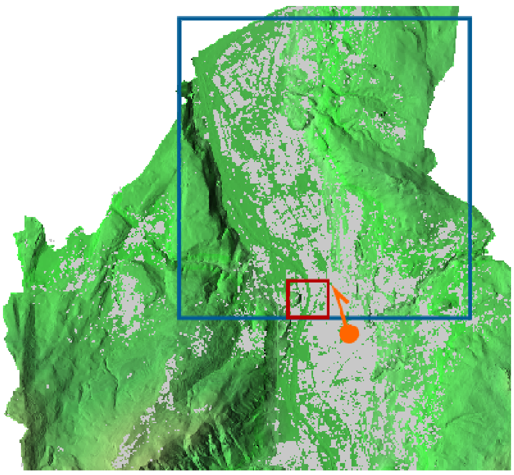

Figure 1. Map of Trento.

IV. CALCULATION OF QUARTERS

Finding a realistic method of simplification is a very important issue in generalization. One of the more common problems is when buildings are being joined through obstacles such as wide roads or rivers. In this case, buildings do not have to be joined to each other, and these buildings from the two sides of the obstacle, should be merged with other, more distant objects, which are, however, located on the correct side of the obstacle. To resolve this problem, we decided to split the urban space into quarters which are divided by the main, significant objects. These objects cannot be involved in the generalization itself.

To calculate quarters, we decided to use the slope of the terrain, water objects and roads. In Trento, it was found that buildings are positioned only on areas with a slope smaller than 30 degrees. Accordingly, areas with slopes greater than 30 degrees of the terrain were excluded. The main road types were used as dividers (excepting negligible roads such as 'footway', 'pedestrian', 'service' and others). The third class of objects for defining the quarters was the water objects. All these three classes – slopes, roads and water objects - were merged into one raster map with 1 meter resolution (which has been found to be adequate for small scale urban generalization). For line objects (roads, narrow rivers) we used a minimal width for the objects which is equal to 1 meter (1 pixel).

The raster map of the merged objects is the base for quarter calculating; further processing can be divided into several consequent steps.

The raster transformations for splitting the city into quarters have been selected because the standard vector approaches (e.g., polygons based on vector roads) have several limitations. The source vector road data may contain features such as unfinished roads, dead end roads, etc., features affecting its topological correctness. Splitting the area into quarters based on these data might result in a very complex polygonal map, containing artifacts. In contrast, the raster transformations approach enables to exclude most of the artifacts and the unnecessary bounds and vertices. As the width of the narrowest roads is about 2-3 meters, the resolution of the raster maps has been defined as 1 meter. Accordingly, the quarter map is composed of polygon bounds which coincide approximately with the road centerlines (±1 meter), as well as not intersecting the buildings.

A. *Region growing of base features*

All pixels of the merged objects got the value “1”; empty space on the raster map got the “Nil” value. Each group of pixels with value “1” has been expanded by adding one pixel (1 meter) and the results are depicted in Figure 2.

B. *Inverting of pixel map*

At this step, the values of pixels were inverted (“1” to “Nil” and vice versa), which results with many pixel areas with the value “1” which are split by “Nil” pixels.

C. *Defining quarter areas having unique values*

To set a unique pixel value to each quarter area, we vectorized the raster map. Each vector that defines a polygonal object got a unique integer identifier. Polygonal objects with areas of less than a pre-defined threshold were removed (in our case, an area of a threshold of 600 square meters was found to give adequate results). Then the vector map was rasterized. For raster values, polygon identifiers were used. As a result (see Figure 3), we got a raster map with group of pixels (a "quarter") and each group (which is

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separated by "Nil" pixels from the adjacent group) got a unique integer identifier.

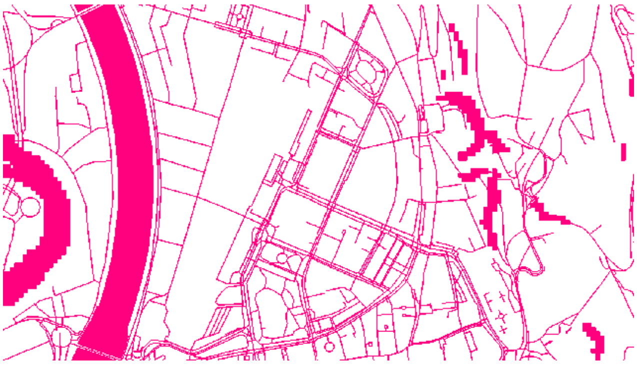

Figure 2. Non-Nil Pixel Groups which Split the City Space into Quarters.

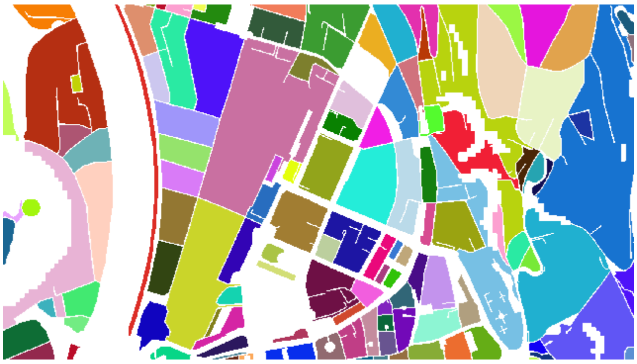

Figure 3. Inverted Raster Map with Unique Pixel Values.

D. *Region growing raster map and final vectorization*

At this stage, the raster map has a lot of empty areas: quarters contain empty areas, and spaces between quarters are empty. The quarters look too complex and contain too many artifacts. To resolve this problem, the non-Nil pixel groups were expanded. Consecutive pixels were added to each unique pixel area until a non-Nil neighbor pixel or threshold is achieved (in our case, 15 pixels/meters out of the current pixel group). Then the raster map was vectorized.

As a result (see Figure 4), we got the final raster map which contains continuous groups of pixels, where each group has a unique integer identifier. Then, the raster map is vectorized into a topologically correct quarter polygons with minimum artifacts. The total number of quarters in Trento was 1,431.

V. GENERALIZATION

The fact that, in urban areas, most (if not all) of the buildings have orthogonal sides, is the background of our raster-based generalization approach. Usually, in adjacent areas (quarters in our case), buildings would be spatially oriented in the same direction. Therefore, the generalization process consists of defining the typical azimuth of buildings' sides for each quarter. Once a typical azimuth is known, by applying the rasterization process in this direction, the staircase-type appearance of lines, or legs of closed polygons, which is very common in the rasterization processes, can be eliminated. A non-rotated rasterization (parallel to the grid axes) while the buildings are positioned in another orientation will result in a staircase-type appearance of the bordering lines of the buildings and too many unnecessary vertices which will prevent achieving a smooth geometry of the generalized objects.

Figure 4. Final Quarters.

A. *Defining the azimuth of buildings' sides*

In urban areas, most of the buildings have orthogonal sides; thus, it is possible to define the average spatial orientation of the buildings. Within each quarter, the azimuths of all the buildings' sides were computed. For each building in the quarter, the longest side and its azimuth were identified. Then, all the azimuths of the other sides are rotated by 90 degrees (clockwise) again and again; and the rotated azimuths (and their lengths) were put in one list. The list was sorted by lengths, and then lengths with the same azimuths (up to a predefined threshold) were averaged. A threshold of 1 degree when looking for close buildings' side azimuths has been found to give satisfactory results. A weighted average of the azimuths of the longest lengths of all the buildings within a quarter is used to define the general orientation of all the buildings of the quarter.

B. *Rotation and rasterization of the buildings in a quarter*

As mentioned above, and in order to significantly reduce the number of vertices of the generalized building and achieve a more realistic appearance of these simplified objects, the rasterization should be carried out in the spatial orientation of the buildings. A rasterization which is spatially oriented parallel to the grid axes will define the buildings which are not oriented parallel to the grid axes in a staircase-type appearance of the buildings' sides. Accordingly, all the buildings within a quarter were rotated counter-clockwise at the angle of the general orientation of all the buildings of the quarter. Then, the rotated buildings were rasterized using a certain pixel size resolution (as explained in the next section). Each pixel with more than half its area covered by the original buildings gets the value "1"; otherwise it gets the value "Nil". Figure 5 shows the result of this stage.

The level of the generalization is a function of the pixel size rasterization process - the greater the pixel size, the greater the degree of generalization. Accordingly, each quarter has been generalized at several levels of rasterization, resulting in several layers of different levels (level-of-detail) of generalized buildings for each quarter. Based on the original data of Trento, and according to our analyses, we found that using pixel size resolutions of 10, 15, 20, 25, 30, 40, 50 and 60 meters produces satisfactory results of a continuous and consecutive appearance of the level-of-detail of the generalized buildings.

Figure 5. The Generalization Process of Buildings in a Quarter: Original Buildings (left); Rotated Quarter and the Generalized 10 meter Rasterized Buildings in red (middle); Final Result (right).

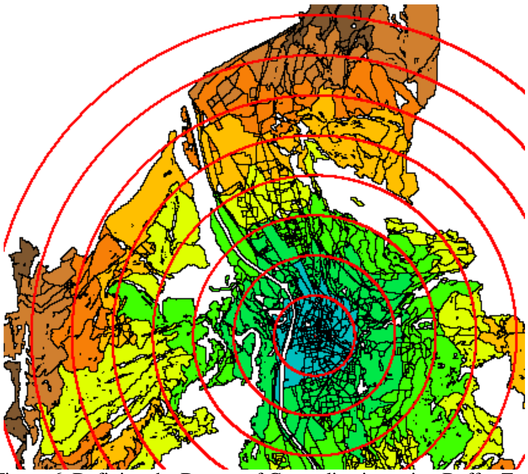

Figure 6. Defining the Degree of Generalization using Buffer Zones: Red circles – Borders of Buffer Zones (red) and Quarter Borders (black).

To draw a 3D perspective of the city with the generalized buildings, the position of a view point has to be defined. Then we built buffer zones around the view point. The buffer zones defined the distances (practically, range of distances) from the view point to each quarter. Then, we set the degree (resolution) of generalization of the buildings for each quarter. Figure 6 depicts the degree of generalization for each quarter, where the colors indicate the degree of the generalization. The relationship between the distances from view point, pixel size generalization, and the colors, are described in Table I. Finally, we merged all the separate generalized layers of all the quarters into one map (see Figure 8) for further 3D visualization. The division of distances from the view point into a scale of continuous intervals was based on several tests, which enabled us to draw a realistic and continual 3D model or perspectives. The results of a 3D visualization, and comparison of the 3D perspectives with the original buildings and with the generalized buildings, are presented in "Figure 9".

TABLE I. DISTANCES FROM THE VIEW POINT, RESOLUTIONS OF GENERALIZATION, AND COLORS.

Distances from view point, meters	**Resolutions of generalization, meters**	**Background colors of the map in "Figure 6"**
0 - 1000	original buildings	
1000 - 2000	10	
2000 - 3000	15	
3000 - 4000	20	
4000 - 5000	25	
5000 - 6000	30	
6000 - 7000	40	
7000 - 8000	50	
>8000	60	

VI. NUMERICAL EVALUATION

Table II presents the number of geometry primitives and the speed of the visualization process as a comparison between the original data and generalized data. As we can see, there is a significant reduction in visualization speed and in the number of polygons and nodes.

TABLE II. RESULTS OF THE GENERALIZATION.

Parameter	**Original building layer**	**Generalized building layer used for 3D visualization**
Number of nodes	114,648	34,391
Number of polygons	46,339	14,956
Speed of 3D visualization, second	6.6	1.2

To evaluate the quality of generalization the mean coefficient of building compactness was calculated for each resolution of generalization (see Figure 7). The coefficient of compactness of a single building is equal to α=P2/(4*π*A), where P – perimeter, A – area (α=1 for a circle, α=1.27 for a square).

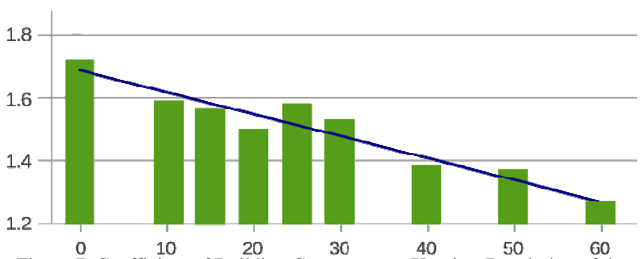

Figure 7. Coefficient of Building Compactness: X-axis – Resolution of the Generalization, 0 – Original Buildings.

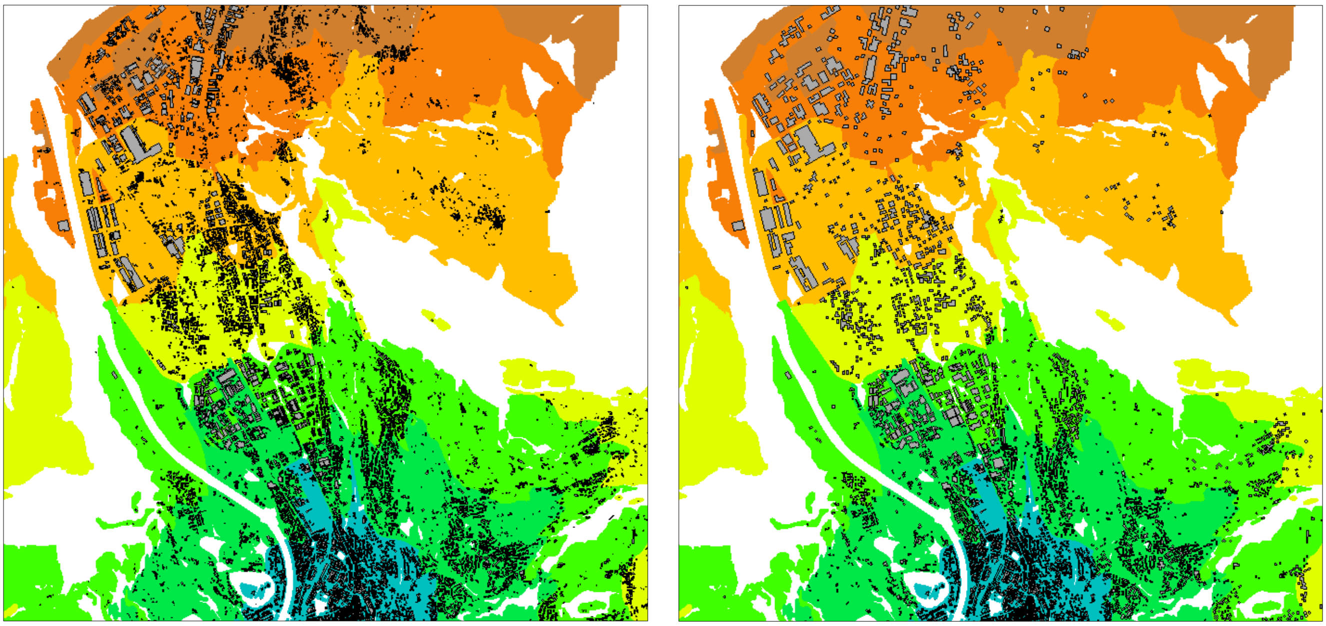

Figure 8. The Northern half of Trento with the Original Buildings (left) and with the Generalized Buildings (right): Different Levels of Generalization and background Colors are according to Table I.

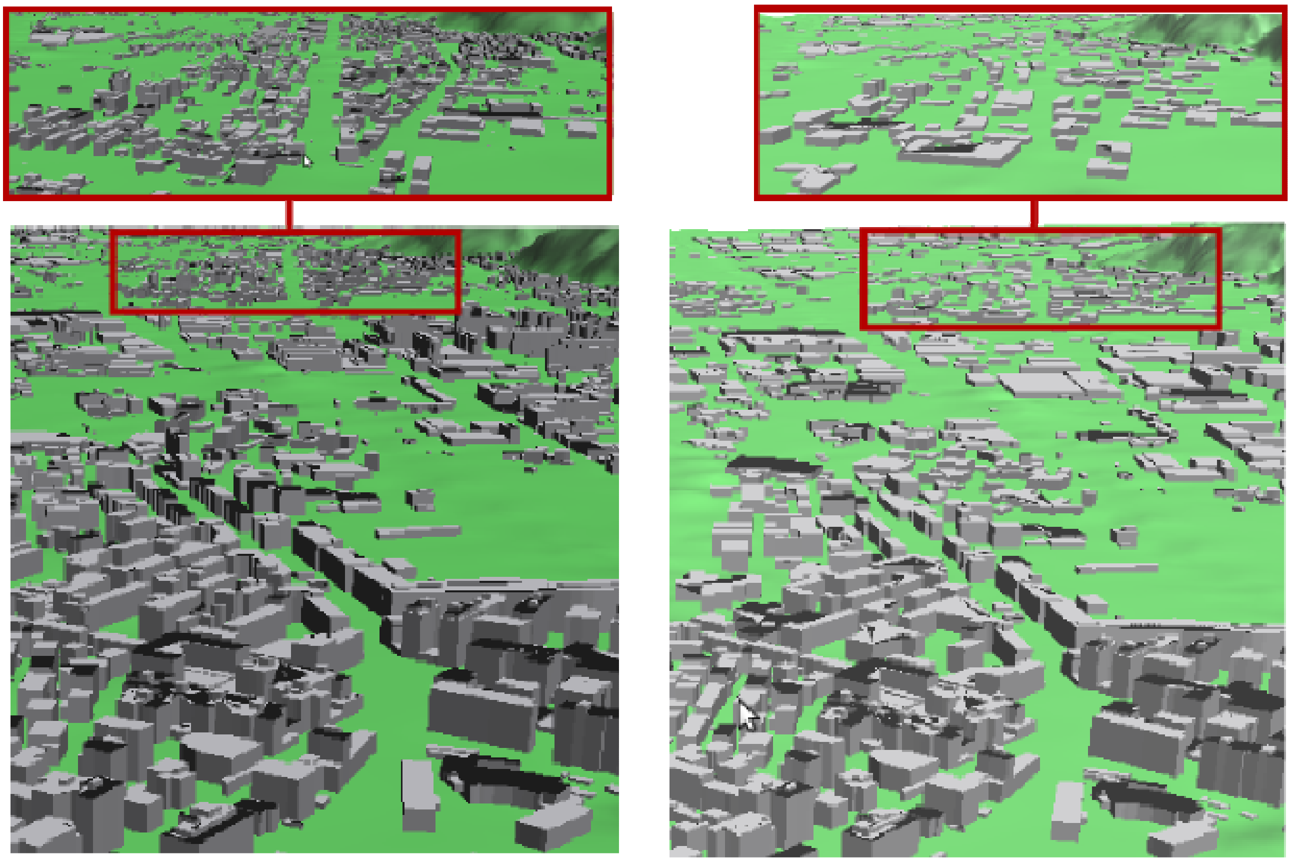

Figure 9. 3D Perspective with the Original Buildings (left) and with the Generalized Buildings (right). Zoomed Areas are Marked in Red.

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In Figure 7, we can see that the coefficients of the buildings' compactness decreases significantly from 1.71 to 1.27, which demonstrates the efficiency of the approach.

The method and the process have been developed by using a standard PC (DELL Vostro 3550), 4 processors: Intel® Core™ i3-2310M CPU @ 2.10GHz, with 1.8 GB Memory. In addition, Ubuntu operating system, GRASS GIS, Bash and Python programming languages have been used.

VII. CONCLUSION AND FUTURE WORK

The raster-based approach of the method is based on standard tools of rasterization, vectorization, region growing, and overlaying. The main advantage of the developed method is the ability to simplistically and efficiently generalize buildings at different levels, achieving variable, but continuous, level-of-detail of the buildings as a function of the depth of the plotted perspectives. The continuity of the generalized product is achieved by subdividing the area of the city into quarters, which take into account the significant objects affecting the process. As a result, the generalized 3D model does not contain unreadable and overly detailed separate buildings on the one hand, and is able to merge further groups of buildings on the other. At the same time, even though the buildings are simplified, the model maintains the geographical correctness and specifications of the urban area. The developed method helps reduce the time, and the required computer resources, for drawing 3D models or perspectives of a city or urban areas.

The current solution is based on a rigid subdivision of the processed area into quarters. This approach of rigid quarters limits the maximum level of generalization to the minimal quarter size on the one hand, and is unable to take into account the density and distribution of the buildings during the process on the other hand. Further research will be focused on improving the suggested model toward a more dynamic and flexible solution. In addition, it is also planned to improve the mechanism of defining the heights of the generalized objects. While in the suggested approach we set a single height to a group of neighbor pixels, it will be more precise to define an individual height to each pixel and only then classify the pixels into groups, which will enable us to achieve a more realistic result.

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